SPECIAL REPORT ON THE OCCASION OF THE 30TH ANNIVERSARY OF THE JAPAN/U.S. FUSION RESEARCH COLLABORATION

Summary Report for the Period 2001-2010

JPN/US

FUSION RESEARCH COLLABORATION

Japan/U.S. Coordinating Committee on Fusion Energy

The Japan-US Coordinating Committee on Fusion Energy (CCFE) is responsible for this report.

This report was prepared for the CCFE by four editors: Stanley L. Milora (Oak Ridge National Laboratory), Takahisa Ozeki (Japan Atomic Energy Agency), Shigeru Sudo (National Institute for Fusion Science), and James W. Van Dam (University of Texas at Austin). The editors solicited written input from key persons in various fields and categories of the US-Japan fusion research collaboration activities.

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March 2011

Japan/U.S. Coordinating Committee on Fusion Energy

Preface

The Japan-US Coordinating Committee for Fusion Energy (CCFE) marked its 30th anniversary in 2010. The historical 30th meeting of the CCFE was held in Korea on October 13, 2010, on the occasion of the IAEA Fusion Energy Conference. Such a long-term cooperative relationship could not have been developed simply by the government officials in Japan and the United States of America (US), and therefore we are grateful that so many researchers made contributions to maintain this relationship.

The history of Japan and US collaboration dates back to the discussions between Prime Minister Fukuda and President Carter in 1977 on a new Japan and US collaboration on fusion. Based on this, a governmental agreement on Japan and US Joint Activity in the field of fusion research and development was established, and the CCFE was established in August 1979. Since then, Joint Activity has been continued steadily for many years. We highly value the collaboration in fusion research carried out between Japan and US in the past, and we would like to ensure the continuation of steady collaboration in the future.

Fusion power can be a very attractive energy source because of its almost inexhaustible fuel resources, high degree of safety, and low burden on the environment. Since the first fusion-related research for energy commenced in the 1950s, considerable progress has been made worldwide. The collaboration between Japan and US has contributed much to this progress. Based on successful research results, the ITER Project for fusion burning experiments was initiated and is now going forward with the cooperation of seven Parties: China, the European Union, India, Japan, Korea, Russia and US. In order to develop an economically attractive fusion reactor, however, many research fields still need to be studied intensively in addition to the ITER activities. These include high beta steady-state operation, tritium breeding systems, development of material science, and so on. Japan and US have experimental devices that are suited to such research fields, and therefore, our collaboration should be further strengthened.

The 20th Anniversary report was published ten years ago, and so this 30th Anniversary report mainly describes the activities and highlighted results during the past decade to the present. We hope that this report will prove useful in reviewing the long-lasting Japan and US Joint Activity, and that it will contribute to the further development of the Japan and US Joint Activity in the future.

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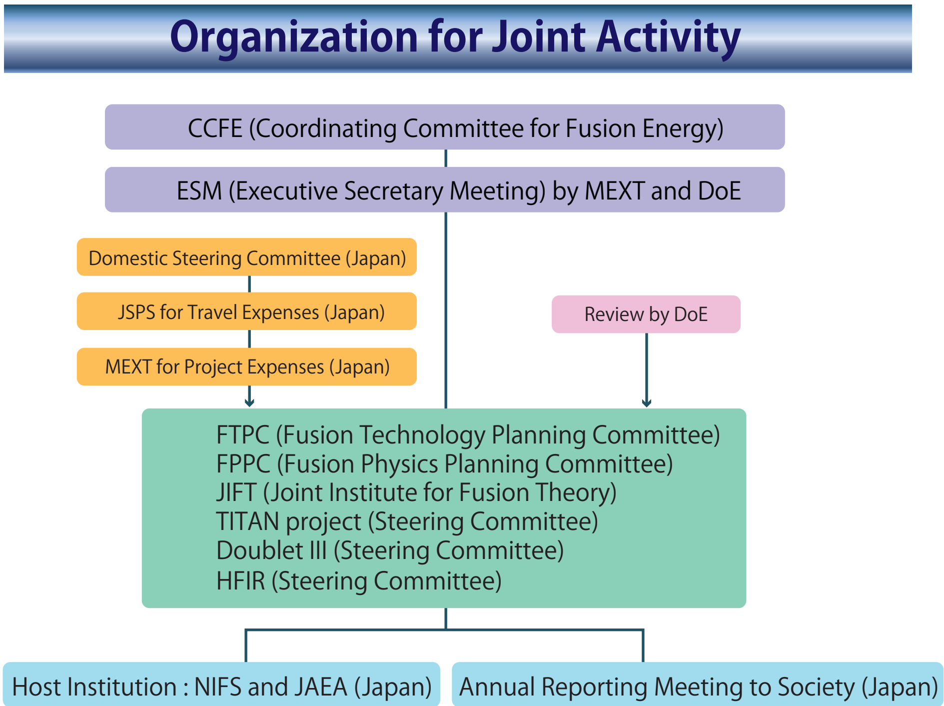
CHAPTER 1 Introduction

The highest coordinating committee for the Japan/US Joint Activity in the field of fusion research is the Coordinating Committee for Fusion Energy (CCFE), which was established in August 1979. Since then, the Joint Activity has been continued for many years to the present. The historical 30th meeting of the CCFE was held in Korea on October 13, 2010. Immediately following this CCFE meeting, a memorable 30th Anniversary Celebration was held, and the Co-Chairpersons from both Japan and US gave congratulatory speeches.

The organizational configuration of the Japan/US Joint Activity is shown in the figure below. The Executive Secretaries Meeting (ESM) is for the purpose of preparation work for CCFE. The research areas represented by Fusion Technology Planning Committee (FTPC), Fusion Physics Planning Committee (FPPC), Joint Institute for Fusion Theory (JIFT), TITAN project, Doublet III, and HFIR submit the exchange activity results of the current year and the proposals for the next fiscal year to the ESM. Each research area is overseen by a Steering Committee that consists of Japanese and US representatives.

Also, Safety Inspection Trips are conducted once every two years. An inspection team from Japan visits experimental facilities in the US, after which the US – Japan Safety Monitor Joint Working Group issues a report about safety, which includes suggestions for improving the safety conditions of the facilities. Then, two years later, an inspection team from the US visits facilities of Japan. This routine has been carried out 13 times. These safety trip activities have contributed much to the safety of the collaborations.



The importance of the Fusion Archives Activity should also be acknowledged. A workshop on the fusion archives was held for the first time in 2005 at UCLA. The resulting fusion historical records are being accumulated at the Fusion Science Archives at the National Institute for Fusion Science (NIFS).

A previous report, entitled *Joint Report: 1980-2000 on the Japan/US Joint Activity**, was published by the CCFE in June 2000 on the occasion of the 20th anniversary. Following this same procedure, we decided to publish a Joint Report mainly for the period of the last ten years, in order to provide an accounting about this long-standing project and to celebrate the 30th anniversary of the Japan/US Joint Activity. In the present report, we have tried to include details in the description of the achievements—specifically, highlights of research results and a list of published papers related to the Japan/US Joint Activity for the period of the last ten years. Some of the activities that have been carried out in 2010 are also included in the present report; other activities are still ongoing and will be published at the next opportunity.

Overall, the Japan/US Joint Activity in fusion research has been highly productive in terms of collaborative projects initiated, papers published, presentations given at workshops and international conferences, and so forth. Also, the scientific friendships and spirit of collegiality engendered by the various types of joint activities have significantly contributed to enhance the research environment in both countries.

*The 20th Anniversary report is available at the following URL sites:

[1] http://www.science.doe.gov/ofes/internationalactivities.shtml on the DOE OFES web page.

[2] http://www.naka.jaea.go.jp/kankoubutu/PDF/JapanUs1980-2000.pdf on the JAEA web page.

[3] http://www.nifs.ac.jp/collaboration/Japan-US/JapanUS-Report.pdf on the NIFS web page.

[4] http://peaches.ph.utexas.edu/ifs/jift/anniversary.html on the JIFT web page.

CHAPTER 2 Fusion Technology Planning Committee (FTPC)

2.1 Objectives

The FTPC (Fusion Technology Planning Committee) is responsible for organizing US-Japan collaboration on the research of fusion technology aiming at realization of fusion energy. After the separation of the FTPC and FPPC (Fusion Physics Planning Committee) in 1991, the subsections in FTPC are 1) Superconducting Magnets, 2) Structural Materials, 3) Plasma Heating Related Technologies, 4) Blankets, 5) In-Vessel/High Heat Flux Materials and Components, 6) Others. Because the joint projects JUPITER-II from 2001 and the TITAN from 2007 have been intensively executed, the main activities related to 2) Structural Materials and 4) Blankets have been performed effectively in those projects. The 6) others covers important subjects such as reactor designs of magnetic or inertia fusion energy (MFE, IFE), tritium system, fueling system and so on.

2.2 Activities

The collaborations are carried out by workshops and exchange visits of researchers, by keeping in mind that the number of the collaboration places should be balanced in US and Japan as much as possible. There were also collaboration activities using tele-video system and e-mail, although the number is quite small. During the years of 2000-2009 under US-Japan collaboration, 74 workshops and exchanges of visits were conducted and 202 researchers were sent to US on various themes related to FTPC. In Japan, 70 workshops and exchange of visits were held and 181 researchers visited to Japan.

2.3 Administration

As for US-Japan universities collaboration, 5 key-persons from Japanese universities and National Institute for Fusion Science (NIFS) are designated for the promotion of collaboration in each subsection of FPPC. The present steering committee of FTPC consists of US DoE key-persons of FTPC and a person in charge from JAEA and a person in charge from NIFS. The steering committee of FTPC is also attended by the key persons of the joint project and the few relevant observers from universities and institutes both in US and Japan, according to the necessity. The steering committee meeting of FTPC is usually held by a tele-video system with complementary e-mails once a year.

2.4 Accomplishments

2.4.1 Superconducting Magnets

High-current superconducting magnets with cryogenics systems are key components to be used in magnetic fusion energy reactors. During the last decade, the US-Japan collaborations focused mainly on high-temperature superconductors (HTS), because of their large potential to realize high magnetic field with excellent operational stability.

In fact, the Mini-RT project at the University of Tokyo and the Levitated Dipole Experiment (LDX) project at Massachusetts Institute of Technology (MIT) chose HTS wires to be partially applied in their magnet systems as the world's first applications of HTS for fusion research. Therefore, the first US-Japan workshop on these HTS systems was held at the University of Tokyo in 2002 to discuss the wire production technology for the first generation HTS (Bi-2223). A second workshop was held at MIT in 2004 for the first plasma with the levitated coils in Mini-RT and LDX, and a third workshop was held at NIFS in 2005 to discuss future plans.

Recently, in 2008 and 2009, intensive discussions have been continued by personal exchanges between NIFS and MIT concerning proposals for joint experiments on Yttrium-based conductor (the second generation HTS) to develop large-current-capacity HTS conductors for fusion magnets.

The technical tour of LDX during the US-Japan workshop on "Use of High-Temperature Superconductors in Fusion ITER Coil Test Results" at the Plasma Science and Fusion Center, Massachusetts Institute of Technology, in October 2004

2.4.2 Structural Materials

Most of the activities on structural materials for blankets and in-vessel components in fusion energy reactors have been effectively performed through the joint projects JUPITER-II from 2001 to 2006 and TITAN from 2007. These projects focused on key subjects such as neutron irradiation effects, thermofluid engineering, tritium behavior, and modeling.

On the other hand the high-power microwave technology developed in fusion plasma heating has been applied to innovative processing of metallic powder as microwave sintering technology. This work has been carried out at Pennsylvania State University and NIFS. Powder metallurgy by means of microwaves is able to achieve no segregation due to grain growth, no re-crystallization, and no impurity concentration as the powder proceeds below the melting temperature.

Therefore, mutual collaborations by personal exchanges have been intensively performed from 2003, for the purpose of developing high-performance low-activation alloys of vanadium and ferritic steel, which are the main candidates for structural materials in fusion energy reactors. The collaborations were productive in revealing the basic physics on thermally non-equilibrium reactions under microwave irradiations. New ideas to reduce the emissions of carbon dioxide have been proposed with the use of this microwave sintering technology.

2.4.3 Plasma Heating Related Technologies

US-Japan collaborations for Radio Frequency Heating Technology have been ongoing since 2000. Major research institutions in the United States and Japan have taken turns to host workshops for the exchange of research information and discussion of collaboration activities. At first, meetings similar to the EU-Japan and US-EU workshops used to be held separately. To improve the efficiency, in 2007 we established a single Japan-US-EU workshop, which has been hosted by rotation since then. The meetings of this combined workshop have been used to discuss major items required for ITER and future large plasma devices and to initiate and organize a number of new international collaboration programs.

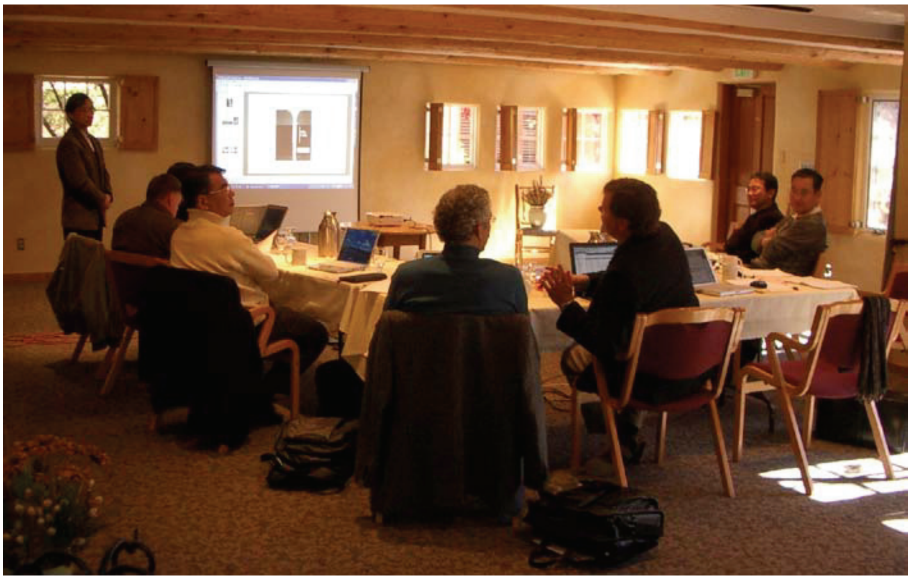
Workshop on RF heating technology in Nara, 2006

In the personal exchange collaboration program, the ICRF Groups of NIFS and University of Tokyo have had active collaborations mainly with General Atomics on comb-line antennas, while the NIFS and JAEA ECH Groups have collaborated with General Atomics and also MIT. Improvement of the transmission efficiency of high-power millimeter waves was one of the urgent issues. The output beam radiated from the gyrotron should be led to the corrugated-waveguide transmission line with an optimized coupling mirror system to take the high transmission efficiency. The collaboration work evaluated the evolution of the intensity profile along the propagation and confirmed that the performance of the mirror system design is correct.

2.4.4 Blankets

Most of the activities with regard to blankets have been effectively performed in the joint projects JUPITER-II from 2001 and the TITAN from 2007. The JUPITER-II project (2001-2006) mainly focused on the Flibe liquid blanket system, with the flow field and its heat transfer performance under strong magnetic field being evaluated in order to establish the turbulent heat transfer modeling of high-temperature and high-Pr number molten salt Flibe flow under strong magnetic field. In the TITAN project, the thermofluid mechanism of liquid metal and its control technique under strong magnetic field have been mainly evaluated since 2007. Both projects have actively promoted the training of many young researchers in both the U.S. and Japan, which has strongly enriched the fusion community as well as contributed to the specific design of the blanket.

In addition to the above-mentioned two projects, HPD (high-power-density) workshops have been held since 1997 in order to discuss high-power-density devices and thermofluid design. The activity in this workshop has focused on the engineering issues that are important to achieve a high-efficiency energy conversion system. The main issues are to identify and solve the engineering issues in some concepts of the first wall cooling system and the blanket system, and then to propose a road map for future development. Information exchange about concepts for a liquid blanket system has continued at the workshops, and personal exchanges have been also performed to solve each of the important issues. Specific subjects discussed are (1) Development of high-heat-flux components satisfying heat removal performance, integrity and maintenance flexibility, (2) Free surface flow including turbulent heat transfer from the liquid surface and its enhancement under a magnetic field, (3) Liquid lithium blanket system that uses coating material for corrosion resistance and its structure optimization, and (4) Diagnostic techniques for high Pr-number and complex flow field in a heat transfer promoter pipe under magnetic field. Also, at the kickoff stage, gas cooling and gas-solid suspension cooling systems were discussed including heat-exchange systems. In order to propose a road map for innovative blanket design, the Plasma-Wall Interaction group, which has been enhancing the specific blanket design, has participated in the above-mentioned HPD workshop.



A group photo during the U.S.-Japan Workshop on "Fusion High Power Density Components and System and Heat Removal and Plasma-Materials Interactions for Fusion" at Santa Fe in November 2006.

2.4.5 In-Vessel/High-Heat-Flux Materials and Components

In this category, mainly four activities have been intensively performed during the past ten years, namely, 1) Divertor plasma experiments, 2) Collected dust analyses, 3) Wall conditioning analyses, and 4) Workshops on these research areas. Divertor plasma experiments have been carried out by personal exchanges with the use of the NAGDIS-II facility at Nagoya University and the PISCES facility at UCSD. Well-controlled linear plasma experiments in NAGDIS-II led to significant progress in understanding the physics of plasma detachment. Engineering research has been intensively performed to explore specific properties of plasma-facing materials, such as tungsten, with the use of high particle fluxes in PICSES. The first analysis of collected dust in Japan was performed with LHD in March 2001 in a collaboration with Idaho National Laboratory (INL). The results were compared with those from tokamak machines in EU and US. These experimental techniques established in LHD were subsequently applied in JT-60U. Wall conditioning of the plasma-facing surfaces of in-vessel components is essential for well-controlled surfaces to achieve high plasma performance with good reproducibility. Experiments using DiMOS in DIII-D were carried out to characterize boronized wall samples.

The workshop on "High Heat Flux Components and Plasma Surface Interactions for Next Fusion Devices" has been held almost every year, alternately in US and Japan. Already from the early days of the US-Japan program, this workshop has covered a broad range of subjects on Plasma Wall Interactions (PWI). During the past decade, the workshop has focused mainly on Plasma Materials Interactions (PMI) in order to understand microscopic mechanisms under multi-particle irradiation and to extrapolate the behavior of materials to burning plasma devices by means of modeling and numerical simulations.

2.4.6 Others

One of the other main activities related to fusion technology is reactor design. A US-Japan Workshop on Fusion Power Plants and Related Advanced Technologies has been held almost every year for more than a decade. In recent years, EU and other countries, including China, have also participated in this workshop, which has featured discussions on wide-ranging topics related to system optimization of a DEMO and a commercial reactor. Two personal exchange programs were also carried out. These programs contributed to the progress in design studies in both the US and Japan through mutual evaluation and comparison of design concepts.

A workshop on fabrication, injection, and tracking of IFE targets has also been held. Detailed technical information specific to each researcher's work was exchanged and has led to the widening of the collaborations in this research field.

A group photo during the U.S.-Japan Workshop on Power Plant Studies and Related Advanced Technologies with EU Participation at UCSD in Feb., 2006.

Another important collaboration between Japan and the US is concerned with tritium handling and control technology. Analytical methods developed in basic investigations at Japanese universities were applied to analyze experimental data from US facilities. Since Japan has no place to gain experience in handling large amounts of tritium, the information obtained through this program was quite valuable for the Japanese participants. Important information on education and training of new up-and-coming tritium researchers has also been transferred through this program.

2.5 Highlights

Application of High-Temperature Superconductors in Fusion Research

Category : Fusion Technology
Year-Number :
2001-FT1-2, 2004-FT1-2, 2005-FT1-1, 2009-FT1-1

Name: Toshiyuki Mito, Nagato Yanagi,
Yuichi Ogawa, Joseph V. Minervini
Affiliation (T.M and N.Y): National Institute for Fusion Science, (Y.O): The University of Tokyo, (J.V.M): Massachusetts Institute of Technology

Application of high-temperature superconductors (HTS) in fusion research is regarded as a pioneering work, and the US-Japan collaboration on this topic was started about ten years ago when the application of HTS was an emerging technology to be considered in real use. Despite this situation, both the Mini-RT project at the University of Tokyo and the Levitated Dipole Experiment (LDX) project at Massachusetts Institute of Technology (MIT) chose HTS wires to be applied partly in their magnet systems as the world's first applications of HTS for fusion research.

At that time, the wire production technology for the first generation HTS (Bi-2223) was being established and institutions, universities and industries in the US and Japan were fiercely competing to manufacture longer and superior wires. Real applications were beginning to be considered for industrial and electric devices, such as cables, motors, transformers and magnets of pulling systems for silicon single crystals. However, it was too early to consider applying HTS for plasma confinement devices in fusion research, other than in current-leads. In these circumstances, it was a great opportunity to start this challenging collaboration as a US-Japan joint program.

The first activity of the collaboration was a workshop held at the University of Tokyo from February 4 to 6, 2002, titled "Application of High Temperature Superconducting Coils for Fusion Plasma Experimental Devices". In this workshop, fruitful discussions were made on a wide range of physics and technological issues, such as evaluations on the electromagnetic properties of HTS wires and on manufacturing methods of Yttrium-based coated-conductor wires (the second generation HTS). The discussion was focused on the two projects of plasma confinement devices both using levitated superconducting coils. In the US, LDX was being constructed as a joint research of MIT and Colombia University, whereas in Japan, the Mini-RT project started as a joint research program of The University of Tokyo, National Institute for Fusion Science (NIFS) and Kyushu University. In LDX, the floating coil was wound using Nb_3Sn superconducting wires, whereas the levitation coil used Bi-2223 HTS wires. In Mini-RT, the floating coil was wound with 400 m of Bi-2223 wires. Fruitful discussions were carried out especially on the R&D activities for their superconducting magnet systems and the future prospects of their research.

The second workshop was held at MIT from October 12 to 13, 2004 with a title "Use of High-Temperature Superconductors in Fusion" under the joint workshop for the "ITER Coil Test Results". By this time, both the LDX and Mini-RT devices were completed and results on the commissioning tests of their magnet systems and first plasma experiments were reported. The first plasma of Mini-RT was successfully obtained in February 2003, and by April 2004, the floating coil was levitated over an hour with a high positional accuracy of ±20 μm. In LDX, although levitation was not possible (at that time) due to a trouble in the HTS levitation coil, the first plasma was produced in April, 2004. In Figs. 1 and 2, the floating coils and first plasmas obtained by LDX and Mini-RT are shown.

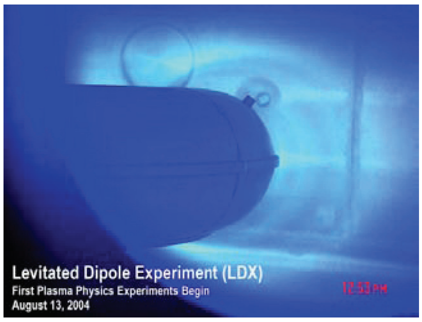


Fig.1: The floating coil and the first plasma of LDX.

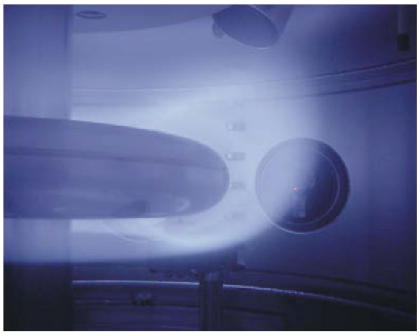


Fig.2: The floating coil and the first plasma of Mini-RT.

The third workshop was held at NIFS on December 9, 2005 with a title "Application of High-Temperature Superconducting Coils in Fusion Plasma Experimental Devices". Based on the successful results of both LDX and Mini-RT, long-term programs on applying HTS for fusion research were discussed. The development of HTS wires to be applied in large-current capacity conductors for fusion magnets was the common interest from both the US and Japanese sides. In December 2008 and October 2009, meetings were held at NIFS and MIT, respectively, to discuss the possible program for developing large-current capacity HTS conductors for fusion magnets by focusing on the Yttrium-based coated-conductors. The plausible future collaboration was also discussed, including joint experiments of reduced-scale conductors using the superconductor testing facility at NIFS.

Microwave Processing of Metallic Powders for Fusion Applications

Category: Fusion Technology
Year-Number: 2003-FT2-1, 2-3, 2004-FT2-1, 2-3, 2005-FT2-1, 2-3,2006-FT2-1, 2-2,2007-FT2-1, 2-2
Name: Motoyasu Sato* M. Tanaka*,
Dinesh Agrawal**, Rustum Roy**
Affiliation:National Institute for Fusion Science*
Material Research Laboratory, Pennsylvania State University**

The Pennsylvania state university, in 2000, demonstrated the world's first microwave sintering of powder metallurgy to the iron-based metal, NIFS developed microwave sintering technologies by applying the high-power microwave experiences on fusion experiments to the dielectric ceramics. The cutting edge laboratories promoted researches on the framework of the joint Japan-US collaboration to both the basic research and applications of microwave sintering technologies. The vanadium steel alloy and ferrite steel are expected to fusion reactor materials. The powder metallurgy by microwave could produce no segregation due to grain growth, no re-crystallization and no impurity concentration as it proceeds below the melting temperature.

(1) Results on Basic Physical Properties

The first year, the "In-Situ observation experiments on sintering process " proposed by Japan. NIFS took the newly developed digital microscope to the U.S.A.. Prof. R. Roy of Pennsylvania state university predicted the thermally non-equilibrium reactions under microwave irradiations. The observations reveled that the localized hot spots were created and maintained for a significant period of time. The hot spot diminishes in a few seconds and loses its energy quickly to the surrounding environment. They reconstructed the micron order crystals into the continuous nano-magnetic domains Such microscopic rapid cooling causes the development of nano-domains. New hot spot continue to get generated in other regions of the sample. This chain process eventually causes the nano-domains spreading all over the material.

Recently, the striking similarity of ultrasound and microwave processing at high temperature was pointed out. It remained us the word of "**coherency**". The series of experiments suggested that the irradiation of magnetic field with high monochromatic frequency spectrum excites oscillations of electrons in the ferromagnetic material coherently directly. The Gibbs free energy (G = H – TS) contains two different ordering terms of the disordered thermal motions (origin of high entropy), the coherent kinetic motions and microscopic ordered structure (origin of low entropy). As the microwave processing uses monochromatic frequency, the electric or magnetic fields generate ordered motions in the material on the first step. The entropy of coherent phonons is lower than the random motion of thermal photons. The decreasing of activation energy has been observed in the reduction process of titanium oxide (TiO_2) under the irradiation of microwave magnetic field. The fall of energy can also be seen on the phase transitions. For example, the nano-crystallographic of ferromagnetic powders in which the hard magnetism converted to very soft one. These experiments show that the microwave couples with different energy path on the phase transitions.

These phenomena require very sophisticated studies of renormalization theories, molecular dynamics, etc. on the bases of ab initio calculation performed by M. Tanaka.

The theoretical researches are going to answers; " how to excite the collective motion in solid material by such monochromatic electromagnetic wave? " and " What is the mechanism to mitigate a driving microwave to a wide frequency spectrum of the blackbody radiation? ". This innovative research is going to open a new door to make bulky nano materials of glassy structures with nano magnetic domains form the micron order crystals.

(2) Contribution to building a low carbon society

The joint discussion with Penn state-U and NIFS, the idea emerged for the steel making process on large-scale comprehensive energy saving. If the electric power to generate the microwave would be supplied by renewable sources or the fusion in the future, the emissions of carbon dioxide that caused by burning coke on making pig iron reduced to the 40% in comparison to the existing blast furnaces. The impurity contents are less than 1/10~1/50 in comparison to cast irons produce by existing blast furnace. It suggests new technology to serve ultra high purity steels for fusion reactor.

The amount of microwave power is estimated experimentally to 500kWh / t. Scales of these microwave source are equivalent to the gyratrons or klystrons used for such large-scale nuclear fusion research such as ITER and LHD, JT60. This is an example to be expected leading the big social return of high technology developed on fusion studies.

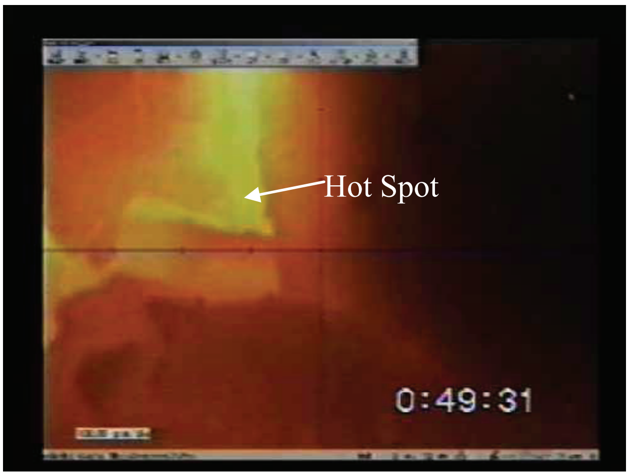


Fig. 1 In-situ observation of hot spot in a ferrite sample exposed to H- field in 2.45 GHz 5 seconds after microwave turned on, the brightest spot exceed 1200 degree C, the dark part was less than 800 degree C. The scale is 100 micron. Temperature gradient was estimated to a few thousands degree C / 1 mm.

RF Heating Technology

Category:Fusion Technology/ Steady-State Operation
Year-Number:2000-FT3-8, 2000-FT3-7, 2001-FT3-01, 2002-FT3-5, 2003-FT3-3, 2003-FT3-2, 2005-FT3-4, 2006-FT3-1, 2006-FT3-2, 2008-FT3-2, 2008-FT3-4, 2009-FT3-2
Name: T.Mutoh, K. Ohkubo, T.Seki, Y.Takase[1], C. Moeller[2]
Affiliation: National Institute for Fusion Science,
[1] University of Tokyo, [2] General Atomic

The US-Japan collaboration for Radio Frequency Heating Technology has been ongoing since 2000. Major institutes in the United States and Japan have hosted workshops in turn to exchange research information and discuss collaboration activities. Originally, the EU-Japan and US-EU workshops were held separately. To improve efficiency, we established a single Japan-US-EU workshop in 2007 which has been hosted by rotation since then. The exchange of researchers was made in parallel with the workshops.

In the personal exchange collaboration program, the NIFS ICRF Group has mainly collaborated with General Atomics for the combline antenna actively while the NIFS and JAEA ECH Groups have collaborated with General Atomics and MIT. The followings are the highlights of the workshops in each fiscal year and the personal exchange activities.

In 2000, diamond windows started to become practical for ECH vacuum windows following the workshop in Princeton. Practical use of diamond windows accelerated rapidly after the exchange of information about the cooling structure at the vacuum seal. The remote steering antenna was devised at GA and the application to ITER was proposed. The ECH and ECCD experiments at JT-60 and the success of electron heating to a Te of 15keV and ECCD of 0.2MA were reported. At the time, low transmission efficiency of the transfer lines was a problem.

At that same time, collaboration research aimed at increasing the standoff voltage of ICRF antennas for heating experiments began between ORNL and ASDEX. As for LHD, one minute of steady state plasma sustained by ICRF was reported.

The US-Japan RF technology workshop in 2001 was jointly hosted with "EU-Japan workshop on antenna technology" in Inuyama. Researchers from US and EU gathered in Inuyama to discuss RF technology widely in the meeting. Low power experimental results on the remote steering antenna were report by both US and the EU, which confirmed the efficacy of the antenna. ECH experiments were actively conducted with JT-60U, LHD, CHS, Heliotron-J and DIII-D. As a result, achievement of high electron temperature, stabilization of NTM instability, ITB formation and effective plasma production were reported.

In 2002 the workshop was held in Los Angeles. Starting with this meeting, US-Japan workshop joined with EU-US and EU-Japan RF technology workshops to improve the efficiency. Regarding ECH, development of the remote steering antennas improved experimentally as well as in analysis. Methods to expand the steering range were reported. Impressive new gyrotron results were also presented: 1.3 MW/1.5s at 110GHz from JAERI and 0.9MW/55s at 140 GHz from EU.

In 2003, the workshop was held at JAEA (former JAERI). Observers from KAERI(Korea) joined the meeting in addition to US, EU and Japan, which further internationalized the workshop. Successful results were reported on the evaluation study of the ECH transmission system between NIFS and MIT and the high power test of the remote steering antenna by JAERI and GA, which were proposed in the previous meeting.

In 2005, the workshop was held in Santa Cruz, USA. Several significant gyrotron advances were reported. The testing of a 1.5 MW CPI tube began at GA. GA also began to replace Gycom tubes with CPI tubes. Successful development of gyrotrons for W7-X (1 MW/140GHz) and ITER (2MW/170G) were reported by Karlsruhe.

In 2006, the workshop was held in Nara, Japan. The ITER construction began to take shape on a large-scale. A JAEA gyrotron demonstrated 0.82MW/10min. As for ICRF heating, LHD 54 min/1.6 GJ steady state operation was reported, which showed RF heating was suitable for steady state operation.

In 2008, the matter of concern was how the workshop members could cooperate for the resolution of the issues which emerged as the ITER development progressed. In the field of ECH, the quality of diamond windows became an issue. It was also when W7-X mass-produced gyrotron quality became an issue. GA and some other institutes reported mechanisms for arcing in vacuum relevant to ICRH antennas.

In 2009, JAEA mostly fulfilled the ITER specification of 1 MW/30 min for gyrotron development and is continuing to make further improvements. Development of a 2MW co-axial gyrotron by the EU has progressed and its completion is expected.

Since 2008, a collaboration has been ongoing between GA and JAEA on high power, very long pulse testing of ITER related ECH components using the 170 GHz JAEA test stand. So far, various miter bends, switches, and a DC break have been tested. The overall loss in the test transmission line has also been examined by thermal imaging with these components.

A collaboration has continued since 2006 on combline antenna for use in the TST-2M tokamak at the University of Tokyo. A fast wave combline antenna originally made by GA for the JFT2M tokamak collaboration was moved to TST-2M along with the 200 MHz transmitter. During the 2006 visit, electrical characteristics of the antenna were measured. A clear pass-band was observed in the frequency range of 160-220 MHz, which includes the planned operating frequency of 200 MHz, and the excitation of a travelling wave with a parallel wave-number of 22 m^{-1} was confirmed and it is now installed and being run at high power. A variation of the combline antenna to launch lower hybrid waves at the same frequency for current ramp-up is now being designed by GA.

Beam Coupling / Mode Content Analysis in Transmission Line of Electron Cyclotron Heating System

Category : Fusion Technology
Year-Number :
2000-FT3-3, 2003-FT3-7, 2007-FT3-6, 2008-FT3-1
Name: Hiroshi Idei, Takashi Shimozuma,
Michael A. Shapro, Richard J. Temkin
Affiliation (H.I): National Institute for Fusion Science (2000), Kyushu University (2003/2007/2008), (T.S): National Institute for Fusion Science, (M.A.S and R.J.T) Massachusetts Institute of Technology (MIT)

Improvement of the transmission efficiency of high power millimeter waves was one of the urgent issues on the Electron Cyclotron Heating (ECH) system in the Large Helical Device (LHD). The output beam radiated from the gyrotron should be led to the corrugated-waveguide transmission line with the optimized coupling mirror system to take the high transmission efficiency. We have been collaborating with MIT group in USA on the coupling of the gyrotron beam into the transmission line[1]. The evolution of the intensity profile along the propagation was evaluated from the IR images at the target in the high power test. The phase profiles required in the mirror system design were retrieved from the intensity evolution along the propagation. The performance of the designed mirror system was confirmed to work correctly at the low power test facilities[2]. (2000)

The alignment of the beam position and angle (within +/- 1mm and +/- 0.2 degrees) are important to attain the high transmission efficiency. The principle experiments shown in Fig.1 were conducted to study of the phase retrieval process and the mechanisms of the unwanted mode excitation. The phase profiles retrieved from the intensity evolution in the experiment were compared to those directly measured at the low power level in detail, and the phase retrieval process was verified experimentally[3]. The phase profiles retrieved at the propagation position of z=150mm coincided well with the measured profiles, as shown in Fig.2. The beam position, radius, symmetry, kurtosis were evaluated with the moment theory including higher orders, describing the beam property. (2003)

Furthermore, a new alignment method of the transmission line basing on the phase retrieval (Fig. 1)[4] was proposed. The irradiant waveguide modes were defined in a free-space propagation to analyze the mode content in the waveguide transmission[5]. In the definition of the irradiant waveguide modes, the fields radiated from the waveguide aperture in Fig.1 were used. The mode content in the waveguide transmission was evaluated from the field intensity and phase profiles measured at a certain propagation position. (2007)

The direct phase measurements were not available for the high power test and the alignment of the LHD-ECH transmission line. The new mode retrieval method was proposed for the high power application. In this approach, the phase retrieval process was not required. This new approach was confirmed to be effective to analyze the mode content transmitted in the waveguide line. (2008).

In the LHD-ECH system, the propagation direction, mode content and the field structure were analyzed in the mirror system and waveguide transmission line (Table I), improving the transmission efficiency as the original task[6]. The experimental verification of the phase retrieval, new definition of the irradiant waveguide modes and their use for the mode expansion deserved a special mention in contribution to the radio frequency and mm wave technologies.

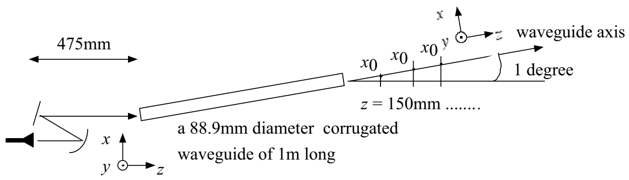


Fig.1: Experimental setup the principle experiments for beam coupling and mode content analysis

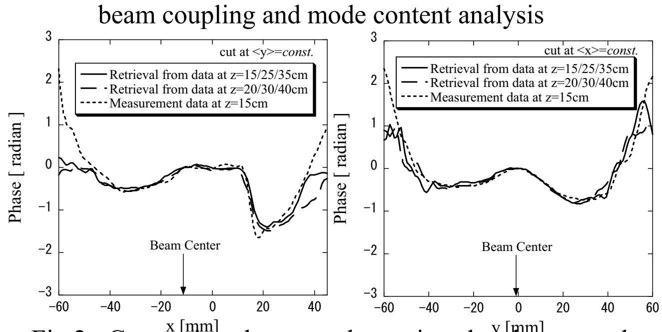


Fig.2 : Comparison between the retrieved and measured phase profiles

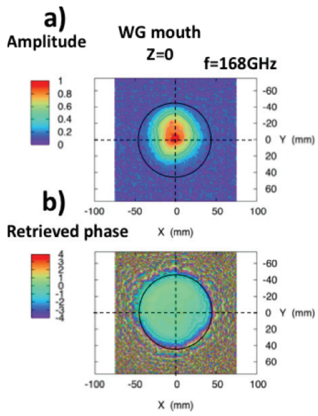


Fig.3 : a) Measured amplitude profile and b) retrieved phase profile

Table I :Result of mode-content analysis. Main HE_{11} mode of 89% is transmitted. The others are unwanted modes.

Mode	Even (%)	Odd (%)
HE11	**88.841**	-
HE12	**0.910**	-
HE13	0158	-
HE14	0.118	-
HE15	0.161	-
HE21	**1.149**	**5.357**
HE22	0.140	**0.684**
HE23	0.079	0.131
HE24	0.012	0.086
HE25	0.036	0.177
HE31	**0.432**	0.048
HE41	0.147	0.021

1) M. A. Shapiro, *et al*., Fusion Eng. and Design, **53** (2001) 537
2) T. Notake, H. Idei, *et al*., Fusion Eng. and Design, **73** (2005) 9
3) H. Idei, *et al*., IEEE Trans. on MTT, **54** (2006) 3899
4) T. Shimozuma, H. Idei, *et al*., JPFR, **81** (2005) 191
5) H. Idei, T. Shimozima, *et al.*, Proc. of IRMMW-THz 2007, 69
6) T. Shimozuma, H. Idei, *et al*., PRR, **5** (2010) S1029

Measurement of RF Transmission Mode in ITER Relevant ECH&CD Transmission Line

Category : Fusion Technology
Year-Number : 2007-FT3-3, 2008-FT3-5, 2009-FT3-3

Name: Yasuhisa Oda[1], Ken Kajiwara[1], Koji Takahashi[1], Atsushi Kasugai[1], Michael Shapiro[2], Richard J. Temkin[2], Keishi Sakamoto[1]
Affiliation: [1]Plasma Heating Research Group, Naka Fusion Research Institute, Japan Atomic Energy Agency, 801-1 Mukoyama, Naka, Japan
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The 170 GHz transmission line (TL) for the electron cyclotron heating and current drive (EC H&CD) system in ITER requires more than 90% power transmission efficiency from the gyrotrons to the plasma using about 100 m length corrugated waveguides. For high transmission efficiency, the good purity of HE_{11} mode is necessary (95%). In this study, the transmission mode in the 170 GHz high power long transmission test line for ITER, which consists of the 63.5 mm corrugated waveguides, was measured and the effect of higher order modes (HOMs) in ITER's transmission line is discussed.

The millimeter wave beam was generated by the 170 GHz high power gyrotron [1] and coupled into the corrugated waveguide through the Matching Optics Unit (MOU) constructed with two phase correcting mirrors. The power is transmitted to the dummy load. Two high power transmission test lines were prepared. One is a short range TL (7 m) and the other is a long range TL (40 m) as shown in Fig. 1. The direction of the RF power is selected by the waveguide switch. The TL system has 7 miter bends including the waveguide switch in the long range TL.

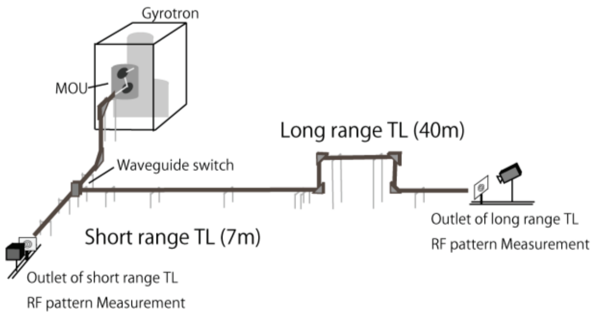


Fig. 1. Schematics of JAEA transmission test line. The diameter of the waveguide was 63.5 mm.

Using measured IR patterns, the mode content was retrieved using the MIT codes. A set of linearly polarized (LP) modes is used. In this analysis, the four LP modes are: fundamental mode LP_{01} (HE_{11}), LP_{11} (even and odd), and LP_{02} (HE_{12}) modes. There was a small difference in the mode content between long TL and short TL. This indicates that the mixture of HE_{11} and LP_{11} modes could be transmitted through the TL without significant mode conversion loss.

When two or more modes travel together down the waveguide, the center of the microwave beam will, in general, be offset from the axis. Also, when the modes reach the end of the waveguide, they will radiate into space with a tilt angle. The offset and tilt angle may be a problem in the launcher / antenna system for plasma heating and current drive. The case of two modes traveling in the waveguide has been analyzed in a recent paper by Kowalski et al. [2]. The paper shows that the offset varies with distance along the waveguide as a cosine wave, while the tilt angle varies as a sine - that is, the tilt angle is ninety degrees out of phase with the offset. With proper normalization, the square of the offset and the square of the tilt angle can be added to express a conservation theorem [2]. The variation of offset and tilt angle repeats with distance down the waveguide at the beat wavelength of the two modes. For the present case, we have most of the power in two modes - the HE_{11} mode and the LP_{11} mode - but there is still significant power in a series of higher modes. For the present case, the experimental values of the tilt angle and offset are plotted vs. extended waveguide length in Figs. 2 and 3 respectively. We also show fits to the tilt angle and offset using sine/cosine functions with a periodicity of 5 meters, which is the beat wavelength of the two major modes (LP_{01} and LP_{11}). The measured values of tilt and offset agree well with the theoretical sine/cosine curve fits. We see from these results that as the microwaves propagate down the waveguide, they will always have some amount of either tilt or offset or both.

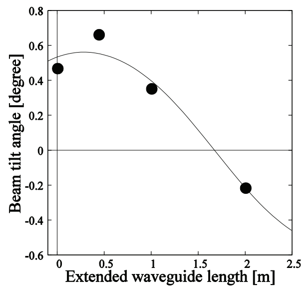


Fig.2. Dependence of tilt angle of radiated beam on length of extended waveguide.

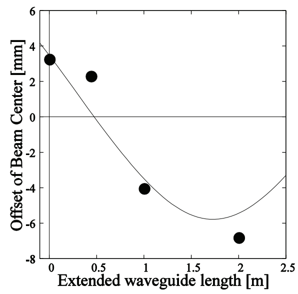


Fig.3. Dependence of offset of beam center at waveguide outlet on length of extended waveguide.

Thus the LP_{11} mode generated at the TL input could affect the beam at the TL output which is an input for the launcher. The initial coupling efficiency at the MOU is important to improve the radiation characteristics from the launchers.

The research at MIT was supported by the US DOE OFES and the US ITER Project Office.

[1] K. Sakamoto et al., Nature Phys. 3, 6 (2007), p. 411.
[2] E. J. Kowalski et al., Proc. Intl. Conf. IR, MM and THz Waves, Busan, Korea, Paper R2D01, IEEE Conf. Proc., Sept. 2009.

Fusion High Power Density Devices and Thermofluid Design

Category: Fusion Reactor Technology/ Diverter, Blanket
Year-Number : 2000-FT4-1,2,6,7,8 2001-FT4-01,02,07 2002-FT4-5, 2003-FT6-1, 2004-FT5-4, 2005-FT5-2, 2006-FT5-2, 2008-FT5-1
Name: Sabro Toda, Hidetoshi Hashizume, *Shinichi Satake, Kazuhisa Yuki
**Clemet Wong, ***Neil Morley
Affiliation:Tohoku University, *Toyama University, **General Atomics, ***UCLA

In order to realize fusion reactor in the near future, the activity in these projects is focusing on one of the most important engineering issues, how to achieve high thermal efficiency in the energy conversion system. The main issue in these activities was initially thermofluid dynamics in high heat flux components like divertor and finally design on blanket system not only for ITER but also for the demo reactor. Information exchange in terms of concepts on liquid blanket system has continued in the workshops and personal exchange has been performed to solve important problems. Main subjects discussed are;

1) to identify engineering issues in present concepts of first wall cooling system and blanket system and then to analyze governing phenomena .

2) to propose solutions for the critical engineering issues and then show a road map to future development.

Through these activities, following results can be summarized:

1) In the development of high heat flux components, it is inevitable to discuss feasibility satisfying several requirements like heat removal performance, integrity and maintenance flexibility. A free surface flow system as a chamber protection scheme is one of the attractive candidates. In case of the cooling of the first wall in an advanced nuclear fusion reactor, the liquid film surface becomes high temperature due to high surface heating from the plasma, and the control of evaporation from the liquid surface is needed to minimize contamination to the plasma. Therefore, in order to reduce the surface temperature, it is important to elucidate the mechanism of turbulent heat transfer from the liquid surface and the promotion of heat transfer by using the turbulence mixture and then a DNS of liquid film cooling in a nuclear fusion reactor was performed by Japan and UCLA members, and the relation between a magnetic orientation and turbulent flow statistics are included in the consideration. The streaky structure with streamwise applied magnetic field are elongated to the free-surface region. The phenomena are corresponding to the reduction of stream wise turbulent fluctuation. From the DNS modeling, Reynolds averaged model and the SGS model for free surface with MHD will be developed by using DNS database in the near future, and the LES will have the ability of providing simulation for the fusion facility[1).]

2) As for liquid lithium blanket system, corrosion resistance of coating materials was discussed and the optimization of structure has been performed to show a development plan based on existing materials and fabrication techniques. This activity is extended to development of new flow channel composing of three insulated surfaces by three layer wall. For this option , basic experimental research is being conducted to demonstrate the performance[2)].

3) The probes suitable for visualizing the flow structure were evaluated for a heat transfer promoter pipe that would be required for hi-Pr number fluid Flibe. A backward scattering type of the probe was selected in consideration of the complicated flow structure around the promoter surface. In addition, the test section to reduce the effect of the laser refraction is designed including the utilization of the matched refractive index method. Finally, the introduction of the test section to the Flibe simulated flow loop was discussed in detail as well as the design of an entrance distance to the test section, and measuring conditions. Based on the experience, experimental data for heat transfer in a pipe filled with pebble bed are collected [3)].

4) The Flibe blanket system proposed by the Japanese side is initially focusing on demo reactor because the operating temperature of Flibe is too high to be applicable to ITER TBM due to the limitation of maximum allowable temperature for available structural materials. Through discussions, this problem was solved by changing the composition ratio of LiF and BeF_2 to reduce the melting temperature, which led to a design window of Flibe TBM and shows a road map to a blanket system of demo reactors by changing the BeF_2 ratio, allowing higher heat transfer performance, with the development of structural materials[4)].

In the development of liquid blanket system, it becomes possible to describe the road map for innovative system through the understanding of present technologies and provide a clear direction for future development and collaboration.

1) S. Satake et al., Fusion Engineering and Design, **61-62**, (2002), 95.
2) M. Aoyagi et al., ISFNT 9, (2009), China (to be published)..
3) N. Seto al., Fusion Engineering and Design, **83**, (2008), 1102.
4)H. Hashizume et al, Fusion Science and Technology, **56**, (2009), 892.

Current plasma wall interaction's issues in fusion devices (Divertor simulator experiment in NAGDIS-II and surface analysis of dust particles and boron)

Category : Fusion Engineering
Year-Number : 2000-FP5-8, 2000-FT6-7, 2007-FT5-2, 2009-FP2-2
Name: S. Takamura*, S. Luckhart**, P. Sharpe***, D. Petti***, N. Ashikawa****
Affiliation: *Nagoya Univ., **UCSD, ***INL, ****NIFS

In this section, three kind of topics based on plasma wall interactions are shown as followings, 1) Divetor plasma experiment using NAGDIS-II, 2) Colleted dust analysis in LHD and 3) boronized wall analysis in DIII-D.

Reduction of huge plasma heat load onto the divertor plate is one of the most critical issues in order to establish long and/or steady state plasma operation in next generation fusion devices. From Prof. S. Takamura (Nagoya Univ.), Dr. D. Whyte, and Dr. E. Hollmann supported by the US-Japan collaboration program, studied the fundamental physics of plasma detachment, which is thought to be the most promising method to reduce the heat load, and has been intensively investigated by using the divertor simulator, NAGDIS-II.

Volumetric plasma recombination was found to play an essential role in detached plasmas, because continuum and a series of line emissions from highly excited levels were observed in the detached plasmas.

In order to understand the energy balance between electrons, ions and neutrals, we conducted the ion temperature measurement by detecting Doppler broadening of HeII (468.6nm). Figure 1 shows that T_e in the downstream rapidly decreases with neutral pressure P, while T_i is gradually decreasing. Around 6 mTorr, T_e and T_i become almost equal, which suggests that the temperature relaxation process between electrons and ions contributes to a decrease in T_e. Numerical simulation with 2D fluid code B2 also revealed that the electron-ion energy exchange process accompanied with the charge exchange process between ions and neutrals is responsible for the electron temperature drop along the magnetic field leading to T_e below 1 eV, where the three body recombination occurs, leading to the detached plasmas [1-2].

Dr. P. Sharpe, Dr. D. Petti (INL) and Dr. A. Sagara (NIFS) investigated deposited dusts into the plasma vacuum vessel in LHD. The INL group has collected the amount dust corresponding to the surface areas. . In this study supported by the US-Japan collaboration program, dusts in helical fusion device were investigated as new type of data. Colleted amount of dusts at a lower region is about 58.7 mg/m^2 and it is smaller than results in JET and ASDEX-U. An averaged diameter of dusts is about 9.64 µm made by carbon and stainless steel in LHD. From results of angler dependence between a horizontal plane and target plates in the vacuum vessel, surface mass density of dusts is similar to each location [3].

Dr. N. Ashikawa (NIFS) and Dr. C. Wong (GA) have been investigated the characterization of boronized wall in DIII-D. Boron films on stainless steel material probes coated by boronization in DIII-D have been analyzed by X-ray photoelectron spectroscopy (XPS) and the chemical bindings of deposited layer with boron are shown. At the top surface of boron film, high concentrations of graphite peak, B-B and B-C bindings are observed and a boron-oxide did not have strong intensity. And then, capacity of oxygen gettering into boron film has still kept after the experimental campaign in DIII-D. We discussed about DiMES system (it is the movable material probe system) in DIII-D during the same program. From under this discussion, Dr. N. Ashikawa and Dr. D. Rudakov started a joint experiment of dust dynamics using pre-characterized dust particles from 2008.

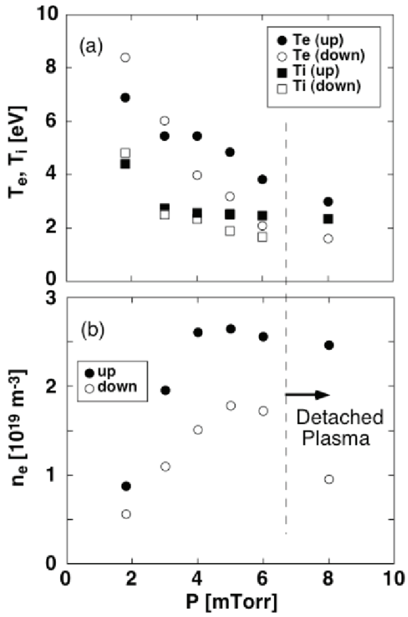


Fig. 1 Dependence of (a): electron temperature T_e and ion temperature T_i; (b): electron density n_e, measured at upstream and downstream, on the neutral gas pressure P.

1) E. M. Hollmann, D.G. Whyte, D. Nishijima, N. Ohno *et al.*, Phys. Plasma, **8** (2001) 3314-3320.
2) D. Nishijima, D. G. Whyte, Y. Uesugi, N. Ohno *et al.*, Proc. of 26th EPS Conf. on Contr. Fusion and Plasma Physics, Vol. 23J (1999), pp.485-488.
3) J.P. Sharpe, V. Rohde, A. Sagara *et al.*, J. Nucl. Mater. **313-316** (2003) 455-459.

High Heat Flux Components and Plasma Surface Interactions for Next Fusion Devices (Heat Removal and Plasma Material Interaction for Fusion)

Category : Fusion Engineering
Year-Number : 2000-FT5-1,2001-FT5-04, 2002-FT5-1,2003FT5-1,2004-FT5-3,2005-FT5-3,2006-FT5-3,2007-FT5-1,2009-FT5-1
Name: N. Noda, Y. Ueda, R. Nygren
Affiliation: NIFS, Osaka University, SNL

Plasma facing components of fusion reactors have to withstand high heat and particle fluxes for several years to keep the compatibility with burning core plasmas. Development of the plasma facing components and materials is a very important and urgent issue for realization of fusion reactors.

This workshop is dealing with several important and timely topics in this field. The participants from Japan and US with some from the other areas exchange the information about current status of research and development of this field and make fruitful discussions. This workshop greatly contributes to development of fusion science and technology not only for Japan and US but also all over the world.

In this report, works on tungsten, the most important material for plasma facing components and blanket first walls, discussed in this workshop are briefly introduced. Tungsten has several preferable features for the reactor first walls such as a high melting point, a high thermal conductivity and low tritium retention. Several issues, however, such as mitigation of impacts on core plasma performance as well as mitigation of material degradation by the plasma flux and the neutron flux must be solved. In this report, the results on the effects of high flux D and He plasma irradiation to tungsten are described. With this energy, no displacement damage of tungsten lattice takes place.

By Nagoya university group, Prof. Takamura and Prof. Ohno were making researches on He plasma effects on tungsten for many years. They found that sub-micron scale holes, so called He bubbles, were formed by He plasma at the temperature above 1600 K. The He ion impinging energy necessary for He bubble structure was only about 6 eV or above, see Fig. 1[1)], which is much below the threshold of the displacement energy of tungsten atoms. He bubble formation probably takes place by recombination of He atoms and thermal vacancies followed by diffusion and agglomeration of these He/vacancy complexes. In addition, for the temperature above about 1100 K, it was found that the cotton-like structure was formed by tungsten nano-fibers with the diameter of a few tens of nanometer[2)]. These results activated several research groups and further progress in understanding formation conditions and its effects on fusion plasma performance has been made.

In ITER, surface temperature of most of first walls and plasma facing materials is about 200 ˚C or less. Under this temperature condition, tritium atoms are trapped at intrinsic and neutron-induced defects. Therefore, He effects on T retention need to be investigated. Experiments of He/D simultaneous implantation into tungsten have been performed in PISCES at the low temperatures. For pure D plasma cases, high flux plasma caused blistering on tungsten[3)]. In this case, D atoms are accumulated not only in grain boundaries but also in grains. The mechanism of D retention in grains could be due to over-saturation of D atoms and successive void formation.

They also found that He implantation greatly reduced D retention and blistering, see Fig.2[4)]. This significant effect has been observed in several plasma and ion beam experiments. Reduction of retention could be due to formation of connected pores to the surface which enhance D diffusion and desorption from the surface.

By virtue of these researches, the understanding of tungsten PMI in fusion reactor environments are increasing. Therefore, this workshop will surely give us further contributions in fusion development in future.

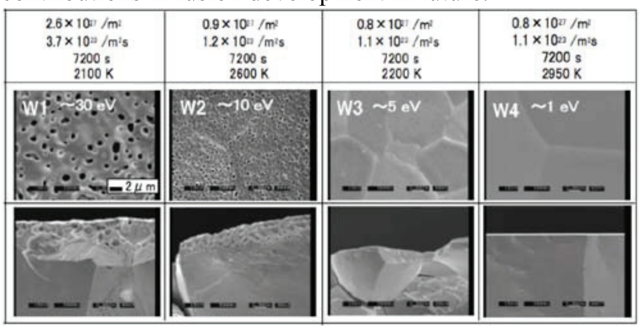


Fig. 1. The dependence of incident ion energy E_{in} for bubble and hole formation on the PM-W surface irradiated by low energy and high-flux He plasma.

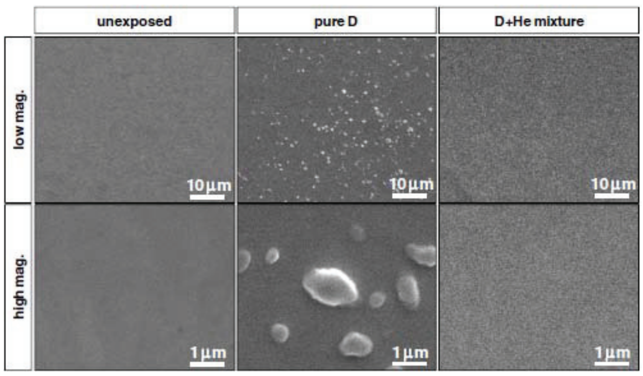


Fig. 2. Surface morphology of SR-W before and after an exposure to pure D plasma or D + He mixture plasma at D ~5×10^{25} m^{-2}, T_s ~573K and c_{He+}~20%..

1)D. Nishijima et al., J. Nucl. Mater. **313-316** (2004) 97.
2)S. Takamura et al., Plasma Fusion Res. **1**, 051 (2006).
3)K. Tokunaga et al., J. Nucl. Mater. **337-339** (2005) 887.
4)M. Miyamoto et al., Nucl. Fusion **49** (2009) 065035 (7pp).

Fusion Power Reactor Design and Related Advanced Technologies

Category : Fusion Engineering/ Reactor Design
Year-Number :2000-FT6-2, 2001-FT6-06, 2003-FT6-4, 2004-FT6-2, 2005-FT6-3, 2006-FT6-1, 2007-FT6-2, 2007-FT6-4, 2008-FT6-2, 2009-FT6-1, 2009-FT6-3
Name: Y. Ogawa[*], F. Najmabadi[**], T. Goto[*†]
Affiliation: [*]Graduate School of Frontier Sciences, The University of Tokyo, [**]UC, San Diego (USA) ([†]National Institute for Fusion Science from FY2008)

To advance design studies of DEMO and commercial reactors that follow after the ITER project, system optimization including the consideration of trade-offs between fusion core plasma design and reactor engineering design is indispensable. In these studies it is important to reflect experimental results of present large-scale devices and the experience obtained from the development of components for ITER. The development of theoretical modeling and numerical simulation codes is also a critical need. To provide an opportunity for information exchange and research cooperation about these issues among Japan, US, EU and other countries including China, workshops and researcher exchange programs have been carried out. The ARIES Team, led by USCD in US, universities and institutes (NIFS, JAEA, CRIEPI) in Japan have engaged in these activities. Several workshops were held with participants from EU and China.

Reactor designs that were evaluated and compared through these activities are summarized as follows:

Tokamak
- Japan: SSTR, Slim-CS, DREAM, VECTOR, IDLT, CREST, Demo-CREST
- US: ARIES-1 through ARIES-4, Pulsar, ARIES-RS, ARIES-AT, ARIES-ST

Helical devices
- Japan: FFHR series
- US: ARIES-CS

Laser fusion
- Japan: KOYO, KOYO-Fast, FALCON-D
- US: HAPL, ARIES-IFE

In tokamak reactor designs, a major concern is the trade-off between reactor economics and early realization, resulting in differences among design concepts. US has always emphasized economic competitiveness of the reactor, which leads to compact designs. US takes the position that the COE of fusion reactors should be similar to present power plants so that it can be introduced into the market in competition with other energy sources including fission reactors. On the contrary, Japan has emphasized early realization and the promotion of public acceptance based on several attractive points of fusion energy. It exactly reflects the difference in the energy situation between Japan and US. For comparison, EU aims at early realization with a certain technology, and China pursues fusion energy development with a view to fusion-fission hybrid reactors, respectively.

In helical reactor designs, following the progress in experiments of Large Helical Device (LHD) at NIFS, the design study of the LHD-type heliotron reactor FFHR has been advanced in Japan. At present, optimization of plasma parameters and design examination of superconducting coil systems are in progress. The development of a system design code for design window analyses also has been advanced. In FY2008, a researcher from NIFS visited UCSD and had discussions with members of the ARIES Team. Improvement of reliability of the system code and establishment of a common basis for comparison among different design concepts are currently underway through crosschecking with the system design code for tokamaks developed by ARIES. On the other hand, US carried out the compact stellarator design ARIES-CS, which aims at high economic efficiency. There also reflects differences in the way of thinking between Japan and US.

In laser reactor designs, aside from KOYO and KOYO-Fast reactor designs with a liquid wall chamber, the possibility of a dry wall chamber design has been examined in the fast-ignition laser fusion reactor (FALCON-D) design study. The HAPL project in US also pursued the possibility of a dry wall chamber. In 2007, a Japanese researcher visited UCSD to discuss dry wall chamber designs. The experimental results of helium irradiation on tungsten and repetitive pulsed heat load tests on the joint material of tungsten – ferritic steel in US were applied to the design study of FALCON-D. It was found that reduced activation ferritic steel (RAFS) armored by ultra fine-grained tungsten (UFG-W) can be a possible candidate for the first wall of a fast-ignition laser fusion reactor [1].

Such crosscutting evaluations on multiple reactor design concepts enabled the extraction of common issues and deepened mutual understanding. For instance, common problems exist between divertor / first wall in magnetic fusion reactors and chamber technology in laser fusion reactors. A quantitative comparison of heat loads on divertors of magnetic fusion reactors and typical laser fusion reactor chamber walls is shown in Table I.

Table I Comparison of heat loads on divertor in magnetic fusion reactor (ITER) and typical laser fusion reactor chamber wall.

	ITER Type –I ELMs	ITER VDEs	ITER Disruptions	Typical IFE Operation (direct-drive NRL target)
Energy	<1 MJ/m^2	ˉ 50 MJ/m^2	ˉ 10 MJ/m^2	ˉ 0.1 MJ/m^2
Location	Surface near div. strike points	surface	surface	bulk (ˉ μm s)
Time	100 –1000 μs	ˉ 0.3 s	ˉ 1 ms	ˉ 1-3 μs
Max. Temperature	melting/ sublimation points	melting/ sublimation points	melting/ sublimation points	ˉ 1500-2000 °C (for dry wall)
Frequency	Few Hz	ˉ 1 per 100 cycles	ˉ 1 per 10 cycles	ˉ 10 Hz
Base Temperature	200 –1000 °C	ˉ 100 °C	ˉ 100 °C	ˉ >500 °C

1) Goto, T. *et al.*, Nucl. Fusion **49** (2009) 075006 (8pp).

Tritium Handling and Control Technology

Category : Fusion Technology
Year-Number : 2001-FT-6-5, 2002-FT-6-7, 2002-FT-6-8, 2003-FT-6-7, 2004-FT-6-3, 2005-FT-6-4
Name: Masabumi Nishikawa, Kenji Okuno*, S. Willms**, C. Gentile***
Affiliation: Kyushu University,*Shizuoka University
**LANL, ***PPPL

At the time this program was initiated, activities in tritium handling in US were focused on tritium handling using a large amount of tritium in TSTA and experimental studies related to experiments at TFTR, and researchers from JAERI took part in these activities as co-workers. TSTA is now closed and has been decommissioned.

This program was started considering that the data obtained in experiments using large amounts of tritium in United States national laboratories could be better understood using analytical methods developed in basic studies performed at Japanese universities. It is considered by the author that research based on understanding about transport phenomena was important in the field of fusion tritium research because the tritium system in a fusion reactor consists of various continuous reactors such as plasma vessel, blanket system and fuel processing system. At that time, however, there was no place to experience handling of a large amount of tritium in Japan, and there were only a few tritium researchers interested in analysis from the aspect of basic phenomena in the US. Then, it is concluded that the co-operation must give good products after discussion with some leading researchers in US.

It was recognized by several researchers in the US that understanding the tritium transport phenomena in concrete materials was important because tritium contamination of concrete walls in a tritium handling facilities is a serious problem. It was also learned during discussion of this program that some US tritiated waste is solidified with cement.

Then, the author started experiments to understand the behavior of tritium in concrete considering that the overall tritium behavior is explained by considering mass transfer steps including adsorption, diffusion and isotope exchange reactions.

The concentration profiles of tritium empirically obtained in concrete by the present authors are compared in Fig. 1 with the estimated profiles using the model constructed by the present author and his co-workers. Fortunately, good agreement is observed in this figure. Tritium release behavior from contaminated concrete walls were calculated using our model as a function of tritium concentration, chemical form of tritium, temperature and humidity in air. The comments given by a researcher of Savannah River to the simulation results is that the simulation results given by the present model are similar to the observations in their experience.

Through the information exchanges performed under this program, the Japanese participants obtained much

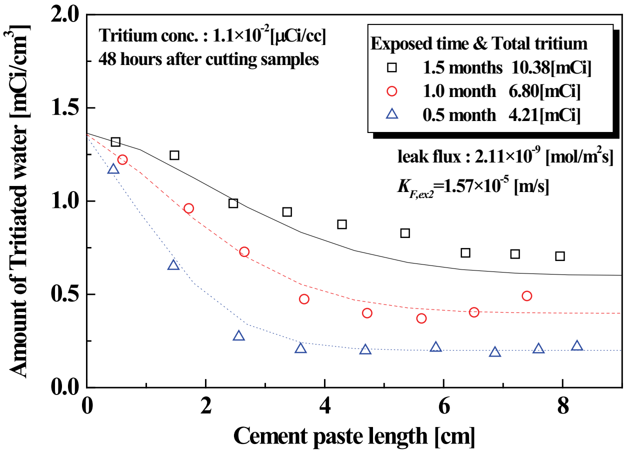


Fig. 1 Comparison of observed values and estimated values for the distribution profile of tritium in concrete.

valuable empirical information from the Princeton Plasma Physics Laboratory and the TSTA group at Los Alamos National Laboratory on settlement, decommissioning, stabilization and surveillance of tritium contaminated laboratories or large tritium handling instruments and techniques for waste management. Important information for training of new tritium researchers was also transferred. Such information together with analysis performed by Japanese universities will be especially valuable in Japan when a tritium handling laboratory is closed in the future.

This program also gave us the opportunity to exchange opinions about tritium fueling systems in the future or in the ITER program with leading researchers in Los Alamos National Laboratory, Savannah River National Laboratory, Princeton University, Idaho National Laboratory, and Rochester University as well as others. Some information obtained in this program was utilized in the Jupiter program and the Titan program.

The following are references about tritium behavior in concrete walls generated by the present authors were initiated from discussions in this program:

1) M. Nishikawa, K. Furuichi, H. Takata, "Study on permeation behavior of gaseous tritium through concrete walls," *Fusion Sci. and Technol.*,**50**, 521-527(2006).
2) K. Furuichi, H. Takata, T. Motoshima, S. Satake, M. Nishikawa, "Study on behavior of tritium in concrete wall," *J. Nucl. Mater.*, **350**, 246-253(2006).
3) K. Furuichi, H. Takata, M. Nishikawa, et al., "Evaluation of tritium behavior in concrete," *J. Nucl. Mater.*, **360-370**, 1243-1247(2007).

Second US/Japan workshop on target fabrication, injection and tracking

Category : Fusion Technology
Year-Number : 2002-FT6-5, 2003-FT6-2, 2003-FT6-8
Name: T. Norimatsu, D. Goodin,
Affiliation: Osaka University, General Atomics (USA),

The Second US/Japan Workshop on Target Fabrication, Injection and Tracking (2002-FT6-5) was held at General Atomics in San Diego, California on February 3-4, 2003. The purpose of this workshop was to allow specialists in the areas of IFE target fabrication, injection, and tracking to exchange detailed technical information specific to their work. The objectives of the workshop were to disseminate detailed technical information, obtain knowledgeable peer review of results, and facilitate a sound scientific understanding of target issues. These objectives were achieved in this very worthwhile workshop.

The following future invitations and actions were planned at the meeting.

1. The US is invited to ILE Osaka for the next workshop on targets in September of 2004.
2. Abbas Nikroo (Head of the Center for Polymer and Coatings Development at GA) will visit ILE target labs in April, 2003. (2002-FT6-2)
3. Japan will send Dr. Yoshida to the USA for an extended stay in March of 2004 to work on tracking with our injection demonstration system. (2003-FT6-8)
4. We will explore doing an injection demonstration with a Japanese fast ignition target on the US injection tracking system.

The first day of the meeting emphasized target fabrication and the second day target injection and tracking. Mike Campbell (GA) welcomed the participants. His presentation emphasized advantages and special challenges of fast ignition for IFE. He presented fast ignition concepts for all drivers and gave recent experimental results from both the US and Japan. Potential advantages of fast ignition include higher gain, reduced fabrication tolerances, and use of longer wavelength drivers which have higher efficiency and smaller aperture requirements. Special challenges include innovative cryogenic layering and 3-D geometry with cones and shells.

Takayoshi Norimatsu (ILE) gave a broad overview presentation on target fabrication and injection activities leading to a laser fusion reactor with a wet wall[1]. This includes work by many researchers on the reactor system, lasers, plasma, and fueling. He described the roadmap (long term research plan), requirements for injection and tracking for both central hot spot and fast ignition, and this year¹s research activities. FIREX-I is a short pulsed laser experiment that has been approved and is being designed[2]. The follow-on FIREX-II experiment is expected to demonstrate fast ignition and burn. They also have plans to demonstrate repetitive laser illumination of targets in the next few years. A simulation experiment on the contamination of final optics in a reactor with wet wall has also started. A preliminary experiment indicated that deposition of metal vapor on the final optics can be prevented by filling low-pressure hydrogen gas in the beam duct.

Dan Goodin (GA) described the viability of an economical target supply for IFE. He described proposed target mass production processes and noted that target cost reductions of 4 orders of magnitude are predicted. He noted that the most difficult issue for direct drive targets is target survival during injection. For indirect drive targets the most difficult issue appears to be target fabrication. Foam shells with seal coatings are being developed by Schafer Corp. High-Z coatings are being experimentally developed at GA. DT layer smoothness is being measured and DT response to rapid heating will be measured at LANL. GA is investigating layering in fluidized bed and other mechanical motion systems. GA has built an experimental target injector in the newly refurbished building 22. GA and UCSD are calculating the effect of the high temperature chamber on target survival.

Keiji Nagai (ILE) described the manipulation of the microstructure of ultra-low-density TPX foams using coagulant alcohol. Poly (4-methyl-pentene) cyclohexane solution is mixed with boiled alcohol solution, gelled and dried with supercritical CO_2. Depending on which alcohol is used, foams down to 2 mg/cc are produced this way.

Rene Raffray (UCSD) described analyses of target heating during injection. He noted highly reflective target surfaces are needed to minimize radiation absorbed from the chamber wall.

Ron Petzoldt (GA) described the status of experimental target injection/tracking system. The system includes a gas gun with an 8 m gun barrel and 17 m free flight distance. Targets are protected in the barrel by sabots that use spring force for axial separation after the target leaves the gun barrel. A sabot deflector removes the sabot and the target proceeds to target detectors that use laser beams and line scan cameras to measure the targets position. From preliminary target position measurements, target downstream timing and trajectory are predicted in real time. All major equipment for single shot operation is now at GA and is being installed. A tour of the injector was also provided.

T. Endo (Nagoya University) described a preliminary conceptual design of target injector for fast-ignition laser fusion and a small experimental accelerator. Hiroki Yoshida (Gifu University) discussed target-tracking work at Gifu University. R. Tsuji (Ibaraki University) described the flying metal pipe for target protection in an IFE reactor.

References

[1] T. Norimatsu, et al., Fusion Science and Technology, 52 (2007) 893.
[2] H. Azechi et al., Nucl. Fusion 49 (2009) 104024

CHAPTER 3 Fusion Physics Planning Committee (FPPC)

3.1 Objectives

The FPPC (Fusion Physics Planning Committee) is responsible for organizing US-Japan collaboration on the experimental research of fusion plasma physics. In the initial phase of the US-Japan collaboration, the experimental collaboration was planned and conducted to promote various concepts of fusion including fusion technology. The separation of the FPPC and FTPC (Fusion Technology Planning Committee) was established in 1991. In order to study more common physics among different machines, since 1992, the collaboration has been conducted to promote plasma core phenomena, plasma edge behavior and control, heating and current drive, and new approaches and diagnostics development. After looking at the imbalance of the number of activities among the categories, discussions on the possibility of the restructuring of the categories were made for a few years. As a result, these categories have been restructured in 2007 to the present status. The present subsections are now 1) Planning, 2) Steady-state Operation, 3) MHD and High Beta, 4) Confinement, 5) Diagnostics, and 6) High Energy Density Science. The physics of various concepts of magnetic and inertial confinement can be discussed together by these subsections, which allows us to deepen the understanding of complex behaviors of confined plasmas.

3.2 Activities

The collaborations are carried out by workshops and personal exchanges of researchers, by keeping in mind that the number of the collaboration places should be balanced in US and Japan as much as possible. There were also collaboration activities using tele-video system and e-mail, although the number is quite small. During the years of 2000-2009 under US-Japan collaboration, 285 workshops were conducted in USA and 528 researchers were sent to US on various themes related to FPPC. In Japan, 141 workshops were held and 404 researchers were sent to Japan. These numbers are much increased compared the previous 20 years in which period 14 workshops per year were conducted in USA and 32 researchers per year were sent to US, and 11 workshops per year were held in Japan and 30 researchers per year were sent to Japan. The highlights of these activities are described afterward.

3.3 Administration

The present steering committee of FPPC consists of US DoE key-persons of FPPC and a person in charge from Japan Atomic Energy Agency (JAEA) and a person in charge from universities including National Institute for Fusion Science (NIFS) and 5 key-persons for 5 subsections from Japanese universities. The steering committee of FPPC is also attended by the few relevant observers from universities and institutes both in US and Japan, according to the necessity. As for US-Japan universities collaboration, 5 key-persons from Japanese universities and NIFS are designated for the promotion of collaboration in each subsection of FPPC. The last face-to-face steering committee of FPPC was held at PPPL in April 2007, but it is usually held once a year by a tele-video system.

3.4 Accomplishments and Highlights

3.4.1 Steady-State Operation

In the ITER era, one of the important research areas in fusion programs is steady state operation of the fusion plasma. The mutual collaboration of steady state operation covers the following subjects; 1) plasma heating and current drive by RF waves, 2) improvement of the negative ion based beam injection system, 3) Physics of plasma current start-up method, especially in spherical tokamak, 4) control of the fluctuations in the SOL and related plasma wall interaction, 5) suppression of the fast events in steady state operation. The topics are:

1) Collaboration of "Plasma heating and current drive" has been performed seven times as workshop from 2000 to 2009. Total number of participants and presentations are 193 persons and 169 topics, respectively. In the experimental area ECH and ECCD, LHCD, HHFW and ICH results have been presented from 8 devices in Japan and 5 in US. EBWCD in spherical tokamaks and LHD becomes recent highlight. Long pulse operation > 5 hours in TRIAM-1M and the current drive with the order of MA in C-mod and JT-60U demonstrated the usefulness of LHCD. Steady state operation in LHD was also achieved by ICH and energetic particles physics is also recent topics. In the theoretical area, benchmark test among various RF physics codes are expected in the collaboration works.

2) Collaboration of "Negative ion based NBI system" has been done between NIFS and PPPL from 2000 to 2007. Two important developments related to long pulse operation of the Cs based NBI system are a) time evolution of beam H fraction with Doppler shift spectroscopy and b) real time measurement of Cs consumption and tungsten filament. Using Doppler shifted spectroscopy the life time of beam component at the full energy is monitored up to 70 sec. The beam uniformity for various Cs consumption rate is measured and analyzed from the viewpoint of beam life time.

3) Collaboration with "Wave physics" including current start-up has been carried out from 2000 to 2009 by University of Tokyo, PPPL, and MIT PSFC. Topics related to this category covered HHFW heating and current drive, solenoidless current ramp-up, TORIC simulation, and LHCD and start-up. In this collaboration test of start-up scenario in ST is common interest. Collaborated experiments about the HHFW and solenoidless start-up were succeeded in NSTX and TST-2. LHCD start-up experiments in MIT showed the higher density limit in LHCD at 4.6 GHz. Current hole experiment aiming at high bootstrap fraction is planned in MIT.

4) Collaboration of "SOL physics and PWI" has been done as personal exchange and workshop. The former is focused on the non-diffusive transport and related dust production. Using a steady state linear device blob generation was studied in a high density plasma under the attached or detached conditions. The latter aims at discussing about plasma surface interaction of high Z materials from both microscopic and macroscopic viewpoints directed towards understanding of steady state operation.

5) Collaboration of "merging and magnetic reconnection" has been performed as workshop from 2000 to 2009. This collaboration among solar, magnetosphere and laboratory scientists helps mutual understanding of the observations and creates common physical view associated with the same physics. Based on the collaboration, a new project; Center for magnetic Self-organization in Laboratory and Astrophysical Plasma has been accepted by US NSF and JSPS. Collaboration with fusion plasma scientists is expected to suppress the fast events disturbing steady state operation.

Workshop on Physics of RF Heating and Current Drive

Category: Fusion Physics/ Steady-State Operation
Year-Number: 2000-FP4-6, 2003-FP4-2, 2004-FP4-1, 2005-FP4-2, 2006-FP4-1, 2007-FP2 -3, 2008-FP2-4, 2009-FP2-1
Name: R.Kumazawa, T.Watari, Y.Takase[1)], M.Ichimura[2)], S.Kubo, J.Hosea[3)], R.Prater[4)]
Affiliation: National Institute for Fusion Science, [1)]Tokyo Univ., [2)]Tukuba Univ., [3)]Princeton Plasma Physics Laboratory(PPPL), [4)]General Atomic(GA)

Workshops on physics of RF heating and current drive were held seven times in the decade. Total number of participants and presentations are 193 persons and 169 topics, respectively. Remarkable results in the experiment and the theory are described as follows.

[Experiment]

Experiment devices:
Japan: LHD, JT-60U, LATE, TST-2, H-J, TRIAM-1M, GAMMA-10, QUEST etc.
USA: DIII-D, Alcator C-Mod, NSTX, HSX, MST etc.

Experimental results obtained on the above devices are reported in four categories of different applied frequency, i.e., ECH and ECCD, LHCD, HHFW, and ICH.

1) ECH and ECCD: Electron cyclotron heating and current drive

A high electron temperature of 15keV at the axis of LHD was achieved with the power of ECH about 3MW, even in the low electron density of $n_e=2\times10^{18}m^{-3}$. A power absorption profile could be precisely known employing the power modulation method and it agreed with the numerically obtained one using a ray tracing method. In addition X-B and O-X-B heating was tried and was verified to be an effective heating method. Recently a collective Thomson scattering method was started to measure an ion-energy distribution using an existent ECH system.

An NTM was suppressed using ECCD on DIII-D and JT-60U, which resulted in the observable improvement of plasma parameters. On the other hand a radial profile of ECCD was measured with MSE on DIII-D. It was compared with the data using a combined code of TORIC-GA and CQL3D as described later and the physics of ECCD was clearly understood.

Experiments of a plasma current startup were successfully carried out on LATE and TST-2. In addition recently the experiment was started on QUEST and the current drive using O-X-B will sustain the plasma for long time.

2) LHCD: Lower hybrid current drive

The plasma discharge for more than 5 hours was achieved on TRIAM-1M. A full current drive operation was carried out on C-Mod with a domestic collaboration of PPPL, i.e., 1MA at $n_e=5\times10^{19}m^{-3}$ using 1.2MW at f=4.6GHz.

A current profile control for ITB formation was succeeded on JT-60U using MSE measured signal. In addition it is worth to note that the plasma current startup was successfully carried out using LHCD power on JT-60U.

3)HHFW heating: Higher harmonic fast wave heating

The increase of 6keV via TTMP process in the electron temperature was achieved with the HHFW heating of 3MW on NSTX. However a degradation of the heating efficiency at the lower $N\phi$ had been reported. It was conjectured as the cause that the HHF wave was able to propagate as the LHW in the scrape-off plasma. Then the reduction of the scrape-off plasma density employing Lithium coating method improved the heating efficiency at the lower $N\phi$.

4) ICH: Ion cyclotron heating

A remarkable progress was achieved on LHD. The plasma was sustained with only the ICH power. The plasma parameters were the same that produced with NBI. The plasma was sustained for one hour, which is one of the main objectives on LHD. A good confinement of high-energy ions with more than 1MeV was confirmed during the long pulse discharges. A plasma production and heating using a folded waveguide antenna was first succeeded. This antenna was designed and fabricated with the collaboration of ORNL.

A high RF power injection up to 6MW was achieved using three antenna sets on C-Mod. It is interesting that there was no difference of the heating efficiency in the RF phase between antenna straps. It is very surprising that the ion cyclotron wave converting from the fast wave was first observed using a phase contrast image (PCI) method. It mainly owed to the progress in the wave analysis of AORSA code as later described.

[Theory]

A big budget was invested to develop the research about RF wave physics in USA. There is a big difference in the number of researchers between USA and Japan, but the Japanese activity is almost equal to that in USA.

Codes of AORSA, TASK and TORIC were based and other codes were combined to them to analyze the plasma heating and the current drive. For example those are AORSA-CQL3D, TORIC-CQL3D, AORSA/TORIC-GENRAY and TASK/WM-FP etc.

The results obtained using a combination code are as follows: A velocity distribution of high-energy ions during ICRF heating was calculated using combined codes, e.g., TASK/WM-FP, GNET-TASK/WM and ORBIT-RF/ AORSA. The WM code is a code calculating the wave dispersion relation and the FP code is for calculating an energy distribution using Fokker-Planck equation. GNET code is a 5D simulation code. ORBIT code is also 5D code. It should be noted that codes of TASK/WM and AORSA could calculate the RF electric field including high-energy ions.

At the first step an initial dispersion relation was calculated using the bulk plasma parameters, then a velocity distribution of high-energy ions was calculated using FP code with the initial RF electric field. At the next step the wave dispersion relation including a high-energy ions was calculated and the velocity distribution of high-energy ions was determined using FP code with a new RF electric field. Then the distribution of high-energy ions was converged after several iteration processes.

Improvement Studies of Negative-Ion-Based Neutral Beam Injection System

Category : Fusion Physics/ Heating
Year-Number : 2000-FP4-4,2001-FP4-04,2003-FP4-1,2004-FP4-2,2005-FP4-1,2006-FP4-2,2007-FP4-2
Name: Y. Oka, L. R. Grisham*
Affiliation: National Institute for Fusion science,
*Princeton Plasma Physics Laboratory (USA)

The LHD was the only machine that relied upon negative ion-based neutral beam injection system, N-NBI, as the principal heating power source, which applied high-power cesium-seeded negative hydrogen ion sources as one key device. Leading objective of the collaboration study was an improvement of the system of N-NB, beam physics study, and the beam heating /operation-method with high power (15MW) long pulsed N-NBI for LHD and possibly ITER plasmas in future. These, founded on main part of study, by NIFS, of the high current negative ion source / heating for the full specifications had been done in collaboration with PPPL which had experiences on positive deuterium NB system at high power level of ~30MW, and also JAEA on beam spectrometer system.

The principle fruits of this collaboration studies were Doppler shift measurements. The beam velocity distribution (Fig.1) were observed systematically with Doppler-shift Halpha spectroscopy on large area negative ion sources of standard LHD-N-NBI system, observing the time evolution for injection pulses as long as 128sec of record value, and the stripping spectrum from beams with single stage accelerators [1, 2]. Full energy component (intensity) of the negative ion beams decreased with time (Fig.2). The beam uniformity appeared to vary with time during one pulse duration. It was attributed to the variation of Cs migration on the plasma grid and/or the Cs recycling, and the stripping losses in the acceleration gap of the ion source. These validated that the spectroscopy was useful tool as a non-interfering beam monitor during high power NB injection shots for the LHD and the ITER under radiation circumstances. In the next place of the fruits, much progress on beam injector operation and maintenance of powerful long pulse N-NBI was achieved by analysis of measurement of Cs consumption (Table I) [3], weight loss (lifetime) of tungsten filament, and the power deposition/energy spectrum of co-accelerated electron beam component (Fig.3) [4] as well as the beam blocking study in N-NBI.

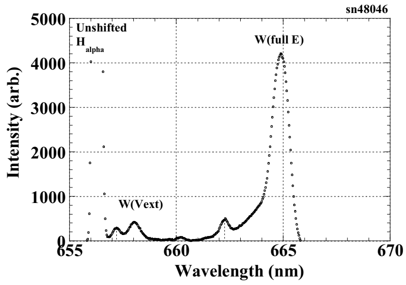


Fig.1 Doppler shift spectrum in Halpha light of the LHD-NNBI beam.

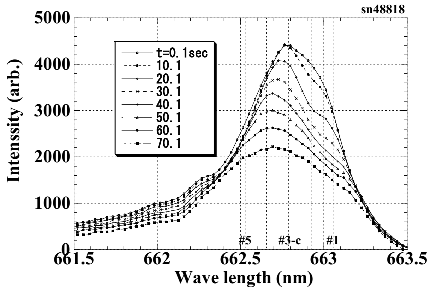


Fig.2 Temporal profile for full energy beam component for 74 s long pulse injection(sn48818).
Vfull=95 kV, Iacc=14A(IS-2B).

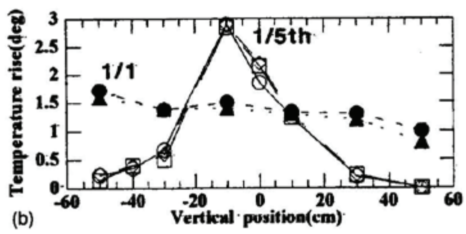


Fig.3 Temperature-rise profile on the dump for co-accelerated electron beam component with LHD-NNBI full-size(1/1) and $1/3^{rd}$-negative ion sources.

1) Y. Oka et al., Rev. Sci. Instrum. 77(2006)03A538
2) Y. Oka et al., Rev. Sci. Instrum. 79(2008)02C105
3) Y. Oka et al., Rev. Sci. Instrum. 75(2004)1803
4) Y. Oka et al., Rev. Sci. Instrum. 73(2002)1054

Table I. Tungsten filament weight loss and Cesium weight loss for LHD ion sources

Ion source	IS-1A	IS-1B	IS-1A	IS-1B	IS-2A	IS-2B	IS-3A	IS-3B
Run No.	10-a	10-a	10-b	10-b	10	10	10	10
W loss rate (mg/shot/source)	···	···	0.12	···	0.28	0.23	0.52	0.3
W atoms/shot/source ($\times 10^{18}$)	···	···	0.39	···	0.91	0.75	1.7	0.98
Coverage of W/shot/source (monolayer)	···	···	0.015	···	0.035	0.028	0.065	0.037
Cs loss rate (mg/shot/source)	0.4	···	1.58	1.57	0.62	0.6	0.17	0.31
Cs atoms/shot/source ($\times 10^{18}$)	···	···	7.18	7.13	2.8	2.7	0.77	1.4
Coverage of Cs/shot/source (monolayer)	···	···	1.04	1	0.4	0.39	0.11	0.2
Ratio of Cs coverage to W coverage	···	···	69	···	11	13	1.6	5.4

Intermittent bursty plasma transport in attached- and detached-plasmas

Category : Physics (edge plasmas)
Year-Number : 2002-FP3-03, 2003-FP3-18
Name: N. Ohno*, S. Krasheninnikov**
Affiliation: *Nagoya Univ., **UCSD

Intermittent convective plasma transport across magnetic field lines, “Plasma Blobs” has been one of the most important issues in fusion-related edge plasma physics, and is thought to play a key role for cross-field plasma transport in the tokamak scrape-off layer. Several experiments have been performed regarding blobby plasma transport, in which intermittent bursts of fluctuation in ion saturation currents measured by Langmuir probes were analyzed to obtain a basic property of the blob’s motion. Such bursty fluctuation has been also observed in other plasma devices. Then, the blobby plasma transport is thought to be common phenomena in magnetically confined plasmas.

We investigated the intermittent convective plasma transport in a attached and/or detached plasma condition of the linear divertor plasma simulator, NAGDIS-II. The NAGDIS-II can generate high density helium plasmas with an electron density up to 10^{20} m^{-3} in a steady state. The diameter of a plasma column is about 20 mm. By increasing neutral pressure P in the divertor test region, we can achieve a detached plasma condition. Ion saturation currents I_{sat} were measured with a Langmuir probe. Images of light emission from a plasma were taken by the fast-imaging camera located at the end of the vacuum chamber. Images taken by a fast-imaging camera clearly show that in attached plasmas, blobs are peeled off the bulk plasma, and propagate outward with an azimuthal motion. In detached plasmas, plasma turbulence observed near the plasma recombining region drives strong intermittent radial plasma transport, which could broaden the radial density profile.

Figure 1 shows the time evolution of the ion saturation current I_{sat} measured at the periphery *(r* = 60 mm) in the downstream. Many positive spikes in I_{sat} were observed. As *P* is increased to produce fully detached plasma, positive spikes in I_{sat}, which is related to be the plasma blob observed by a high-speed camera, becomes wider and their amplitudes increase. Then, the averaged value of I_{sat} increases with *P* at *r* = 60 mm as shown in Fig. 2, although the averaged I_{sat} at the center of the plasma column dramatically drops. These experimental results indicate that the plasma blobs due to the instability in the detached plasma drives strong convective radial transport, which leads to a broadening of the plasma profile. This could play an important role in the reduction of the particle and heat flux to the divertor plate as well as the plasma recombination processes in plasma detachment.

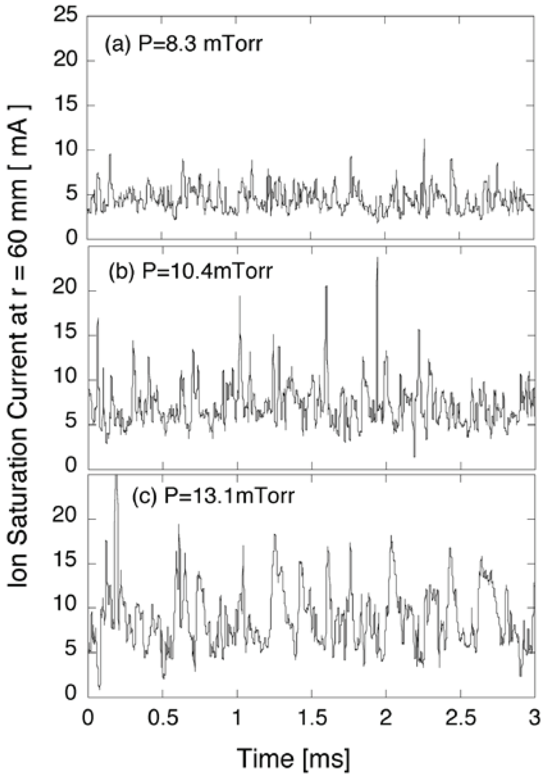


Fig. 1 Neutral pressure dependence of time evolution of I_{sat} at *r* = 60 mm.

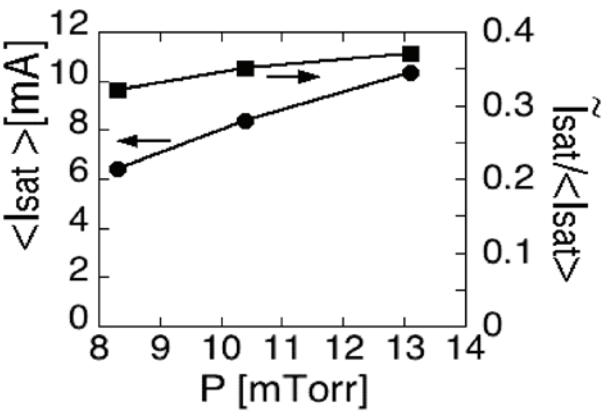


Fig. 2 The averaged value of I_{sat} and fluctuaion level as a function of neutral pressure *P*.

1) N. Ohno, K. Furuta, S. Takamura, Journal of Plasma Fusion Research, Vol.80, No.4, 2004, pp.275-276.
2) N. Ohno, V. P.Budaev, K. Furuta, H. Miyoshi, S. Takamura, Contributions to Plasma Physics, Vol.44, No.1-3, 2004, pp.222-227.

Study of dust transport in fusion devices

Category : Physics (edge plasmas)
Year-Number : 2006-FP3-3
Name: N. Ohno*, S. Krasheninnikov**
Affiliation: *Nagoya Univ., **UCSD

Dust particles have been found in magnetically confined fusion devices. The dust particles could be generated due to strong plasma-wall interaction, and be transported into core plasmas. Such dust particles would not pose serious problem on safety and operational issues in present devices, however, in future devices such as ITER (International Thermonuclear Experimental Reactor), dust particles could be serious problem because dust formation in the next-step devices is expected to increase by several orders of magnitude due to long pulse operation. Dust accumulation inside the vacuum vessel contributes to huge tritium inventory. In addition, dust penetration into the core plasma could cause degradation of plasma performance and disruption.

Comprehensive study of dust formation and transport becomes one of the most critical issues in fusion plasma, however, few experiment of dust transport has conducted and our present knowledge of the mechanism of transport of dust particles in fusion devices is rather limited. In order to control the dust transport, it is necessary to clarify dominating forces acting on dust particles in fusion devices. In large fusion devices, it's difficult to investigate a systematical study of dust transport because no one knows the size and the mass of dust particles transported in the devices. Then, we need to conduct the dust transport experiment by using given dust particles in high density deuterium plasma relevant to edge plasma condition of fusion devices.

We have investigated dust particle transport in high density deuterium plasma with toroidal divertor configuration by using toroidal divertor plasma simulator NAGDlS-T (NAGoya D1vertor plasma Simulator with Toroidal magnetic configuration). Carbon dust particles, are set on Piezoelectric vibrator installed from bottom of the vacuum vessel. Dust particles are illuminated by the halogen lamp and their motion was measured by using high-speed camera as shown in Fig.1.

It is found that the dust particles were transported radially across the magnetic field. The direction of the dust motion depends on the direction of toloidal magnetic field (Fig. 2). Figure 3 shows calculated forces acting on a dust particle in plasma. It is found that a friction force between an ion flow and a dust particle is much larger than other forces, electrostatic and gravitational force in the experimental condition. Therefore, the friction force is a dominating one. This calculation indicates that the dust motion in Fig. 2 is mainly detemined by diamagnetic ion flows in front of the piezoelectric vibrator.

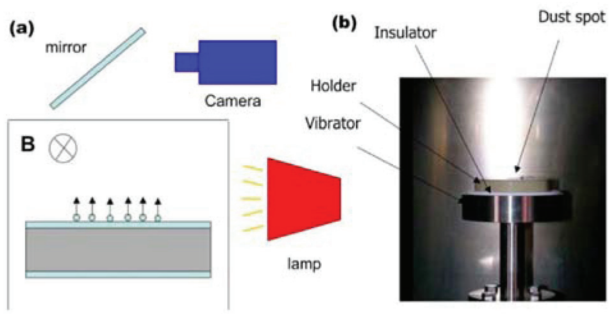


Fig. 1 Experimental Setup.

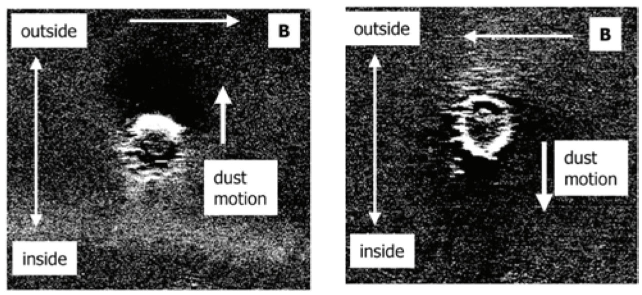


Fig. 2 Dust transport depending on direction of magnetic field.

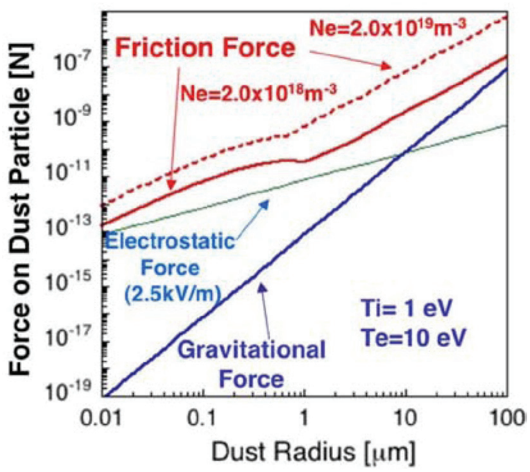


Fig. 3 Dependence of force acting on a dust particle on its radius.

1) N.Ohno, M.Yoshimi, M.Tokitani, *et al.*, Journal of Nuclear Materials, **390-391** (2009) 61-64.
2) Takashi Yamada, Noriaki Matsui, Noriyasu Ohno, *et al.*, Int. Symp. on EcoTopia Science, 2007, Nagoya, Japan
3) Takashi Yamada, Noriaki Matsui, Kengo Yada, Noriyasu Ohno, Makoto Takagi, 8th Workshop on Fine Particle Plasmas, 2007, Toki, Japan

3.4.2 MHD and High Beta

The first US-Japan MHD workshop on Active Control of MHD Mode in Toroidal Plasmas was held in San Diego in conjunction with the 3rd US MHD meeting in November 1998. Since then, the US-Japan MHD workshop has been held annually. In these US-Japan MHD workshops, useful research information is exchanged, and a variety of MHD control issues are discussed. In order to achieve steady-state high-beta tokamak operation it is necessary to stabilize various instabilities, especially the neoclassical tearing mode (NTM) and the resistive wall mode (RWM). Common MHD issues of tokamak and helical plasmas were discussed, and the importance of 3D effects on plasma control physics was clarified.

Rotating magnetic field (RMF) current drive, a steady-state current drive method for field-reversed configuration (FRC) originally developed on Rotamak, was developed further on the much larger TCS device at the University of Washington. A new RMF current drive system was developed for the FIX device at Osaka University with assistance from the TCS group. The RMF antennas in this system, located inside the metal flux-conserving vacuum vessel, kept the sustained FRC plasma away from the plasma wall. Efficient formation of an oblate FRC with a large amount of magnetic flux can be achieved by counter-helicity merging of spheromaks. Various collaborative experiments on counter-helicity plasma merging, which results in high-beta FRC formation, were conducted on the MRX device at PPPL. Equilibrium and stability of the FRC plasma was studied, including the role of the Hall effect during counter-helicity merging, global stability of oblate FRC, and sustainment by the central solenoid.

Fast-ion-driven MHD instabilities such as the energetic particle continuum mode (EPM) and the Alfvén eigenmode (AE) could induce anomalous transport of fast ions/alphas in D-T burning plasmas. A scintillator-based lost-fast-ion probe (SLIP) was first installed on CHS, and subsequently two SLIPs were installed on LHD in collaboration with PPPL to detect lost fast ions with gyroradius and pitch angle resolution in the presence of EPM/AE. Recurrent bursting magnetic fluctuations (most likely EPMs) are often observed in LHD when a low density plasma is heated by tangential NBI. Fast ion losses correlated with EPM bursts were detected by SLIP, indicating that the EPM causes spatial redistribution and loss of beam ions.

MHD Stability Control of Toroidal Plasmas
Basic Processes of Active MHD Control

Category : Fusion Physics/ Core Plasma Phenomena
Year-Number : 2003-FP2-2, 2004-FP2-9
Name: Kozo Yamazaki, Takahisa Ozeki
Michio Okabayashi, Gerald Navratil
Affiliation: National Institute for Fusion Science
(Present: Nagoya University)
Japan Atomic Energy Research Institute
Princeton Plasma Physics Laboratory
Columbia University

For the achievement of high performance toroidal plasmas, it is necessary to stabilize various instabilities. Especially, relevant to steady-state high-beta operation of tokamaks, the stabilization of RWM (Resistive Wall Mode) and NTM (Neoclassical Tearing Mode) is one of main research issues. As for feedback-control plan of tokamak plasma instabilities, FSX (Feedback Stabilization Tokamak) project was discussed in 1996, and extended to the non-axisymmetric magnetic field application and ECH/ECCD stabilization experiments at Columbia University (HBT-EP) and GA (DIII-D) reported in the first US-domestic MHD meeting. The first US-Japan MHD workshop on 'Active Control of MHD Mode in Toroidal Plasmas' was held in San-Diego combined with the 3rd US-domestic MHD meeting.

As an extension of this workshop, the 6th MHD Workshop on "MHD Stability Control of Toroidal Plasmas" was held in Naka JAERI, Feb.2-4, 2004. This was the 5-day joint workshop combined with the Large Tokamak workshop on "Physics of Current Hole" (W56) and the Fourth meeting of the ITPA (International Tokamak Physics Activities) Topical Group on MHD, Disruption and Control. Within the US-Japan workshop, totally more than 30 talks, including JT-60U, LHD, NSTX, NCSX, DIII-D, Alcator C-Mod, ASDEX-UG, ITER results, were presented. The sessions of the workshop are "stability in helical system and control (Ref.1)", "stability in innovative confinement concept", "non-ideal and non-linear MHD stability behavior", "neoclassical tearing mode and steady state issues", and "stabilization and destabilization by wall, error field, rotation and others".

Moreover, the 7th US-Japan MHD Workshop on "Basic Processes of Active MHD Control" was held in Princeton Plasma Physics Laboratory, during November 21(Sunday)-23(Tuesday), 2004, just after the American Physical Society Meeting. This was organized as both US-Japan Workshop and 9th US-domestic Workshop on MHD Stability Control. Seven researchers from Japan attended it, and totally about 40 talks were presented in the workshop including several European researchers. The memorial talk for two late distinguished MHD researchers, Anders Bondeson and Torkil Jensen, was presented. The main sessions of the workshop are "modelling feedback, resistive wall modes (RWMs)" (Ref.2), "non-axisymmetric devices", "plasma response to non-axisymmetric fields", "ballooning, neoclassical tearing modes (NTMs) and other" and "active control experiments". The summary and next-year planning (US domestic Workshop in the University of Wisconsin and US-Japan Workshop in JAERI) were discussed on the final session.

In these US-Japan MHD workshops, useful research information exchange was performed among Japan, US and EU, and a lot of MHD control issues of tokamak, helical systems and RFP were discussed. Especially, the common MHD issues of tokamak and helical plasmas (TABLE I) was discussed, and the importance of 3D effects on plasma control physics was clarified in these workshops.

The above description is based on 2003 and 2004 collaboration researches. In 2010, the 13th US-Japan workshop will be held in the University of Wisconsin. The reason why we can continue our MHD workshop for a long time might be due to synergetic effects between US-side Tokamak-relevant control researches and Japan-side broad research programs. Especially, 3-dimensional effects in MHD tokamak control physics become rather important.

The part of the research achievement of this workshop will be published in the Journal PPCF (Plasma Physics and Controlled Fusion) as a special issue of Active MHD Control.

TABLE I Operational limits in tokamak and helical systems [from Ref.1]

	STANDARD TOKAMAK	STANDARD HELICAL
Confinement	Gyro-Bohm	Gyro-Bohm (Global) Helical Ripple Effect (Local)
Beta Limit	Kink-Ballooning Mode Resistive Wall Mode Neoclassical Tearing Mode	Low-n Pressure-Driven Mode
Density Limit	Radiation & MHD Collapses	Radiation Collapse
Pulse-Length Limit	Recycling Control Resistive Wall Mode Neoclassical Tearing Mode	Recycling Control Resistive mode (?)
Beyond limit	Thermal collapse Current quench	Thermal collapse

1) Yamazaki, K., Kikuchi, M., J. Plasma Fusion Res. SERIES, Vol.5 (2003) pp 28-35.
2) Okabayashi , M., et al, Nucl. Fusion **45** (2005) 1715

Steady Current Drive and Efficient Formation of High-beta FRC Plasmas

Category : Fusion Physics/ MHD and high-beta
Year-Number : 2001-FP2-20, 2005-FP4-5
Name: M. Inomoto, A. Hoffman*, M. Yamada**
Affiliation: Osaka University, *University of Washington, **Princeton Plasma Physics Laboratory

Collaborative researches on steady current drive method using rotating magnetic fields (RMF) and on efficient formation method using counter-helicity merging of spheromak plasmas were carried out to expand the capability of the field-reversed configuration (FRC) plasmas. The FRC is a high-beta plasma confined solely by the poloidal magnetic field and is suitable as a reactor core plasma for advanced fuel nuclear fusion, nevertheless, experimental studies on improvement of confinement have been hindered because of (a) lack of promising heating / current drive methods and (b) difficulty on producing FRC plasma with large trapped magnetic flux.

Steady current drive method using RMF has been developed to solve the former issue. FRC current drive using RMF was demonstrated on rotamak device at Flinders University and then larger experimental apparatus of the TCS device was constructed at University of Washington. With great efforts of the TCS researchers, we developed a new RMF current drive system on the FIX device at Osaka University. Major difference from the previous experiments was that the RMF antennas in our system were located inside the metal flux-conserving vacuum vessel. This new RMF method conduced to keep the sustained FRC plasma away from the plasma wall because of the preferential penetration of the RMF. Fig. 1 shows the typical waveform of RMF discharge on the FIX device. The internal field reverses just after the application of the RMF, forming FRC plasma with about 1ms duration. The ratio of the separatrix radius to the wall radius is about 62%, which is rather smaller than those observed in the other devices.

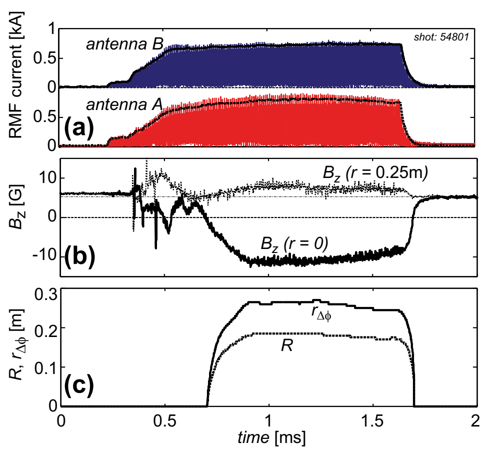


Fig. 1. Time evolutions of (a) RMF antenna currents, (b) axial magnetic field, and (c) separatrix and major radii [1].

Different from the conventional theta pinch method which has difficulty increasing the trapped magnetic flux, the counter-helicity merging of spheromaks provides efficient formation scheme to provide an oblate FRC with large amount of magnetic flux. Thus the oblate FRC plasma produced by the counter-helicity merging is expected as target plasma of the neutral beam injection heating. In this collaborative program, we carried out various experimental researches on the counter-helicity plasma merging and resulting high-beta FRC formation in MRX device at Princeton. The main research contents were the contribution of the Hall effect on the counter-helicity merging, global stability of the oblate FRC, sustainment by the center solenoid coil, and so on. Typical example of the Hall effect is summarized in Fig. 2. Radial inward/outward displacement of X point during merging was observed according to the toroidal field polarities of initial spheromaks. A simple Hall-MHD model illustrates that this X-point motion corresponds to the quadrupole out-of-plane magnetic field caused by the Hall effect in collisionless reconnection, in which the Hall electric field enhances the reconnection rate. We also observed that the outflow structure was modified due to the pressure change on the downstream region which is caused by the global change of the magnetic field. The polarity of the counter-helicity merging also brings about the changes of density and toroidal flow profiles of the FRC plasma, indicating that the combined effect determines the equilibrium and stability of the FRC plasma.

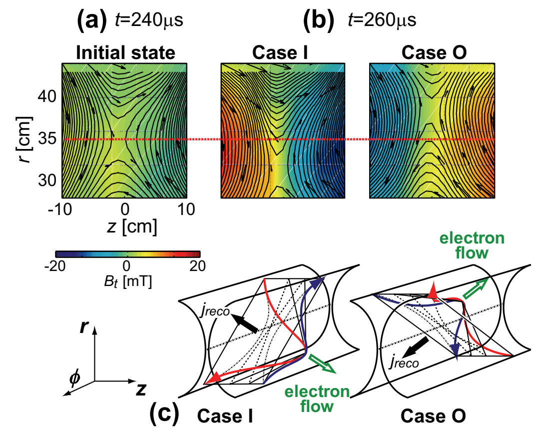


Fig. 2. Poloidal magnetic flux contours (solid lines) with poloidal magnetic field (arrows) and toroidal magnetic field (color coded) at t=240 μs (a) and at t=260μs (b) in cases I (left) and O (right) counter-helicity merging, and corresponding three-dimensional illustrations of reconnecting field lines in the Hall-MHD regime (c) [2].

1) Inomoto, M., et al., Phys. Rev. Lett. **99** (2007) 175003
2) Inomoto, M., et al., Phys. Rev. Lett. **97** (2006) 135002

Energetic-Particle Diagnostic in the Large Helical Device (LHD)

Category : Fusion Physics/Phenomenon in Reactor-Relevant Plasma
Year-Number : 2003-FP2-4
Name : Mitsutaka Isobe, Douglass S. Darrow*
Affiliation : National Institute for Fusion Science, *Princeton Plasma Physics Laboratory

Fast-ion-driven MHD instabilities such as energetic-particle continuum mode (EPM) and Alfvén eigenmode (AE) are of great concern in current fusion plasma experiments because those instabilities may lead to anomalous transport of fast ions/alphas essential in maintaining self-ignited state in a future D-T burning plasma. Alfvénic modes destabilized by fast ions are regularly observed in tokamak plasmas with strong, super Alfvénic ion tails. They are also destabilized in heliotron/stellarator plasmas. In helical plasma experiments, the confinement of magnetically trapped fast ions has been so far one of key arguments because of the symmetry breaking of the system. It must be noted that the issue related to trapped-ion orbit in a three-dimensional magnetic field configuration is currently being solved as a consequence of numerous efforts in optimizing configuration. However, a great deal of attention should be paid to redistribution and/or losses of fast ions induced by energetic-ion-driven MHD instabilities because the interplay between fast ions and fast-ion driven MHD instabilities is not fully understood yet. To predict what will happen in fast-alphas-driven burning plasmas and furthermore, to explore possible discharge scenarios that can avoid serious events associated with fast ions, phenomena caused by fast ions in existing experiments should be carefully investigated.

Scintillator-based lost-fast ion probes (SLIP) are being employed in the Large Helical Device (LHD) to detect lost fast ions while EPM/AE are destabilized due to tangentially injected beam ions. The SLIP was originally proposed and developed in Princeton Plasma Physics Laboratory (PPPL) to study loss process of MeV fusion products, beam ions and fast ions accelerated by ICRH [1]. A project of the SLIP in National Institute for Fusion Science (NIFS) was initiated in 1997. Dr. D.S. Darrow of PPPL who has a thorough knowledge of the SLIP was invited to NIFS as a visiting professor for about one year. As a result of his great contribution, the SLIP was successfully installed onto CHS [2]. Subsequently, Dr. Darrow visited NIFS in the framework of Japan/U.S. Cooperation in Fusion Research and Development, helping us in transferring the SLIP technology to LHD. At present, LHD is equipped with two SLIPs at inboard and outboard sides of the torus.

Fig. 1 depicts basic functions of SLIP. The SLIP is based on a magnetic spectrometer concept, providing gyroradius and pitch angle (χ=arccos($v_{//}$/v)) of escaping fast ions as a function of time. As seen in Fig. 1, ions with larger gyroradii strike the scintillator farther from the apertures than those vdth smaller gyroradii. Their strike points are dispersed across the orthogonal dimension of the scintillator according to their pitch angles.

Recurrent bursting magnetic fluctuations which are most likely EPMs are often observed in LHD when NBs are tangentially injected into relatively low density plasmas (n_e~1x10^{19} m^{-3}). Fig. 2 shows time traces of the amplitude of magnetic fluctuations filtered in frequency of 10~40 kHz, fast-neutral flux measured with E//B-NPA oriented so as to detect fast-neutral particles charge-exchanged with co-going beam ions, beam-ion loss rate to SLIP placed at the outboard side and stored energy evaluated from a diamagnetic loop signal. In this shot, volume-averaged beam ion β is comparable to the bulk plasma β. Correlated with each EPM burst, fast-neutral flux (E~148 keV, χ < 40 deg.) and beam ion loss rate to the SLIP significantly. E and χ of detected escaping beam ions are ~160 keV and ~30 deg., respectively and are consistent with energy of anomalously transported beam ions measured with E//B-NPA. This observation tells that there exist co-going beam ions redistributed toward the peripheral region at the outboard side and some of transported beam ions are lost due to EPMs.

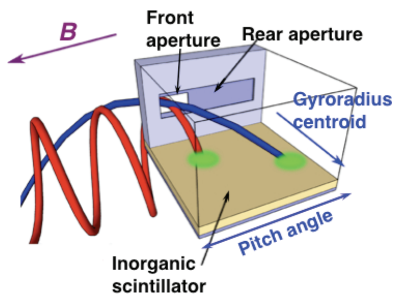


Fig. 1. Basic function of scintillator-based lost fast ion probe.

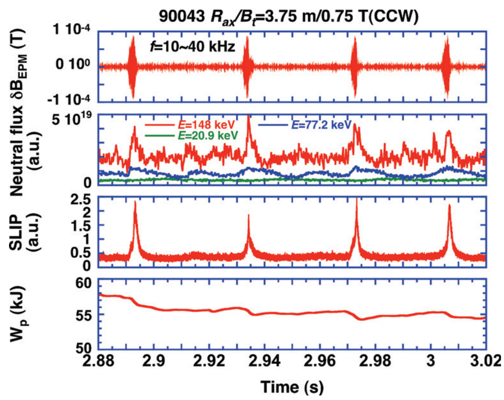


Fig. 2. Time traces of δB_{EPM} at the Mirnov coil position, charge exchange fast neutrals for three different particle energies, beam-ion loss rate to SLIP (E~160 keV, χ~30 deg.) and W_p.

1) Zweben, S.J., Nuclear Fusion **29** (1989) 825.
2) Isobe, M. et al., Rev. Sci. Instrum. **12** (1999) 4589.
3) Isobe, M. et al., Fus. Sci. Technol. to be appeared in July 2010.

3.4.3 Confinement

The mutual collaboration of confinement physics experiments has been developed between US and Japan. One example is the US-Japan personal exchange program related to the coaxial helicity injection (CHI) experiment on National Spherical Torus Experiment (NSTX) of Princeton Plasma Physics Laboratory (PPPL) and Helicity Injected Spherical Torus (HIST) of University of Hyogo. The purpose of this US-Japan collaboration is to investigate potential of application of the CHI current drive and start-up methods to Spherical torus (STs). The related experiments were successful and the studies moved to the transient CHI experiments. These results also demonstrated the potential for the application of this method to future machines. With regard to NSTX, another experimental collaboration of the plasma current ramp-up by vertical field was conducted and the obtained results were transferred to the domestic confinement experiment of QUEST at Kyushu University. A series of US-Japan experimental collaborations concerning radiofrequency (RF) wave physics on tokamaks, including spherical tokamaks (ST), were carried out with the groups at University of Tokyo, PPPL and Massachusetts Institute of Technology Plasma Science and Fusion Center (MIT PSFC). Remote execution of experiments from Japan to PPPL were carried out successfully. In this collaboration, the start-up experiment was carried out over two years with successive improvements. However, while plasma initiation was achieved, but not I_p ramp-up. At MIT, heating and current drive experiments by the ICRF fast wave and the lower hybrid wave (LHW) were carried out on the high field tokamak Alcator C-Mod.

From the viewpoint of plasma confinement theory, the US-Japan collaboration study of the two-fluid low-collisionality equilibrium model and its application to rapidly-rotating high-performance spherical torus was carried out with the group of Niigata University in Japan and the NSTX group at PPPL. The calculation results were found to be markedly different from static or slowly flowing equilibrium.

US-Japan workshop on Physics of Plasma Merging and Magnetic Reconnection has been held to discuss recent progress in physics and applications of plasma merging/magnetic reconnection. The first MR workshop MR2000 was held at University of Tokyo in Japan and, after MR2000, the MR200X workshop have been held by 50-60 invited and contributed speakers every year either in US or in Japan. Based on these activities, a new reconnection and dynamo COE project: Center for Magnetic Self-Organization in Laboratory and Astrophysical Plasmas was accepted by the US National Science Foundation (NSF) in 2008 and by Japan Society of the Promotion of Science (JSPS) in 2010, which are now exploring a new stage of US-Japan collaboration on magnetic reconnection and self-organization caused by reconnection. On the other hand, the first US-Japan MHD workshop on Active Control of MHD Mode in Toroidal Plasmas was held in San-Diego combined with the 3rd US-domestic MHD meeting. As an extension of this workshop, the 6th MHD Workshop on “MHD Stability Control of Toroidal Plasmas” was held at Naka JAERI in 2004. The 7th US-Japan MHD Workshop on “Basic Processes of Active MHD Control” was held at PPPL in 2004. In these US-Japan MHD workshops, useful research information exchange was performed among Japan, US and EU, and a lot of MHD control issues of tokamak, helical systems and RFP were discussed.

Coaxial helicity injection (CHI) start-up and current drive for ST plasmas

Category : Fusion Physics/ High beta, Heating and current drive
Year-Number : 2000-FP4-9, 2001-FP4-07, 2003-FP4-5, 2004-FP4-3, 2006-FP4-3, 2007-FP3-4, 2007-FP3-5
Name: M. Nagata and R. Raman*
Affiliation: Himeji Institute of Technology / University of Hyogo and University of Washington*

Spherical torus (STs) has a potential to lead to an attractive high-beta fusion reactor but in which efficient current drive methods are required for plasma start-up and steady-state sustainment of discharges because there is no enough space in the center post to install a solenoid coil with a large amount of flux. Coaxial Helicity Injection (CHI) is one of the most attractive candidates to resolve the non-inductive current drive and plasma start-up issues for STs. This approach was initially investigated in Helicity Injected Torus-II (HIT-II) [1] of University of Washington (UW), National Spherical Torus Experiment (NSTX) [2] of Princeton Plasma Physics Laboratory (PPPL) and Helicity Injected Spherical Torus (HIST) [3] of University of Hyogo. The UW group with a member of T.R Jarboe, B.A. Nelson and R. Raman has been leading the CHI research on NSTX. The CHI experiment on NSTX is in the charge of R. Raman who takes care of experimental collaborator (M. Nagata) from Japan by the US-Japan personal exchange program. The main purpose of this collaborative experiment is to investigate potential of application of the CHI current drive and start-up method to STs.

The experimental set-up of CHI on NSTX is shown in Fig.1 (a). In the initial experiment, a peak plasma current up to 390 kA was successfully generated and maintained for 300 ms by CHI (injector current 25 kA, voltage 1kV). DC power supply (50 MW) was used in this experiment. As shown in Fig. 2, the plasma rotation (20 km/s) driven in the $\boldsymbol{E}\times\boldsymbol{B}$ toroidal direction by CHI was clearly identified by an ion Doppler spectroscopic measurement [4]. The n = 1 mode was also observed to rotate in the same direction. This rotating kink behavior observed for the first time in NSTX is consistent with the electron locking model [1] developed in the HIT-II experiments to explain the mechanism of CHI current drive. During the steady-state CHI operation, MHD relaxation mechanism for current transfer is required to generate closed flux. Thus, its identification was one of main research subjects after the first achievement. Then we had moved on the experiment for the purpose of plasma start-up. The transient CHI method for the start-up was proposed in order to produce a high quality start-up equilibrium having enough closed flux. In the initial CHI start-up discharge (capacitor banks:50 mF, 2 kV), we achieved that 3 kA of injector current produces ~120 kA of plasma current, so the current multiplication is ~40. Also, results from Fig. 1(b)(c) and equilibrium reconstructions demonstrated the presence of closed-flux surfaces.

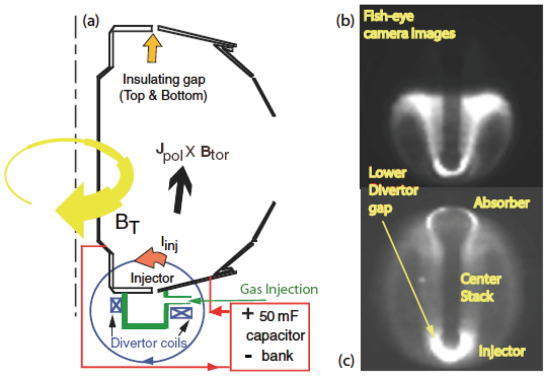


Fig. 1. Schematic showing application of CHI in NSTX (a), fast camera fish-eye image of the plasma during the early phase (b) and later in time of the CHI start-up discharge (c).

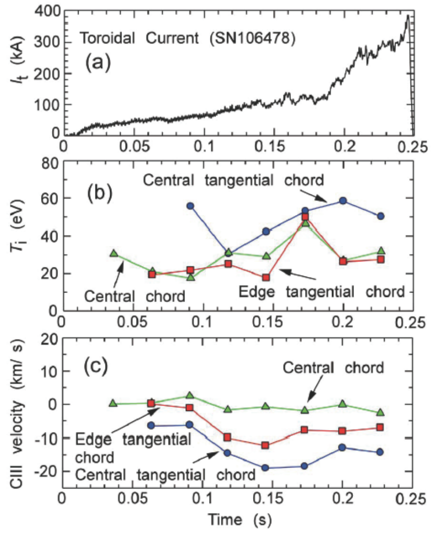


Fig. 2. Time evolution of the toroidal current (a), Doppler ion temperature (b) and CIII ion flow velocity (c).

After a significant development of the transient CHI experiments, the CHI started discharges were successfully coupled to induction to show compatibility between the transient CHI and the conventional OH drive. It was shown that the CHI started plasma current 100 kA ramped up, reaching a peak value of 700 kA (injector current 3 kA) [5]. In this discharge, neutral beams were also injected to heat the plasma (T_e>0.8 keV), triggering an H-mode transition. These achievements demonstrate the potential for the application of this method to future machines.

1) T.R. Jarboe et al., Nucl. Fusion **41** (2001) 679.
2) M. Ono et al., Nucl. Fusion **41** (2001) 1435.
3) M. Nagata et al., Phys. Plasmas **10** (2003) 2932.
4) M. Nagata et al., Plasma and Fusion Research: Rapid Communications **2** (2007) 0035.
5) R. Raman, et al., Nucl. Fusion **49** (2009) 65006.

Plasma current ramp-up by the vertical field in NSTX

Category: Fusion Physics/ Confinement
Year-Number : 2000-FP2-18,2001-FP2-18, 2002-FP2-15, 2003-FP2-13,2005-FP2-13, 2006-FP2-6, 2008-FP4-3
Name: O. Mitarai, C. Kessel, M. Ono, and M. Peng
Affiliation: Kyushu Tokai University, PPPL and ORNL

Purpose of collaborative research and its background:

As the spherical tokamak (ST) has no space for the central solenoid (CS), it is desirable to start-up the plasma current without a CS. One of such techniques is the plasma current ramp-up by the vertical field, which was proposed by author. This technique was already demonstrated in JT60U, TST-2, and MAST. To confirm this effect and to apply this technique to the other ST device, NSTX, I (Mitarai) have applied for US-Japan collaborative research project.

Research subjects and obtained results:

During 2000 and 2006, it was planned to observe the plasma current ramp-up by the additional heating in the constant ohmic current phase (OH clamp experiment) in NSTX and then planned to move the heating power to the initial plasma current start-up phase. From 2008, the plasma current start-up in CTF has been studied, which is a common subject to above vertical field induction.

1. Distinguishable results

Although I have visited NSTX to make experiments for several years, remote experiments have been done finally with Dr. C. Kessel (PPPL) due to machine time schedule. As shown in Fig.1 in the OH clamp experiment, only one shot was obtained with plasma current increment by the vertical field and RF heating power, but the other shots did not show any plasma current increment. In the case of plasma current of 500 kA, the plasma current was not additionally increased by NBI heating as shown in Fig. 2. Those reasons were not cleared yet, but we suspect that the distance between the plasma and RF antenna was widened, leading to the difficulty of RF injection. On NBI experiments, the base plasma current might be too low for

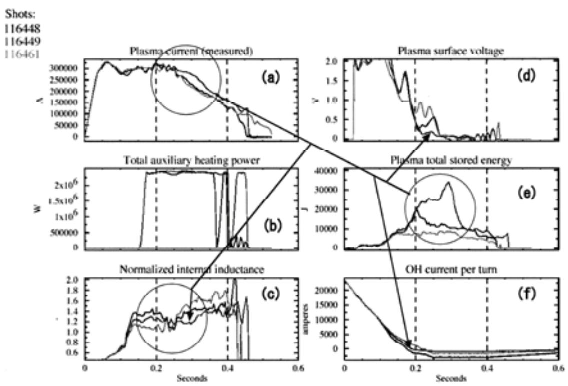


Fig. 1 OH clamp experiments in NSTX. (a) the plasma current,(b) RF power, (c) the internal inductance,(d) the surface loop voltage, (e) plasma energy, and (f) Ohmic coil current. (#115448 and #116449: RF with OH clamp. #116461 No RF with OH clamp.)

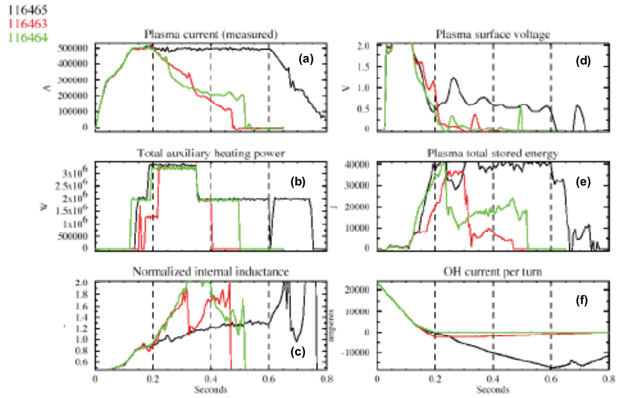


Fig. 2. OH clamp experiments in NSTX. (a) the plasma current,(b) NBI power, (c) the internal inductance,(d) the surface loop voltage, (e) plasma energy, and (f) Ohmic coil current. (#116463 and #116464: NBI with OH clamp. #116465 No OH clamp.)

the efficient heating due to worse high energy particle confinement. Also experiments were conducted in the larger internal inductance phase which provides the larger plasma inductance, leading to the difficulty of the plasma current increment [1].

2. Study of OH operation in NSTX and the plasma current ramp-up in CTF

I have obtained very important information on Ohmic Heating (OH) operation in NSTX, which has never been seen in the published papers or Laboratory reports. In NSTX sophisticated operations have been conducted to control of the poloidal field coil current for producing the field null regime for breakdown. Therefore, I have conceived the idea to install the cancellation coil (CC) in the domestic ST, QUEST, for producing the field null for better plasma breakdown and plasma current start-up because QUEST has no such sophisticated PF control system in the initial phase. Actually in QUEST the good plasma current start-up was obtained using CC at the second shot. Thus, the knowledge obtained during the US-Japan collaboration was very useful for the domestic experimental program.

I and Dr. M. Peng (ORNL) have been studying the plasma current ramp-up in CTF using the same concept. Although the plasma current ramp-up to 16 MA by ECRH and NBI without CS, we are planning to install the small CS for a reliable plasma current start-up [2].

3. Summary of my US-Japan collaboration

Although I have gotten slightly negative results in NSTX experiments, I have efficiently utilized information obtained during US-Japan collaboration for the domestic experimental programs. As a result, the plasma current ramp-up by the vertical field was clearly observed in QUEST during the constant OH current phase (OH clamp experiment) differently from NSTX. I can conclude that my US-Japan collaboration was very successful.

1) O.Mitarai, C.Kessel and A. Hirose, JEEE, Vol.129/ No.9/Sec.A (2009) p605
2) O.Mitarai, Under preparation of resubmission (2010)

Collaborations Related Radiofrequency Wave Physics

Category : Fusion Physics/ Steady-State Operation, Heating and Current Drive
Year-Number : 2000-FP4-8, 2001-FP4-8, 2002-FP4-6, 2003-FP4-3, 2004-FP4-4, 2005-FP2-6, 2006-FP4-4, 2007-FP2-4, 2008-FP2-1, 2009-FP2-4
Name: Y, Takase, M. Ono*, J.R. Wilson*, J.E. Menard*, R.R. Parker**, P.T. Bonoli**, J.C. Wright**
Affiliation: The University of Tokyo, *PPPL, **MIT PSFC

A series of collaborations concerning radiofrequency (RF) wave physics on tokamaks [including spherical tokamaks (ST)] were carried out with groups at Princeton University Plasma Physics Laboratory (PPPL) and Massachusetts Institute of Technology Plasma Science and Fusion Center (MIT PSFC) as listed below.

FuY 200: Heating experiments by HHFW on NSTX
01: Heating and current drive experiments by HHFW on NSTX
02: HHFW Current Drive Experiments on NSTX
03: Current Drive and Current Ramp-up Experiments on NSTX
04: Solenoidless Current Ramp-up Experiments on NSTX
05: Solenoidless Current Ramp-up on NSTX
06: TORIC Simulations of HHFW Heating and Current Drive in TST-2
07: Lower hybrid current drive and current profile control experiments
08: Lower hybrid current drive experiments
09: TORIC-LH Simulations of LHCD Scenarios for TST-2

ST has the advantage of being able to confine high beta plasmas stably. However, this means that the plasma has a very high dielectric constant. It is believed that the high harmonic fast wave (HHFW) could be used effectively for heating and current drive even in plasmas with very high dielectric constant. TST-2 at the University of Tokyo and NSTX at PPPL share the common objective of HHFW heating and current drive, and started to collaborate on HHFW experiments on NSTX. Besides obtaining important experimental results on electron heating, the dependence of the antenna loading resistance on the neutral pressure was clarified by analyzing data from HHFW plasma start-up experiments. In Japan, successful results were achieved in plasma current (I_p) start-up experiments without the use of the Ohmic heating coil on JT-60U and TST-2. An experimental scenario was developed for NSTX and an experimental proposal was formulated based on these achievements. Since there were occasions when experiments could not be conducted as planned during the visiting period, due to problems with experimental hardware or software, arrangements were made to enable remote execution of experiment (not as a mere participant, but as a session leader). Remote execution of experiment was carried out successfully from the University of Tokyo in 2004. The start-up experiment was carried out over two years with successive improvements. Plasma initiation was achieved, but not I_p ramp-up. The reason is belieed to be insufficient RF power delivered to the plasma forming region.

At MIT, heating and current drive experiments by the ICRF fast wave and the lower hybrid wave (LHW) are being carried out on the high field tokamak Alcator C-Mod, which is in stark contrast to the ST. Experimental results are compared directly with the state-of-the-art full wave analysis codes TORIC and TORIC-LH. Application of TORIC and TORIC-LH to ST plasmas, which are vastly different from conventional tokamak plasmas, has contributed to identifications of errors in these codes. These codes have been improved successively and can now be applied to HHFW and LHW in ST plasmas. TORIC-LH has been used to examine scenarios to be used in the planed I_p ramp-up experiments by the LHW on TST-2. TORIC-LH has the advantage of being able to treat diffraction effects, which cannot be handled by ray-tracing codes. Results indicate that low I_p, low density plasmas are suitable targets for lower hybrid current drive (LHCD), but the propagation region for the LHW becomes restricted to the plasma edge as I_p and density increase. It is therefore important to keep the density low and to control the wavenumber spectrum. These results provide guidance to I_p ramp-up experiments on TST-2. LHCD experiments have started on Alcator C-Mod after a long period of preparation. This is presently the only LHCD experiment in both Japan and the US. Experimental collaboration on LHCD was carried out over two years. In 2007, experiments focusing on parametric decay, which is considered as a candidate responsible for density limit for LHCD, were conducted since the usable LH power was limited to less than 0.5 MW. The experiment could not be performed during the visit due to a problem with the toroidal field coil, but was carried out remotely from Japan as a session leader. Even with the frequency of 4.6 GHz, the upper limit of density for LHW-.electron interaction in deuterium plasma was around 1×10^{20} m^{-3}. This result is an important input to the selection of frequency for the ITER LHCD system. In 2008, a continuous density scan was carried out over a wide range, and it was confirmed that the density limit for LHCD at 4.6 GHz is 1×10^{20} m^{-3}, and does not depend sensitively on either the LHW wavenumber spectrum or the magnetic field strength. An indication of broadening of the LHW absorption profile was observed when the electron temperature increased to around 5 keV. In addition, an experimental proposal to create a current hole and an internal transport barrier using LHCD during the I_p ramp-up phase was drafted. If successful, this technique may be used to form an advanced tokamak plasma with high bootstrap current fraction on Alcator C-Mod.

MR2001-2009 Workshops (Physics of Plasma Merging and Magnetic Reconnection)

Category : Fusion Physics/ Steady-State Operation
Year-Number : 2008-FP2-1, 2009-FP2-2 etc. (2000-2009)
Name: Yasushi Ono
Affiliation: University of Tokyo

The purpose of MR Workshops (US-Japan workshop on Physics of Plasma Merging and Magnetic Reconnection) is to discuss recent progress in physics and applications of plasma merging/ magnetic reconnection. A series of this workshops have been supported by major four communities: laboratory reconnection experiments, solar observation, magnetosphere observations and theory/ simulations. We had the first MR workshop MR2000 at University of Tokyo from Feb. 29 to Mar. 4, 2000. About 130 researchers from the four communities discussed the reconnection physics for a week. After MR2000, the MR200X workshops have been held by 50-60 invited and contributed speakers every year either in US or in Japan mostly. Figures 1 show photos of laboratory experiments of magnetic reconnection: MRX, TS-4, SSX, VTF, UTST, MST and Caltech Rec. Exp. The series of workshop made clear that each research field has advantages and disadvantages. The solar observation can measure a nice 2-D image of the sun but a limited local parameters such as magnetic field and current density because of long distance from the satellites to the sun. The magnetosphere observation can measure all local parameters but not their special profiles because of a limited number of satellites. The laboratory experiments is the most powerful tool to measure 2-D /3-D profiles of all parameters but their plasma parameters such as the Lindquest numbers are low due to their limited special scale. The theory and simulation can test all kind of physics under the most ideal conditions but based on some specific assumptions. The collaboration of these four communities made significant progress in solving the fast reconnection mechanisms an its heating characteristics and also in exploring fusion applications of reconnection. Especially, the high power heating of fusion plasma heating became a economical startup method for Spherical Tokamaks (STs) and Field-reversed Configuration (FRCs) for the past 10 years. The most recent MR2009 conference was held at Princeton Plasma Physics Laboratory from March 2 to 4, 2009. The key subjects were (1) solar satellite "Hinode" observation of reconnection on solar coronas and chromosphere, (2) theories and experiments for solar flares and micro jets, (3) non-thermal particle acceleration of reconnection, (4) plasma flow and reconnection in laboratory experiments, (5) two-fluid reconnection in magnetosphere and laboratory, (6) current sheet and plasmoid ejections in magnetosphere and laboratory, (7) relativistic magnetic reconnection, (8) trigger mechanism of reconnection and solar flares, (9) 3-D reconnection research. Presentations from the major four fields revealed several important common physics: Hall reconnection, plasmoid and current sheet ejection, non-thermal particle, Hall effect, plasmoid ejection, 3-D reconnection, anomalous resistivity due to magnetic fluctuations, relativistic reconnection, promoting the interrelationship and concrete collaborations among laboratory experiments, theories and observations.

Based on contribution of US and Japanese communities of magnetic reconnection, a new reconnection and dynamo COE project: Center for Magnetic Self-Organization in Laboratory and Astrophysical Plasmas was accepted by the US National Science Foundation (NSF) in 2008 and by Japan Society of the Promotion of Science (JSPS) in 2010, which are now exploring a new stage of US-Japan collaboration on magnetic reconnection and self-organization caused by reconnection.

1) Ono, Y., Kakuyugokagaku **77** (2001) 948-954.

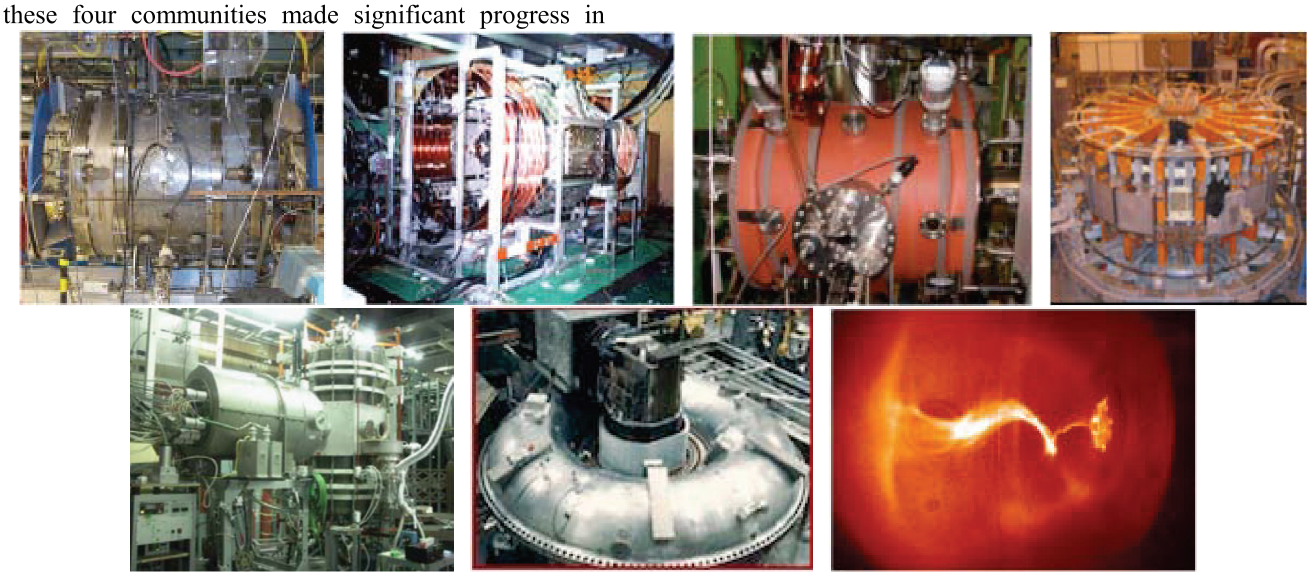


Fig. 1: Laboratory Experiments of Magnetic Reconnection: MRX (Princeton Univ.), TS-4 (Univ. Tokyo), SSX (Swarthmore College, VTF (MIT), UTST (Univ. Tokyo), MST (Univ. Wisconsin), Reconnection Exp. (Caltech)

Two-fluid low-collisionality equilibrium model and application to rapidly-rotating high-performance spherical tours

Category : Fusion Physics/ High Beta
Year-Number : 2008-FP3-6, 2009-FP3-6
Name: Akio Ishida, L.C. Steinhauer*, Y.-K. M. Peng**
Affiliation: Niigata University, *Redmond Plasma Physics Laboratory, University of Washington, **Oak Ridge National Laboratory

The multi-fluid axisymmetric equilibrium model of collisional plasmas was developed earlier [1] where the species surface function plays a crucial role.

$$Y_\alpha = \psi + (m_\alpha/q_\alpha)Ru_{\alpha\phi} \quad \text{for } \alpha = i \text{ or } e$$

Here ψ the poloidal flux and $u_{\alpha\psi}$ the species toroidal velocity. Instead of the adiabatic relation [1], we adopt in this low-collisionality model the isothermal relation for each species: $T_\alpha = T_\alpha(Y_\alpha)$. This can be deduced from Eqs. (67), (68) of Ref.[2] assuming the poloidal ion flow is less than the ion toroidal flow and taking symmetry of the formalism into account. The system of equations includes second-order partial differential equations and a Bernoulli equation for each species. To demonstrate the usefulness of the present equilibrium model, we apply it to reconstruct a high-performance, long-lived NSTX plasma with high beta and near sonic rotation [3]. The computational results are summarized in Table and Figs.1,2. The aspect ratio A, elongation κ, the q-values are in reasonable range of NSTX [Table]. Fig.1 compares profiles of this example equilibrium with NSTX shot 113460 (see Fig.2 of Ref. [3]). Maximum values of temperatures, density and toroidal velocity are shown in Table. The ratio of the ion toroidal velocity to the ion thermal velocity at the magnetic axis is near unity. As a result, the species toroidal current density is significantly larger than the net toroidal current density [Table]. This extraordinary result differs markedly from static or slowly flowing equilibria. Fig.2 shows the ion fluid force balance. The ion pressure gradient force (red) is significantly larger than the Lorentz force (blue) and $\mathbf{E}+\mathbf{u}_i\times\mathbf{B}$ does not vanish so that two-fluid effects cannot be neglected. The centrifugal force (purple) is significant near the magnetic axis. As a result of large two-fluid effect, species diamagnetic drift rather than the E×B drift is a major contributor to the cross field drift. This implies that usefulness of flute-mode suppression by E×B drift shearing is uncertain in an equilibrium like this. Note that the ion current is predominantly parallel to the magnetic field. This follows from the fact that $j_{i\phi}B_z$ (not shown) is significantly larger than $(\mathbf{j}_i\times\mathbf{B})_R$. One consequence of the large parallel ion flow near the ion thermal speed is a significant increase in the fraction of passing ions and reduction of trapped ions. This may affect the standard theories of neoclassical model and the associated plasma transport (energy, momentum, particles including impurities) [4].

Table. Various computed values

$A = 1.4$	$T_{e,max} = 1.1keV$
$\kappa_{95} = 2.4$	$T_{i,max} = 1.3keV$
$q_0 = 1.5$	$n_{max} = 0.6\times10^{20}m^{-3}$
$q_{95} = 10.3$	$u_{i\varphi,max} = 249km/s$
$\beta_T = 0.1$	$(u_{i\varphi}/v_{th,i})_{axis} = 0.9$
$I_p = 1.2MA$	$(j_{i\varphi}/j_\varphi)_{axis} = 2.9$
$f_{2F} = 1.9$	$(j_{e\varphi}/j_\varphi)_{axis} = -1.9$

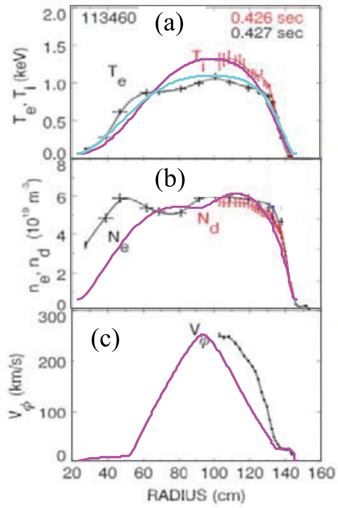


Fig. 1.Comparison of profiles of the computed equilibrium with NSTX shot 113460 (see Fig.2 of Ref.3): a) computed ion (pink) and electron (cyan) temperatures; b) computed density (pink); c) computed ion toroidal flow velocity (pink).

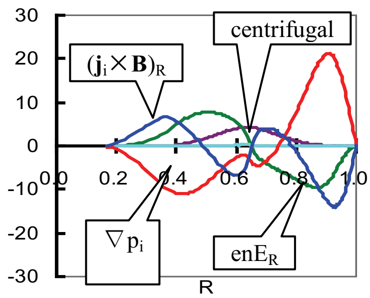


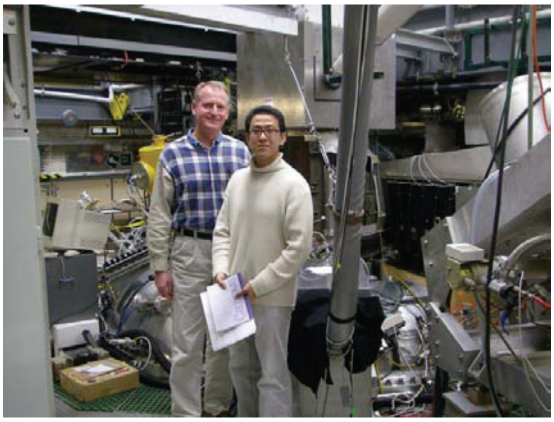
Fig. 2. Ion fluid force balance: pressure gradient force (red), Lorentz force (blue), electric force (green) and centrifugal force (purple).

[1] L.C. Steinhauer, Phys. Plasmas **6,** 2734 (1999).
[2] J.J. Ramos, Phys. Plasmas **12**, 052102 (2005).
[3] Y-K.M. Peng et al., Plasma Phys. Control. Fusion **47**, B263 (2005).
[4] The present result was submitted to Phys. Rev. Letters, April, 2010.

3.4.4 Diagnostics

The diagnostics area is one of the most active areas in the US-Japan collaboration in the field of the experimental fusion research. The development of various kinds of innovative diagnostic instruments has been done. One of them is the development of millimeter wave imaging technology, aiming at visualizing 2D and 3D structure of plasma. The University of California at Davis (Neville C. Luhmann, Jr. and Calvin Domier) and Kyushu University (A. Mase and N. Ito) have successfully collaborated on the development of various millimeter-wave devices for advancement of plasma imaging diagnostics. As an example, 1×16 beam shaping and 1×8 beam steering phased array antenna (PAA) are fabricated by EF2 technology under the collaboration among UCD, KASTEC, and Kyushu Hitachi Maxell, Ltd. The devices are being applied to microwave imaging reflectometry (MIR) and electron cyclotron emission imaging (ECEI) systems on DIII-D, LHD, KSTAR and TEXTOR.

NCSX tour during the Microwave Diagnostic (Imaging) Workshop at Princeton in 2005.



Dr. T. Akiyama and Dr. D.L. Brower in front of the MST Reversed-Field Pinch at Madison.

Neutral particle diagnostics using the silicon surface barrier detector (SD-NPA) started from 1998 under the collaboration of ORNL and NIFS. This program has been proposed from the United State side to investigate fast ion distributions in the Large Helical Device (LHD). The specifications of the method are to observe the low energy particle, to have the lower noise by the liquid nitrogen cooling, and to have six horizontal channel and vertical scan system. The dependence of the energetic particle spectra on the magnetic axis has been investigated. The result obtained is agreed with the theoretical prediction. N. Nishino at Hiroshima University has been contributing on the development of two-dimensional ion flow measurement system with Stephen Paul and Robert Kaita at PPPL. The first attempt to measure the ion flow of NSTX plasma at PPPL was performed. Development of an advanced impurity transport diagnostic system has been carried out, under the collaboration between NIFS and the Johns Hopkins University (JHL). The system consists of a Tracer-Encapsulated Solid Pellet (TESPEL) developed by NIFS and a spectrometer using a multi-layer mirror developed by JHL. In this system, a charge exchange spectroscopy can reduce drastically an ineludible line-of sight integral effect in a spectroscopy. This diagnostic system has been applied on the LHD and NSTX. US-JAPAN Workshop on "Compact Plasma Neutron Source for Neutron Assay" was originally inaugurated at Kansai University in 1983 and which has been alternatingly organized in Japan and the United States. The last WS has been held from 12 to 13 October 2009 at University of Wisconsin, Madison, USA. About 55 attendants including 12 from Japan discussed on the plasma physics and the facility engineering of plasma neutron sources as well as applications for space propulsion and the production of n-type semi-conductor in addition to the neutron assay. The measurements and the modeling for numerical analysis have made a large progress. The new ideas for the improvement of the device such as the magnetized follow cathode, the formation of the cathode by the electron injection and the cylindrical geometry device applying an axial magnetic filed were discussed.

With advancement of the US-Japan cooperation, the growing amount of experimental data promoted a Japan-US collaboration to test a freely available TCP acceleration method for faster throughput. Typical results showed 90 % of Gigabit Ethernet capability. A series of network performance tests were made to utilize higher bandwidth on actual 1 Gbps SINET3 and ESnet connection between MIT (USA) and NIFS (Japan).

NIFS data acquisition group visited the MDSplus lab of MIT to have a meeting for virtual laboratory on fusion experiments.

A group photo during the U.S.-Japan Workshop on Millimeter-Wave Plasma Diagnostics at UCD in 2008.

Development of Advanced Microwave Diagnostic Systems for Magnetic Confinement Plasmas

Category: Fusion Physics/ Steady-State Operation
Year-Number:2004-FP5-18, 2007-FP5-6, 2009-FP5-2
Name: Atsushi Mase, Neville C. Luhmann, Jr.
Affiliation: Art, Science and Technology Center for Cooperative Research, Kyushu University, University of California at Davis (UCD)

The cooperation program originated in recognition of the importance of millimeter to submillimeter-wave diagnostics in magnetically confined plasmas in the early 1980's. The transmission and scattering processes of electromagnetic waves were mainly utilized as diagnostic tools. As the electron density in magnetically confined plasmas increased, radar reflectometric process, so called reflectometry, began to be used in 1990's since it provides good spatial resolution and temporal resolution while requiring a single viewing chord and minimal vacuum access in contrast to interferometry and Thomson scattering. Significant advances in microwave and millimeter-wave technology together with computer technology have enabled the development of a new generation of diagnostics for visualization of 2D and 3D structures of plasma (mean value of density/temperature and their fluctuations).[1] The main subjects of the exchanges are "the study of advanced microwave to millimeter-wave plasma diagnostic systems and "the application of the diagnostic systems to large magnetic confinement devices".

The present cooperation includes execution of workshop and personnel exchanges. The obtained results include fabrication of microwave electronic devices and development of diagnostic systems using the fabricated devices. Microwave imaging, for example, electron cyclotron emission imaging (ECEI) and microwave imaging reflectometry (MIR), constitute one of the significant results.[2]

Figure 1 shows the system configuration of the MIR. It consists of focusing optics, a planar-type array detector, and a multichannel intermediate frequency (IF) receiver. The optics can be designed by using a ray tracing code and/or a 2D finite-difference time-domain (FDTD) simulation code. The detector consists of the integration of an antenna array featuring a down-converting mixer using a Schottky barrier diode bonded to each antenna. Both US and Japanese groups have developed several types of antenna elements, such as, bow-tie antenna, dual-dipole antenna, and Yagi-Uda antenna. The comparative study of the imaging array has given good performance of the characteristics. The system also uses a multichannel IF circuit after a heterodyne detection. Microwave integrated circuit power dividers split each of the detector channels into typically 8 portions, each of which has a filter, detector, and video amplifier. Therefore, we can obtain the signals at the poloidal and/or toroidal positions corresponding to the detector number multiply 8 (radial position). In Fig. 1 is shown a new IF circuit designed at KASTEC where band pass filters are installed in both sides of a COM line to resolve the IF signal into separate frequency bands. This type of IF system has been applied to the ECE heterodyne receiver of KSTAR tokamak, under the Japan-Korea collaboration program.

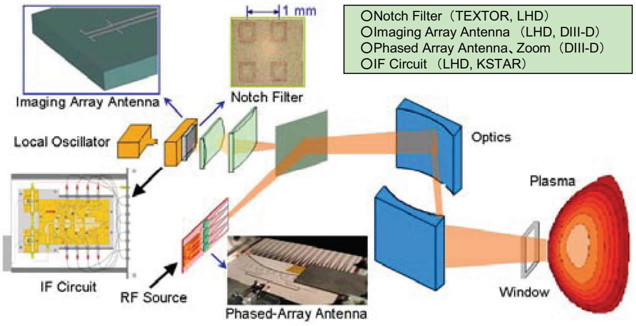


Fig. 1. Configuration of microwave imaging system.

The KASTEC and UCD groups have also investigated the use of new micro-fabrication technologies, electro fine forming (EF2) by Kyushu Hitachi Maxell, Ltd.-Kyushu University and lithographic galvanoformung abformung (LIGA) by UCD. As an example, quasi-optical notch filters with rejection frequency in the range of 110-170 GHz and less than 2 dB transmission losses in the pass band are obtained by EF2,[3] which are better performance than those fabricated by conventional etching process. The notch filter is employed to protect the mixer arrays from stray ECRH power. The filter has been installed in the ECEI systems in TEXTOR and DIII-D tokamaks operated by UCD-PPPL and FOM group.

The 2D and 3D profiles of plasma density/temperature and dynamic behaviors of their fluctuations have been measured by using the above-mentioned imaging systems in TEXTOR, DIII-D, and LHD. The measurements have clarified the physics issues such as stability, wave phenomena, and fluctuation-induced transport.[4, 5]

The continuous development of advanced microwave/ millimeter-wave devices is necessary for the improvement of next generation of imaging diagnostics. Those are beam steering devices, high performance antennas, and high-frequency filters.[6]

The recent exchanges from Japan to the US give priority to the dispatch of young researchers including graduate students, since the device fabrication and characterization have been the main research subjects of the exchanges. The period of stay is in the range of 2-3 weeks. A longer stay will be desirable for the collaborative experiment using the diagnostic system installed in the magnetic confinement devices. Also, the dispatch of young researchers from the US to Japan will also become important for the buildup of new cooperation group.

1) A. Mase *et al.*, Plasma Device Operations **17** (2009) 98.
2) H. Park *et al.*, Rev. Sci. Instrum. **74** (2003) 4239.
3) Z. Shen, N. Ito, Y. Liang, L. Lin, C. W. Domier, M. Johnsaon, N. C. Luhmann, Jr., A. Mase, and E. Sakata Plasma Fusion **2** (2007) S1030.
4) H. Park *et al.*, Phys. Rev. Lett. **96** (2006) 195003.
5) S. Yamaguchi *et al.*, Rev. Sci. Instrum. **79**(2008)10F111.
6) Lu. Yang, N. Ito, C. W. Domier, N. C. Luhmann, Jr. and A. Mase, IEEE Trans. MTT-**56** (2008) 767.

Development of Microwave Reflectometry

Category : Fusion Physics/ Diagnostics
Year-Number: 2002-FP5-37, 2005-FP5-21, 2006-FP5-16
Name: Akira Ejiri, William Peebles,
Shigeyuki Kubota
Affiliation: The University of Tokyo,
University of California, Los Angeles

Various microwave reflectometer experiments were carried out on the NSTX device, under the collaboration between the University of Tokyo and the UCLA microwave diagnostics group. Two types of microwave correlation reflectometers were tested. In addition, RF induced density oscillation was measured.

Correlation reflectometry is the method to extract information from the correlation of two or more reflectometer signals. We have tried to extract the pitch angle of magnetic field lines, and the magnetic field strength.

In general, the parallel correlation length of fluctuations is long, while the perpendicular correlation length is short. Therefore, we can expect that the two reflectometer signals show a high correlation, when the measurement positions are connected by the same magnetic field line. We used three reflectometers in the NSTX device. Two were located on the same poloidal cross-section, while the third was separated toroidally by about 20 cm. The microwave frequency of one of the two reflectometers at the same poloidal cross-section was swept, while the other two frequencies are fixed to different values. By calculating the correlation between the first two microwave signals, we obtained the radial correlation function, and confirmed that the correlation took the maximum when the two measure the same position. By calculating the correlation between the signals from the two toroidally separated reflectometers, we confirmed that the correlation took the maximum when the two measured the same flux surface. These results agreed with our expectation. However, the relationship between the latter correlation and the perpendicular distance between the magnetic fields are not clear. As a result, we could not prove the pitch angle measurement.

The O-mode cutoff frequency depends on the density, while the X-mode cutoff frequency depends on the density and the magnetic field strength. Therefore, the O-mode and the X-mode microwave reflectometer frequencies to measure the same position are different. By finding the frequencies, the magnetic fields strength can be obtained as a function of density. The experiments were performed on the NSTX devices, and we have succeeded in the magnetic field measurement [1].

Electron heating experiments by High Harmonic Fast Wave (HHFW) were carried out on the NSTX and the TST-2 spherical tokamak devices. It was shown that parametric decay instabilities (PDIs) deteriorate the electron heating efficiency. Since, the PDI is a nonlinear phenomenon, it is highly desirable to measure the RF electric field strength in the plasma. Since the RF electric field induces the electron density oscillation, the fields can be measured by reflectometry. The microwave reflectometer experiments were performed on the NSTX and the TST-2 devices.

In NSTX, the RF frequency was 30 MHz, and the intermediate frequency of the heterodyne microwave reflectometer was 28.5 MHz. Therefore, the RF-induced signals were expected to appear at 30-28.5=1.5 MHz. Figure 1 (a) shows the power spectrum of the reference signal around 1.5 MHz. Since the reference signal is independent of the plasma, the sharp peak at 1.5 MHz represents the RF-induced noise. A similar sharp peak appeared in the power spectrum of the plasma signal (Fig. 1(b) red). By analyzing these components, we concluded that these sharp components arose from the frequency modulation of the microwave source, which is induced by the RF at 30 MHz. However, the plasma spectrum shows addition broad components (Fig. 2(b) blue). The broad components probably include the RF-induced density oscillations in the plasma. Thus, we could obtain the upper boundary for the density oscillation from the broad component. The upper boundary was 0.2 rad, which corresponds to the electric field of 20 kV/m.

In TST-2, we used a different type microwave reflectomter, and noise reduction efforts were made. As a result, we have succeeded in the direct (phase) measurement of the RF- induced electron density oscillation and the RF electric field [2].

1) M.Gilmore, W.A.Peebles., S.Kubota, X.V.Nguyen, and A.Ejiri, Rev. Sci. Instrum. **74** (2003) 1467-1472.
2) T. Yamada, A. Ejiri, Y. Shimada, T. Oosako, J. Tsujimura, and Y. Takase and H. Kasahara, Rev. Sci. Instrum. **78** (2007) 083502.

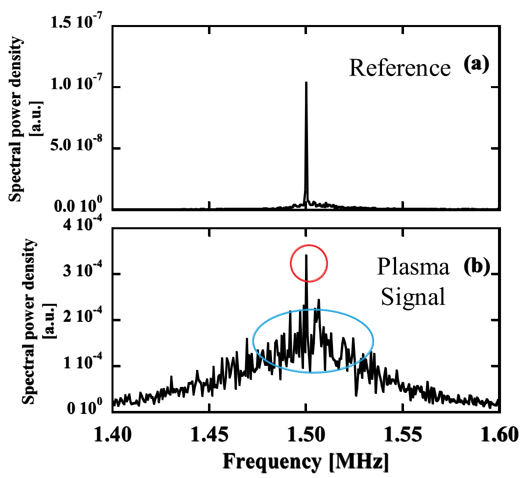


Fig. 1. Power spectrum of the reference signal (a) and that of the plasma signal of the heterodyne microwave reflectometer, during the HHFW heating in NSXT.

Development of two-dimensional ion flow measurement system

Category : Fusion Physics/ Diagnostics
Year-Number : 2009-FP5-7, 2008-FP5-4, 2007-FP5-7
Name: Nobuhiro Nishino, Stephen F. Paul, Lane Roquemore, Robert Kaita
Affiliation: Graduate School of Engineering, Hiroshima University, Princeton Plasma Physics Laboratory (PPPL)

This system is the natural extension of a point measurement SWIFT (shifted wavelength/Interference Filter Technique)[1] system invented by S. Paul to two-dimensional measurement. The method for ion flow derivation by SWIFT is as follows. In Fig.1 the Doppler shift is determined from the ratio of the light intensity from two detectors. One detector views the plasma through an interference filter whose pass band has a negative slope, and the other channel views the identical volume of plasma through a positive-slope filter. The signal ratio varies as the line is shifted across the pass bands. For interference filters with linear pass bands, that is, constant slopes, the ratio is not sensitive to ion temperature, and the shifted wavelength reduces to a simple function of the signal ratio, the channels' relative responsibility, and the two filters' transmission curves. Therefore, using two-dimensional sensor it can be easily extended to two-dimensional measurement system. It is very attractive to use a fast camera as a two-dimensional sensor, because the space and time resolution of ion flow measurement is needed within a few cm and sub mil-second[2], and fast cameras are used already as plasma diagnostics. The ultimate target for the time resolution of this system is within a few tens microsecond to reveal the flow profile in turbulence. Figure 2 shows schematic of the proto-type 2-d SWIFT system installed in NSTX. The system mainly views plasma edge near the center stack region. Before installing the throughputs of the optical components were relatively calibrated, however, we did the double check for the efficiency of two channels without filters using D discharge. As far as the system views normal plasma, the light intensity was enough strong to be capable to take a picture with the speed of several thousand FPS (frame per second). Then we installed two filters in it and proposed XMP of He discharge. During He discharge two images near the center stack were clearly seen. Figure 3 shows two images through the negative and positive slope filters, respectively. In Fig.3 red lines are drawn to identify the same position in two images. The left side of red lines indicates near the middle of the center stack and the light intensity ratio of these regions was almost constant except during IREs and disruptions. On the other hand, the right side of red lines indicates near the inner plasma edge and the line intensity ratio of these regions changed during normal plasma discharge even except IREs and disruptions. This difference shows that proto-type SWIFT possibly measured the ion flow[3]. Hereafter this system has many points to be modified, however, in principle we conclude two dimensional ion flow measurement can be performed by this system.

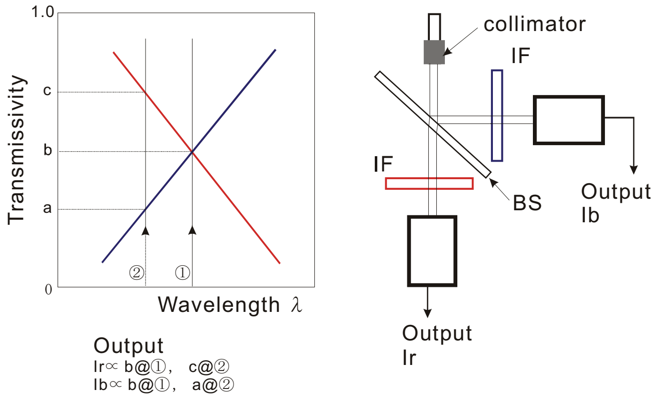


Fig. 1. Doppler shift measurement using two filters

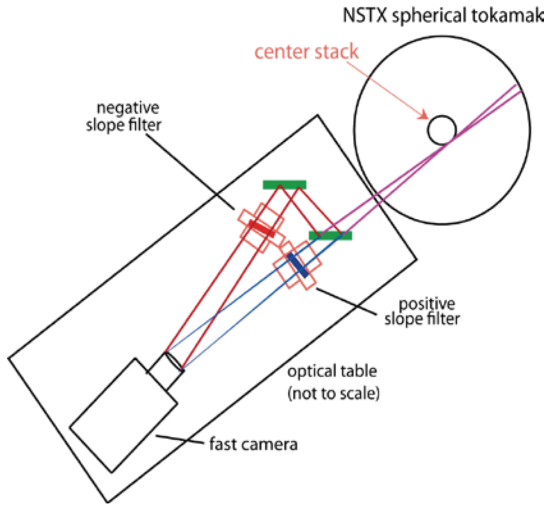


Fig. 2. Proto-type of SWIFT installed in NSTX

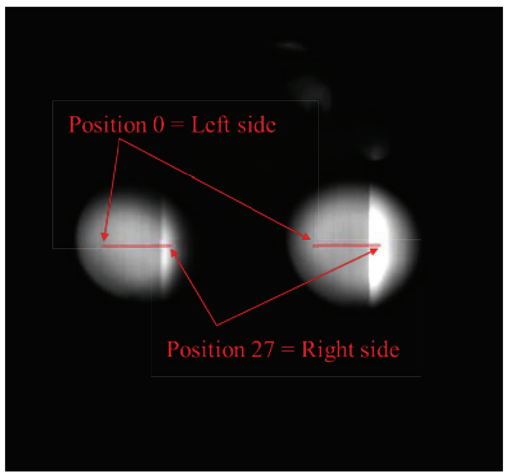


Fig. 3. He discharge plasma near center stack

1) Paul, S. F., Rev. Sci. Instrum. **74** (2003) 2098
2) Paul, S. F., et al., Presentation in APS-DPP06
3) Nishino, N., et al., JPFSR **8** (2009) 640

Compact Plasma Neutron Source for Neutron Assay

Category: Diagnosis
Year-Number: 2009-FP5-1, 2008-FP5-8, 2006-FP5-1
Name: Masami Ohnishi, Gerald Kulcinski
Affiliation: Kansai University, Faculty of Engineering of Science, University of Wisconsin

A compact plasma neutron source possesses a simple structure as shown in Fig.1.[1)] After the vacuum chamber is filled with a deuterium gas of up to several Pa, then a high voltage is applied between the cathode and anode. The glow discharge occurs and the deuterium ions are accelerated into the mesh cathode. The fusion events happen between the accelerated ions or the accelerated ions and the background deuterium molecules. The facility is given the name of Inertial Electrostatic Confinement (IEC) fusion.

Figure 2 depicts the neutron production rate achieved in the devices:[1)] the red bars show the Japanese facilities and blue ones show the results by US facilities. Almost all facilities achieved the neutron production 10^6 to 10^7 s^{-1}. The yellow bars display an exceptionally higher neutron production rate. These facilities were equipped with 6-ion guns.[1)] The neutron assay application requires a production rate larger than 10^9 s^{-1}. In order to increase the production rate, we have to rely on fusion events between the accelerated ions. Low pressure operation, ion guns, a large current discharge with ion sources, and a high voltage power supply are necessary for achievement of the higher performance neutron sources.

The IEC device can be operated at low pressure, less than 0.01Pa, with the assistance of a magnetron discharge and showed neutron production rates that scaled in inverse proportion to the gas pressure, which may be evidence of the occurrence of the fusion between the accelerated ions.[2)] The similar dependence on the gas pressure can be found in the devices with the 6 ion guns. The large current discharge of 5A was demonstrated with RF ion sources in short pulse (6 micro-seconds) in Kansai University. For these experiments, the working gas was "normal" hydrogen, the peak voltage was 70 kV and the gas pressure was 0.2 Pa. A power supply of voltage 300 kV and current 60 mA was developed for increasing the neutron production rate by accelerating the ions to high energy in the University of Wisconsin devices. This high performance power supply may enable He^3-He^3 fusion to occur at rates exceeding 10^3/s.

It was shown that more than 50% of the D-D fusion events are caused within the cathode region by the use of a time of flight diagnostic. On the other hand, the D-He^3 fusion events were shown to happen mainly within the cathode wires. The diagnosis confirmed the supposition that the fusion events occur between the accelerated D ions and the He^3 embedded in the cathode.

Other applications, including neutron assay, were extensively studied. The IEC fusion device was developed as a neutron source for land mine detection and showed good performance. The fundamental experiments to detect highly enriched uranium (HEU) and explosives were carried out and exhibited effectiveness. The cylindrical IEC device was shown to produce a neutron production rate similar to the spherical device[3)] and to be useful for neutron transmutation doping, which is a semiconductor manufacturing method. The IEC device implanted helium in W for material testing of the first wall in a fusion reactor. Since the IEC device is very useful for not only neutron assay but also various other applications, further efforts to increase the neutron production will be continued within the US-Japan collaboration.

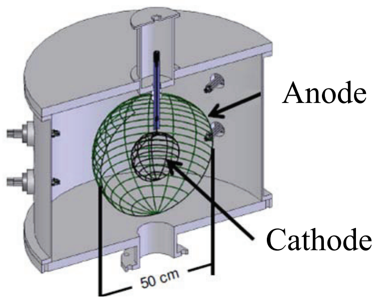


Fig.1 Schematic view of IEC device[1)]

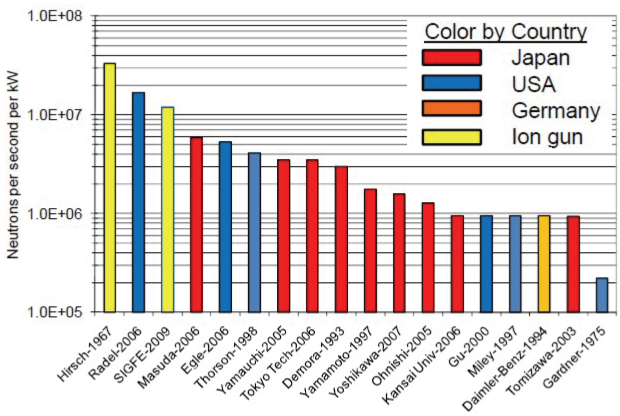


Fig.2 Neutron production rate of IEC devices[1)]

1)B.Egle: 11th US-Japan Workshop on Compact Plasma Neutron Source for Neutron Assay (Madison, 2009).
2) K. Masuda: ibid
3) K. Tomiyasu: ibid

VUV imaging diagnostics for the study of a tracer-encapsulated solid pellet (TESPEL)

Category : Fusion Physics/ Diagnostics
Year-Number: 2003-FP5-8, 2004-FP5-26, 2006-FP5-22, 2007-FP5-15
Name: N. Tamura, D. Stutman*, H. Kugel**, S. Sudo
Affiliation: National Institute for Fusion Science, *Johns Hopkins University, **Princeton Plasma Physics Laboratory (PPPL)

In the Large Helical Device (LHD) of the National Institute for Fusion Science (NIFS), we are establishing an advanced impurity transport diagnostic system by means of a Tracer-Encapsulated Solid Pellet (TESPEL). In this system, a Charge eXchange Spectroscopy (CXS), which can reduce drastically an ineludible line-of-sight integral effect in a spectroscopic measurement, is a key element. The past study has revealed that the CXS with a negative-ion-based NBI, the acceleration voltage in which is so high (~180 keV), for measuring the spatio-temporal behavior of tracer impurity ions introduced into the LHD plasma by the TESPEL should be performed in the VUV and soft X-ray domain. Thus this research subject is aimed to develop the spectroscopic system with a high spatial resolution, a high sensitivity and a high efficiency for the light in the VUV and soft X-ray range. A multi-layer mirror (MLM) has a high reflectivity for the light in the VUV and soft X-ray range. So the development of the system has been done in collaboration with the Johns Hopkins University (JHU) plasma spectroscopy group (main collaborator: Dr. Dan Stutman), which has a significant background in the spectroscopy by using the MLM. As a first step, in order to assess the capability of the MLM-based spectrometer for the tracer impurity measurement, a proto-type soft X-ray spectrometer with a flat Ni/C MLM for measuring Mg XII (λ = 45.5 Å), which was built by the JHU group, was installed on LHD. A typical result from the experiment with the TESPEL containing a magnesium tracer is shown in Fig. 1. As can be seen from Fig. 1, the signal from the magnesium tracer impurity ions was successfully obtained with a high S/N ratio by the prototype spectrometer [1, 2].

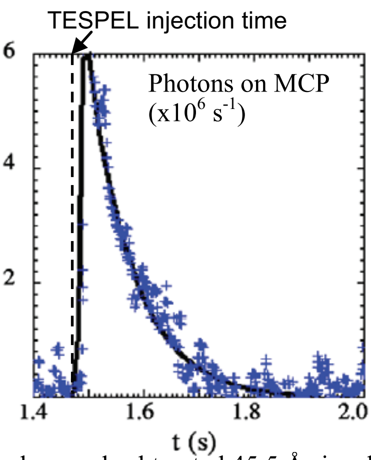


Fig. 1. Background subtracted 45.5 Å signal (+) and MIST simulation assuming 7 x 10^{17} Mg atoms injected at $r/a < 0.7$ and 1.5 m^2/s constant diffusivity [from Ref. 2].

Based on this result, the NIFS group built a soft X-ray spectrometer with a flat Ru/B_4C MLM for measuring F IX (λ = 81 Å). The effective excitation rate of F IX for a CX excited transition is slightly lower than that of Mg XII. However, in terms of the contribution of CX excitation in the wavelength of interest, F IX is larger than Mg XII. At the same time, the JHU group made an imaging spectrometer with a concave Mo/Si MLM, which has been provided from the NIFS group, for measuring Li III (λ = 135 Å). The MLM-based imaging spectrometer allows us to have the high spatial solution for soft X-ray measurement easily. The prototype imaging spectrometer was installed on the National Spherical Torus eXperiment (NSTX) device, in which Dr. D. Stutman has been involved, of the Princeton Plasma Physics Laboratory for obtaining the test data. In order to accelerate acquiring the data from the imaging spectrometer in the tracer impurity measurement, the TESPEL injection into a NSTX plasma was performed. As shown in Fig. 2(a), the TESPEL was successfully injected into the NSTX plasma by using a lithium pellet injector, which is already installed on NSTX. Figure 2(b) shows the temporal evolution of a signal from the imaging spectrometer in the case that a lithium tracer was introduced. As a reference, the signal in the case that any tracer impurity was not introduced into the NSTX plasma is also shown in Fig. 2(b). As can be seen from Fig. 2(b), the MLM-based imaging spectrometer successfully captured the signal from the tracer impurity ions introduced into the NSTX plasma [3]. These achievements enable us to improve the performance of the advanced impurity transport diagnostic system.

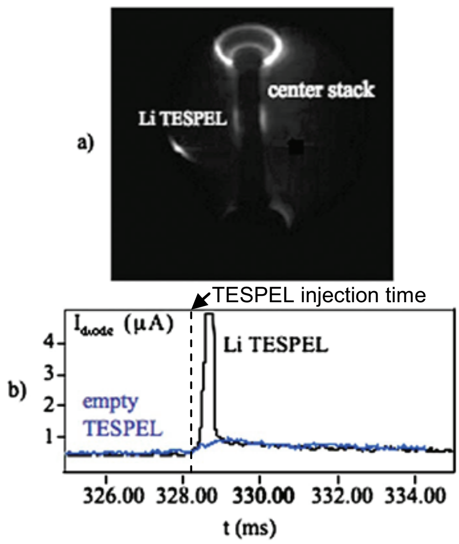


Fig. 2. (a) Image in Li I light of LiH-filled TESPEL, injected in low density NSTX L mode. (b) Telescope traces following injection of empty and LiH-filled TESPELs in low density L mode. A current amplifier with 10^6 V/A gain and no diode bias was used in this measurement.[from Ref. 3]

1) D. Kalinina et al., J. Plasma Fusion Res. **80** (2004) 545.
2) D. Stutman et al., Rev. Sci. Instrum. **76** (2005) 013508.
3) D. Stutman et al., Rev. Sci. Instrum. **77** (2006) 10F330.

Data Access Optimization for “Virtual Laboratory” on Fusion Experiments

Category : Fusion Physics/ Diagnostics
Year-Number : 2008-FP5-7, 2009-FP5-13
Name: Nakanishi Hideya, Joshua A. Stillerman
Affiliation: National Institute for Fusion Science, Massachusetts Institute of Technology (MIT)

Experimental or observational devices of the so-called big sciences in the world have a common tendency to gradually become bigger in size and fewer in number. This increases the need for their data to be shared over high-performance wide-area networks.

TCP/IP is *de facto* standard Internet technology and is integral to remote data sharing platforms. However, it has a well-known long fat-pipe network (LFN) problem that causes drastic speed lowering in long-distance communications [1]. This lessens the effective throughput even though physical layers have much wider bandwidths. It is a significant obstacle to wide-area data transfers and remote data sharing in general for fusion and other big science research projects.

To further scientific collaboration, some virtual private networks have been constructed on the Japanese academic information highway SINET3. One of them is dedicated for fusion research and named SNET. The LFN problem is also serious on the 1 Gbps SNET; for example, standard Windows or Linux PCs can use only 40 Mbps between NIFS and Kyushu Univ. whose distance is 1000 km with about 20 ms round-trip time (RTT) on network. More distant Japan-US communications with 200 ms RTT, the effective throughput is down to only few Mbps.

A TCP/IP WAN commercial accelerator, Fujitsu Wan Director A100, was applied on the top of some primary SNET sites. It provides 300 Mbps throughput between NIFS and Kyushu Univ. stably, however, its embedded encryption prevents it from reaching the 1 Gbps physical bandwidth. The cost is prohibitive for most academic uses [1].

The growing amounts of experimental data prompted a Japan-US collaboration to test a freely available TCP acceleration method for faster throughput. Typical claimed results were 90% of Gigabit Ethernet. A series of network performance tests were made to utilize higher bandwidth on an actual 1 Gbps SINET3 and ESnet connection between MIT (USA) and NIFS (Japan) [2].

With the combination of tuned TCP parameters and the packet pacing by inserting pause packets, the observed throughput did reach 90 % of the 1 Gbps ideal bandwidth (Fig. 1). Its effective throughput was 750 Mbps that is 2.5 times higher than WDA100. Note that the necessary software is completely free.

This successful achievement using 90 % of full bandwidth has proved the technical possibility to share the enlarged experimental data internationally. Its advanced technology together with coming 10 Gbps networks will be essential for the next-generation projects like ITER. Additional improvement by using the guaranteed quality of network service (QoS) is also planned.

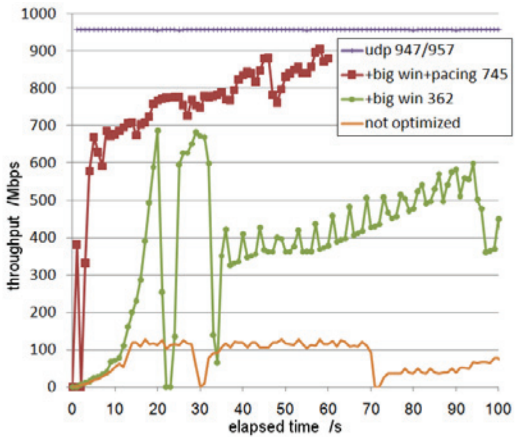


Fig. 1. LFN test results between NIFS and MIT

A different approach to above mentioned data throughput acceleration, is to use a compressed transport to run remote user interfaces for applications that operate on computers close to the data. Extensive tests looking at data of Alcator C-Mod were performed from Japan (Fig. 2).

As remote data access performance is dominated by the transaction costs, reducing the number of transactions required for data access improved the remote data display significantly. However, running a compressed X Window server NX [3] and running the application close to the data was significantly better still.

Continuous data growth causes that 80% of the whole data is less than 3 years old. We also concluded that this detracts from the usefulness of most caching schemes.

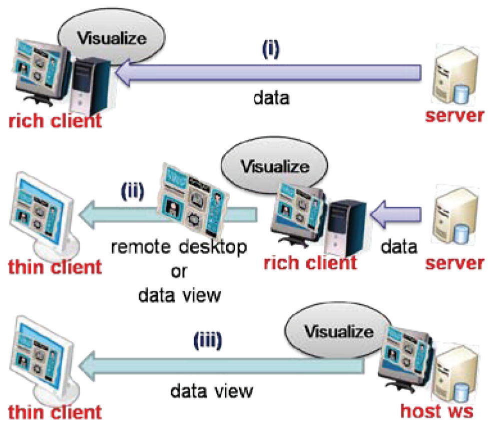


Fig. 2. Possible methods for distant data access: Using MDSplus client/server, US-JA tests were done on **(i)~(iii)** methods.

1) Nakamura, M., *et al.*, Proc. ISPAN (2004) 294.
2) Nakanishi, H., *et al.*, Proc. 7th IAEA TM on Control, Data Acquisition, and Remote Participation for Fusion Research, Aix en Provence, France, 15-19 June 2009.
3) http://www.nomachine.com/

Neutral Particle diagnostics using the silicon diode array

Category : Fusion Physics/Diagnostics
Year-Number : 2004-FP5-19, 2003-FP5-1
Name:Tetsuo Ozaki, Jim Lyon
Affiliation: National Institute for Fusion Science
Oak Ridge National Laboratory

Neutral particle diagnostics using the silicon surface barrier detector (SD-NPA) starts from 1998. The neutral particle spatial distribution can be easily obtained. The project has been proposed from the United State side in order to install it on LHD and to investigate the mechanism of the energetic particle in the helical plasma. The specifications of the method are to observe the low energy particle, to have the lower noise by the liquid nitrogen cooling and to have six horizontal channel and vertical scan system in order to see the particle on the whole two dimensional area. The meaningful time window is 100 ms[1].

Figure 1 is the schematic drawings of the main part and the movable stage. In the LHD, all equipments are controlled remotely because nobody can enter the LHD hall during discharge. The experimental data are acquired automatically. Figures 2 and 3 show the vertical and horizontal sight lines from the SD-NPA on the LHD. The pitch angle and the equivalent radius are varied by the small different sight angle because the LHD has a complicated magnetic configuration. The pitch angle is defined as an angle between the magnetic line and particle direction. Figures 4 (right and left) show the pitch angel and the equivalent radius.

Figure 5 shows the difference of the energetic particle spectra when the magnetic axis is varied. In the helical device, the cross section of magnetic surface is different from that of the particle orbit surface. In the standard magnetic configuration, the cross section of the particle orbit surface is shifted inner than that of the magnetic surface. The cross section of the particle orbit surface is determined by the device. However the cross section of magnetic surface can be changed by the variety of the vertical magnetic strength. When the magnetic axis is moved inner, the particle confinement can be improved although the plasma stability becomes worse theoretically because the cross section of the magnetic surface is close to the particle orbit surface. When the particle emits to the outside of the plasma, the particle is lost due to the charge exchange between the background neutral and the particle. In Figure 5, much particle remain in the plasma when the magnetic axis is shifted inner. The result obtained from the detector is agreed with the theoretical prediction.

In the LHD, the high-Z gas is used in order to obtain the high plasma parameters, especially the high ion temperature. By this way, the high ion temperature can be obtained because the ion density is relatively small and the input power can be concentrated to the ion. In the experiments, the neon and the argon gases are used instead of the hydrogen gas. In the high-Z plasma, much particle flux can be obtained even at the high-energy range. This means that the pitch angle scattering becomes large in the high-Z plasma. The high ion temperature can be obtained because the mechanism induces the input of the energy to the ion. SD-NPA provides the spectrum differences between the low and high-Z plasmas.

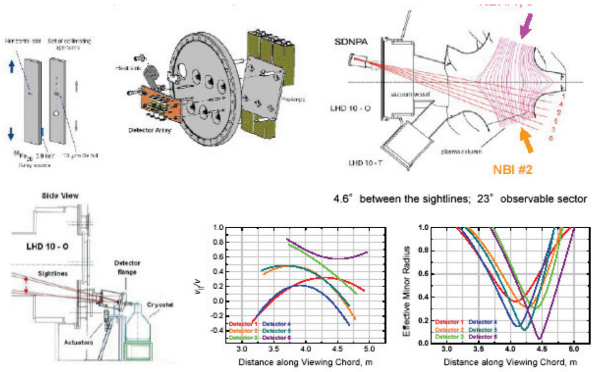


Fig. 1 (left upper) the main part and the movable stage,
Fig. 2 (left lower) the vertical sight lines,
Fig. 3 (right upper) the horizontal sight lines,
Fig. 4 (right lower) (left) the pitch angle,
(right) the equivalent radius.

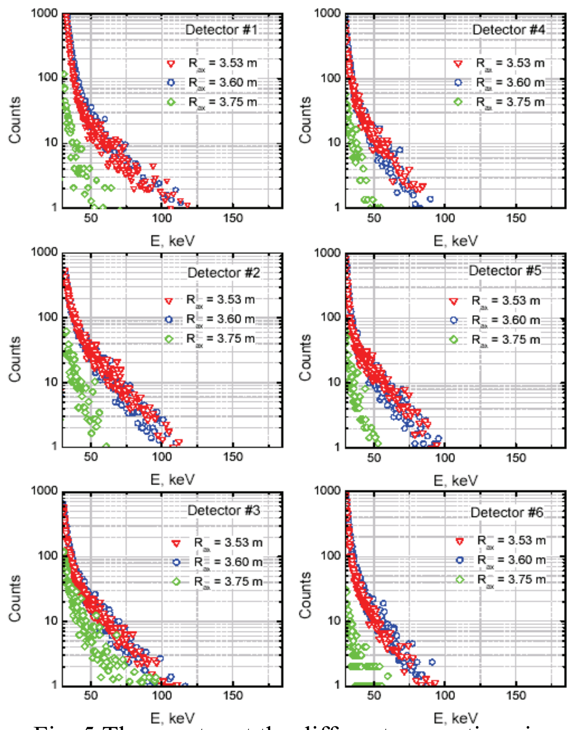


Fig. 5 The spectra at the different magnetic axis.

1) P.R. Goncharov, J.F. Lyon, T. Ozaki, S. Sudo, et al. JPFRS, 5 (2001), pp. 159 - 162.

3.4.5 High Energy Density Science

The Japan-US collaborations on the high energy density science have played important rolls in the inertial confinement fusion and the high density plasma physics of both countries in the last decade. The subjects covered in the collaborations are 1) Fast ignition laser fusion theory and simulation, 2) Impact Ignition laser fusion, 3) Fabrication, injection, and tracking of fast ignition targets, 4) Heavy ion inertial confinement fusion, 5) Plasma devices for probing warm dense matter, 6) Fast ignition experiments, and 7) Laser laboratory astro-physics. Several workshops and personal exchanges have been organized to initiate collaboration works and to start joint experiments and simulations.

In the theory and simulation for fast ignition, the principal investigators are K.Mima and H.Nagatomo (ILE, Osaka University) for Japan and Y.Sentoku (University Nevada, Reno), G.Shvets (University Texas, Austin), R.Sephens (GA), and C.S.Liu (University Maryland, Collage Park). 4 workshops and one joint workshop with the experimental group were held. The highlights of the workshops are the developments of integrated code and code validation by experiments. The Osaka University, NIFS and Setsunan University developed the integrated code, FI3, which connects three different codes, namely, PIC, Fokker Planck code, and radiation hydro codes. On the other hand, University Nevada, GA, and LLNL developed a hybrid code named LSP and a large scale PIC with collision, named PICKLS. Based upon those codes, relativistic electron generation and transport, and the resulting heating process of imploded plasmas were investigated.

In collaboration with fast ignition experimental group lead by K.Tanaka (Osaka University) and R.Stephens (GA), the relativistic electron energy spectrum, transport, hydrodynamics and integrated performance of fast ignition cone target were investigated. One of the highlights of the experimental group is the joint experiment at ILE, Osaka University with GXII and Peta watt lasers and at LLE, University Rochester with OMEGA-EP laser on the heating processed, hydrodynamics diagnostics and integrated performance of cone targets.

As a new ignition scheme, the impact ignition was also studied jointly with NRL group. The principal investigators are H.Azechi and M.Murakami of ILE, Osaka University and Steve Obenshain (NRL). This group collaborated on the high velocity acceleration of a foil and integrated impact heating experiment, theory and simulation. The highlights of this activity are the demonstration of the acceleration of foil up to 1000km/sec and 100 timed enhancement of neutron yield by the impact. Those experiments were carried out with NIKE Kr laser and GXII laser. The result of the neutron enhancement was published in Physical Review Letters.

In the target fabrication, injection, and tracking, the principal investigators are T.Norimatsu (ILE, Osaka University) and D.Goodin (GA). Two workshops in the US and one workshop in Japan were held. The objectives of this field were fabrication of fast ignition target and related R&D of low density foam and injection and tracking of a reactor size target. The foam cryogenic target has been developed by the collaboration among GA, NIFS, and ILE, Osaka University. The R&D toward the higher quality target is continuing.

As for the heavy ion beam inertial fusion, The 4 workshops and 3 personal exchanges have been organized by S.Kawata (Utsunomiya University), M.Ogawa (Tokyo Institute of Technology), G.Logan (Lawrence Berkley National Lab.), and R.Davidson (Princeton University). The Japanese research group collaborated with the US Virtual National Laboratory for Heavy Ion Fusion for many years on the HIF target design, HIB driver technology, and physics of beam transport and injection. A new target design for mitigating RT instability has been proposed.

Finally, the collaboration on the basic high energy density physics was organized by R.Kodama (Osaka University), M.Ozaki (Osaka University), R.Smith and M.Key (LLNL). The highlights of this collaboration are "Development of plasma device related to laser proton acceleration" and " Proton probing for laser-driven dynamically compressed matter". The further collaborations in this field are expected by using large laser facilities in US (NIF) and in Japan (LFEX).

Workshop on Theory and Simulation of Fast Ignition Laser Fusion

Category: High Energy Density Science
FY and Number: 2003-FP5-25, 2004-FP5-30, 2005-JF1-3, 2007-FP5-8
Principal Investigator: Kunioki Mima, Hideo Nagatomo
Affiliation: Institute of Laser Engineering, Osaka University

The goal of the workshops is to realize an integrated simulation code for fast ignition laser fusion. In the four workshops, the following 4 topics are discussed. The one is the numerical modeling of plasma physics related to fast ignition. The second is code validation by comparing the results with experimental results. The third is the integration methodology of a few different simulation codes. The final subject is application of integrated code to target design and the analysis of experimental data.

Two workshops were held in US, and two workshops were in Japan. In those workshops, LLNL (A.Kemp, R.Town, S.Wilks, S.Hatchett, M.Key, B.Langdon) GA and Univ. Nevada (Y.Sentoku), GA (R.Stephen), LANL (R.Mason), UCLA (W.Mori), Ut.Texas, Austin (G.Shvets, T.Ditmyer),PPPL(NatFisch), Un. Meryland (CS Liu), Univ. Rochester (J.Myatt, C.Ren) participated from USA.

From Japan, Osaka University (K.Mima, H.Nagatomo, H.Shiraga, T.Johzaki, K. Tanaka, H.Shiraga, H.Azechi, and R.Kodama), NIFS (H.Sakagami), Setunan University (T.Taguchi), Kyushu University (Y.Nakao), and so on participated.

AS the related subjects, the workshop shed light on the relativistic laser plasma physics related to fast ignition and other applications of ultra-intense laser. The workshop consists of overview the present status of relativistic laser plasma physics and some special topics. In particular, the methodology for comprehensive simulation of relativistic laser plasmas has been investigated. The fast ignition integrated interconnected code (FI3) has been developed at ILE, Osaka University, which includes 4 simulation codes ; PIC, PIC-fluid hybrid , Fokker Planck, and Radiation Hydro. The highlights of the discussions were on electromagnetic turbulence generated by relativistic electron beam, radiation recoil effects on the extremely high intensity laser plasma interactions, the high energy ion generation, and so on. The dynamics of the Weibel instability and the following electromagnetic turbulence are found to play important rolls in the cone shell target fast ignition. The more theory and simulation discussions will be continued further in the following workshop. The joint workshop for the validation of simulation codes, was held at Ootsu city in Japan, in 2007.

Two examples of achievement in the workshops are described in the following. The Japanese group proposed the integrated simulation code called FI[3]. The structure of this integrated simulation code is shown in the Fig.1. The FI3 can describe the over all processes included in the fast ignition. On the other hand, the US group developed LSP as a fast ignition integrated code. In the workshop, the results of these two simulation codes are compared to improve the both simulation code. In the discussion, hot electron spectrum is one of the most important issue in the fast ignition research.

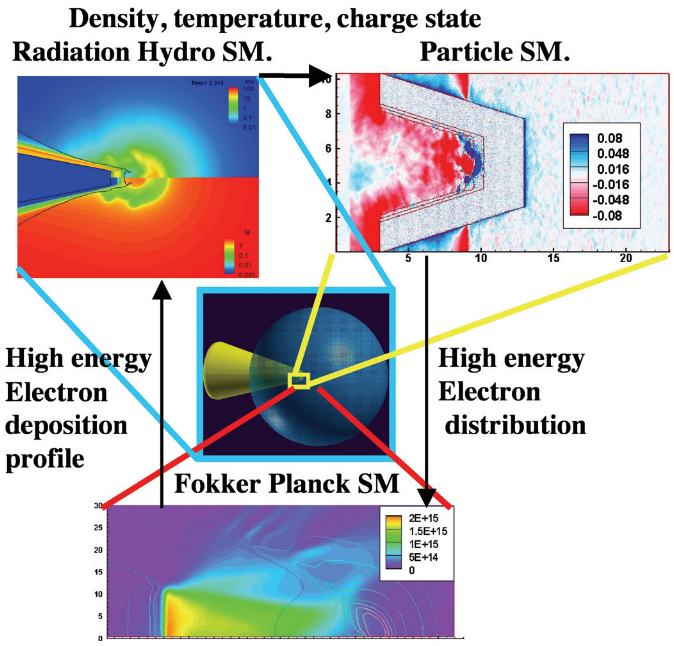


Fig. 1. FI3 (Fast Ignition Integraed Interconnecting Code) Radiation Hydro simulation, particle simulation and Fokker-Planck simulation are interconnected

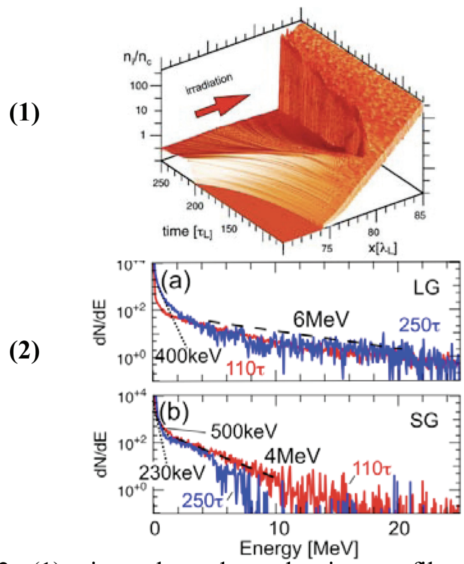


Fig.2 (1) time dependent density profile of plasmas interacting with pico second heating pulse, (2) electron energy spectrum for long scale (a) and short scale cases

1) H. Sakagami, *et al.*, *Laser Part. Beams* **22**, 41(2004); **24**, 191 (2006).
2) A.Kemp, Y.Sentku, etal, PRL 101(2008)075004

Basic and integrated studies for fast ignition

Category : High Energy Density Science
Year-Number : 2002-FP5-13,
Name: Kazuo A. Tanaka, Richard Stephens
Affiliation: Osaka University, General Atomics

The fast ignition scheme of inertial fusion energy consists of various aspects of relativistic laser matter interactions as well as the feasibility study of the scheme itself by making use of integral type experiments. We have conducted the basic and integrated studies for FI. The basic study includes details of hot electron production with an ultra-intense laser pulse. The integrated includes a model FI experiment, which shows an enforced heating of a core with a PW (Peta watt) ultra-intense laser pulse. The collaboration has been achieved with Richard Stephens et al. at General Atomics and Max Tabak et al. at Lawrence Livermore National Laboratory, U.S.A.

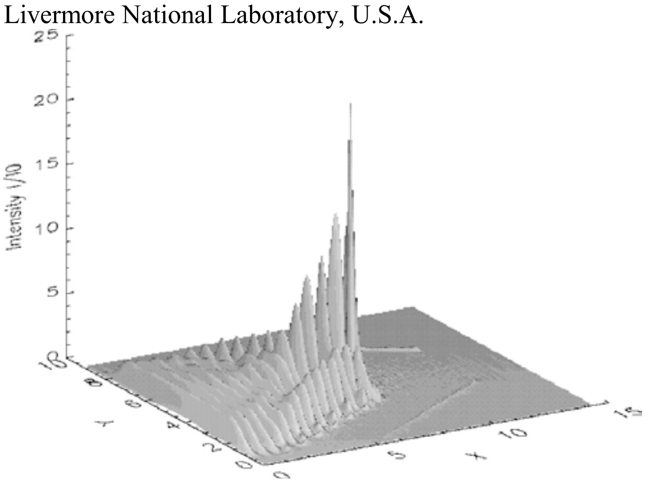


FIG. 1. The *E* field is shown of an ultra-intense laser pulse incident into a 54° cone perpendicular to the polarization in the three-dimensional particle in cell (PIC) simulation. The concentration of the *E* field along the cone axis is clearly shown. 20 times increase is indicated over the original intensity 4x10^{18} W/cm^2. The scale of *X* and *Y* directions are normalized by the laser wavelength 1 μm. The figure is at t=100 fs, while the ultra-intense laser pulse is 20 fs. The simulation is calculated in 14x9x9 μm box.

A PW laser system has been constructed in the same laser bay of the GEKKO 12 laser beam system at the Institute of Laser Engineering, Osaka University. The PW system has a 50 cm beam diameter and can deliver up to 500 J on-target within 0.5 ps at 1053 nm with a 5 nm bandwidth. The GEKKO laser system has 12 green beams whose oscillator takes a part of the PW front-end light. The synchronization is within 10 ps between the PW and GEKKO pulses because both systems use the same origin of light. The GEKKO laser system delivers 2.5 kJ at 532 nm onto a target with random phase plates with a 1.2 ns quasi-square pulse shape. The two laser systems were used to conduct a FI model experiment where the PW laser pulse is injected through a Au cone to heat a compressed core imploded by the GEKKO laser beams.

A Au cone inserted on a plastic shell is imploded and is heated to model enforced heating of an imploded high density core using both GEKKO and PW laser systems. The gold cone has a 30° opening angle with a 5 μm tip thickness at 50 μm diameter. The shell is 500 μm in diameter with 7-μm-thick wall and its material is CD (deuterated plastic). A typical laser intensity pattern is shown in Fig.1 simulated with PIC simulation. The gold cone appears to increase the laser intensity.

Nine laser beams of the GEKKO irradiate a CD shell for implosion with 1.2 ns pulse at a 532 nm wavelength width of a flat top shape at an energy of 2.5 kJ. Random phase plates are inserted in all the beams. Implosions are also simulated with a one-dimensional fluid code. The implosion timing is monitored with an x-ray streak camera and agrees well with the simulation. At around the maximum compression, the PW laser of 300 J in 0.6 ps is injected into the Au cone tip. According to our simulation, the Au cone tip survives to the maximum compression. The imploded core is created at about 50 μm away from the tip, which gives a very good coupling of hot electrons to the core. The compression process is also monitored with an x-ray framing camera making use of the x-ray backlight of Pt at 2 keV, which could give an estimation of the core density. The diameter and the density of the core are 30–50 μm and 50–100 g/cm^3, respectively. The density is reduced from fitting the back lighting data with a simulation. The PW injection is confirmed as a clear x-ray signal with the x-ray streak camera.

Neutrons of 10^4 are observed just from implosion without the PW heating. When the ultra-intense laser pulses at 0.5 PW are injected into the cones at max compression, the neutron yield increased to almost 10^7. In the previous study of fast heating at a 100 TW laser power, a similar compressed core was created and was estimated to have a 300 eV plasma temperature. In this experiment the temperature rise from 300 to 800 eV is also consistent with the 1000 times neutron increase.

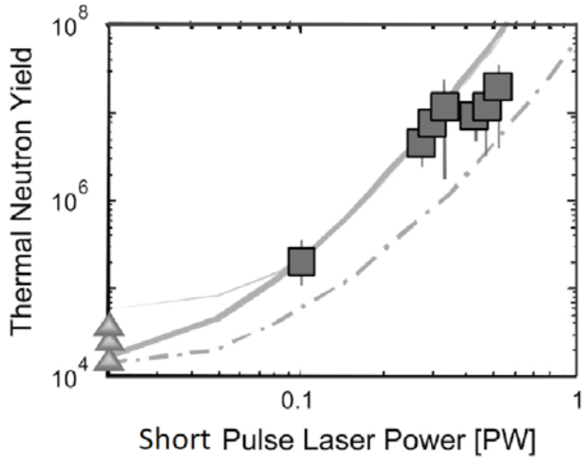


FIG.2. Neutron number vs fast heating laser power. The triangles show the data without fast heating. The squares show the data with fast heating. The neutron increase is 1000 times with the heating compared to the ones without it. The fitted curves are the ones with 30% and 15% coupling efficiencies from the ultra-intense laser to the core heated energy.

1. KA Tanaka et al., PHYSICS OF PLASMAS 10, 1925 (2003)
2. R Kodama et al., Nature, **412**, 7989, (2001); R Kodama *et al.*, *ibid.* **418**, 933 (2002).

Japan-US Workshop on Progresses of Impact Ignition

Category: High Energy Density Physics
Year-Number: 2009-FP6-3
Name: M.Murakami, H.Nagatomo, T.Johzaki, Y.Arikawa, T.Watari, Steve Obenscain
Affiliation: Institute of Laser Engineering, Osaka University, Naval Research Laboratory

In impact ignition scheme [1], a portion of the fuel (the impactor) is accelerated to a super-high velocity, compressed by convergence, and collided with a precompressed main fuel. This collision generates shock waves in both the impactor and the main fuel. Since the density of the impactor is generally much lower than that of the main fuel, the pressure balance ensures that the shock-heated temperature of the impactor is significantly higher than that of the main fuel. Hence, the impactor Here we report major new results on recent impact ignition research: (1) A maximum velocity ~ 1000 km/s has been achieved under the operation of NIKE KrF laser at Naval Research Laboratory (laser wavelength = 0.25μm) in the use of a planar target made of plastic and (2) We have performed two-dimensional simulation for burn and ignition to show the feasibility of the impact ignition.
Impact ignition, as well as the other designs such as hot-electron-driven fast ignition [2] and shock ignition, reduces driver energy requirement by heating a portion of DT fuel in terms of an additional heating mechanism. The significant advantage for these approach is to separate the compression from the heating. This report describes experiments that, for the first time, reach target velocities in the range of 700 – 1000 km/s. The highly accelerated planar foils of deuterated polystyrene, some with bromine doping, are made to collide with a witness foil to produce extreme shock pressures and result in heating of matter to thermonuclear temperatures. Target acceleration and collision are diagnosed using large field of view monochromatic x-ray imaging with backlighting as well as bremsstrahlung self-emission. The impact conditions are diagnosed using DD fusion neutron yield, with over 106 neutrons produced during the collision. Time-of-flight neutron detectors are used to measure the ion temperature upon impact, which reaches 2 – 3 keV. The experiments are performed on the Nike facility, reconfigured specifically for high intensity operation. The short wavelength and high illumination uniformity of Nike KrF laser uniquely enable access to this new parameter regime. Intensities of (0.4 − 1.2) x 10^{15} W/cm^2 and pulse durations of 0.4 − 2 ns were utilized. Modeling of the target acceleration, collision, and neutron production is preformed using the two-dimensional radiation hydrodynamics code with a non-LTE radiation model. Moreover, detailed analytical model addresses the feasibility of even higher velocities. (see Fig.1)

Our hydrodynamic simulation shown in Fig. 2 demonstrates [3] that ignition occurs when an impactor with a velocity of 1750 km/s and a density of 50 g/cm^3 collides with the main fuel with a density of 400 g/cm^3. Here, the implosion and acceleration processes are neglected. The impactor in a bullet-shape initially has spatial extensions of 60 and 70 μm in the perpendicular and the parallel directions with respect to the collision axis, respectively. The main fuel has a concave shape to tamp the impactor, as is observed in an implosion with a cone. The impactor energy is only about E_i ~ 10 kJ, whereas the main fuel has a much higher energy than this. However, if the energy of the main fuel is reduced so that it is one to two times the impactor energy, i.e., E_m ~ 10-20 kJ, and if a typical coupling efficiency of η_c ~ 10 % from the laser to the internal energy of the fuel assembly is assumed, we estimate that the laser energy for ignition will be E_L = $(E_i+E_m)/\eta_c$ ~ 200-300 kJ. This energy is much lower than that required for central hot spot ignition and is comparable to that required for conventional fast ignition. The primary challenges are thus to generate such high velocities while maintaining target integrity and to achieve such high impactor densities. Throughout this study, unless stated otherwise, we define the time origin as the time of maximum compression of the main fuel.

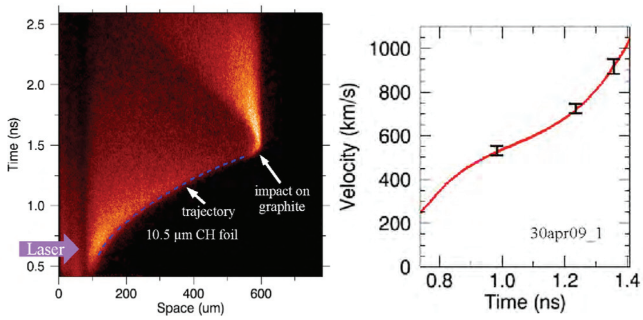


Fig. 1. X-ray image of impact collision (left) and temporal evolution of the velocity

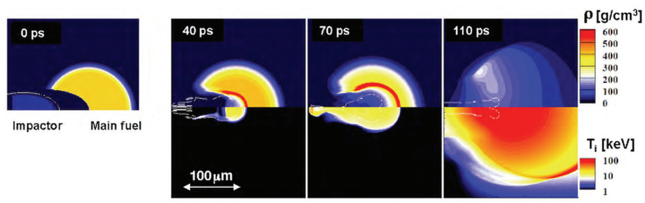


Fig. 2. Snapshots of density and temperature distributions obtained from the two-dimensional simulation. At t = 110 ps, ignition and burn can be observed with temperatures > 30 keV.

1) Murakami, M. and Nagatomo, H., Nucl. Inst. & Meth. Phys. Res. A**544** (2005) 67.
2) Azechi. H., *et al.*, Nucl. Fusion **49** (2009) 104024.
3) Azechi, H., *et al.*, Phys. Rev. Lett. **102** (2009)235002.

Plasma Devices for Probing Laser-Driven High Pressure Condensed Matter

Category: High Energy Density Science
Year-Number: 2006-FP5-26, 2007-FP6-17,
Name: R. Kodama and N. Ozaki, Raymond Smith, Mike KEY
Affiliation: Graduate School of Engineering, Osaka University, Lawrence Livermore National Laboratory

Plasma Device developments; Relativistic plasma shutter for intense proton generation

The development of ultrashort, high-power lasers has produced record pulse intensities up to 10^{22} W/cm^2.[1] However, as the peak intensity increases the required contrast ratio between: (i) a temporal pedestal caused by the ASE; (ii) prepulses, caused by the residual aberrations of the spectral phase, and the main pulse needs to be proportionally improved to allow for pre-plasma free interaction with solid targets. The use of high contrast, prepulse free pulses for interaction of ultrahigh intensity lasers with solids is of primary importance for a number of high field experiments such as high harmonic generation and proton acceleration. Specifically, experimental data and particle-in-cell simulations suggest the maximum proton energy increases, in some cases, dramatically, as the target thickness is reduced for sufficiently high laser intensity and contrast.[2]

A relativistic, transmissive plasma shutter (Fig. 1) was tested in order to improve the sub-100 ps contrast of a high-intensity laser pulse and allow a clean interaction with ultrathin targets. The relativistic plasma shutter was a thin foil placed in front of the main target so that the leading edge of the laser pulse fully ionizes the foil. In order for the plasma shutter to be effective, the ablated foil must expand such that the peak electron density n_e is greater than the nonrelativistic critical density and less than the relativistic critical density. This plasma will transmit the high-intensity peak pulse while rejecting the low intensity pedestal resulting in an increase in temporal contrast. Here, the improved contrast was confirmed by measuring high-energy protons at three different angles from the target rear with and without a plasma shutter inserted. The result was the production of 1.8 MeV protons from a shuttered 30 nm target, while no protons were detected for a 30 nm standalone target. The relativistic plasma shutter technique is simple to implement and scalable as the laser power is increased.

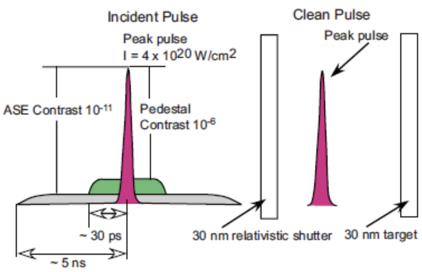


Fig. 1: Schematic of the relativistic plasma shutter for ultra intense laser pulses.

Proton probing for laser-driven dynamically compressed matter

Motivated by the IFE research, the development of pulsed power facilitie has allowed the emergence of a new field, High Energy Density laboratory Physics.[3] Among the techniques commonly used for generation of HED matter states, shock compression has been very successful either on the principal Hugoniot or on off-Hugoniot states. However current standard visible diagnostics cannot access parameters as important as density. In crucial contexts, this uncertainty prevents reaching the high precision required to discriminate between theoretical models. Moreover, the development of new high energy laser facilities, such as NIF or LMJ, will allow us to study very high pressures, over 10 TPa, where the validity of optical diagnostics must still be verified. This is the reason why significant efforts have recently been carried on in order to develop new diagnostics able to penetrate compressed matter, permitting the investigation of its microscopic properties. A novel approach employs energetic protons as radiographic source for density characterization of warm dense plasmas. Protons have a greater ability to penetrate thick materials, giving a higher signal to noise ratio and they can provide views from multiple angles.

Nano-second pulse laser beams were used to launch a shock wave into a main target and hence create a warm dense shocked state. The shock was then transmitted into a sliver of low-density carbon foam. The proton beam was generated in the interaction of a pico-second pulse laser beam with a gold foil. The detector was placed at a distance from the main target on the transverse axis, giving a projection magnification of > 10. The detector consisted on a film pack containing radiochromic dosimetry films. Each film accounts for a different proton energy in the range 3.5-15 MeV. Protons of different energies have a different time of flight from the source to the shock target and so changes occurring on time scales corresponding to the variation in TOF can be detected. The possibility to use this technique as in situ diagnostic of warm dense states was for the first time demonstrated. High quality radiography of shock compressed targets have been obtained (Fig. 2).

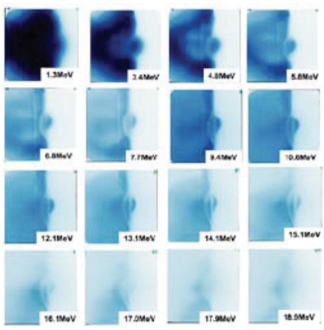


Fig. 2: Whole RCF set for a snapshot taken 7ns after the main ns pulse beams.

1) S. W. Bahk et al., Opt. Lett. 29, 2837 (2004).
2) S. S. Bulanov et al., Med. Phys. 35, 1770 (2008).
3) Frontiers in high energy density physics, N.R.Concil, The National Academy Press (2003).

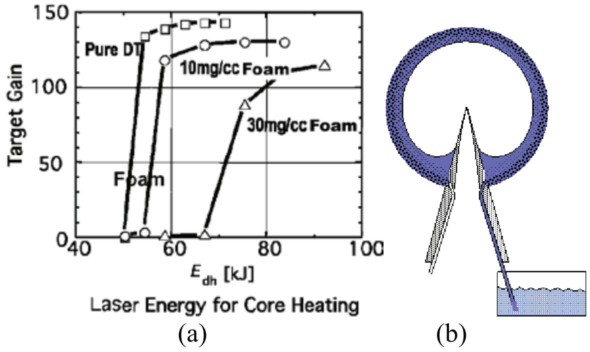
Fabrication, Injection and Tracking of Fast Ignition Targets

Category : High Energy Density Science
Year-Number : 2001-FP5-37, 2004-FP5-8,
Name: Takayoshi Norimatsu, D. Goodin*
Affiliation: Institute of Laser Engineering, Osaka University, * General Atomics, USA

The Japan-US workshops on Fabrication, injection, and tracking of fast ignition target were held at General Atomics USA in 2001, ILE, Osaka university in 2004 and GA in 2007, respectively. Followings are highlights from 2001 and 2004 workshops, which were reported elsewhere [1].

Fabrication of low-density foam and drilling of fragile foam shell are current issues in the fabrication of fast ignition target with reentrant cone. Fuel loading to the targets is a challenging issue in the mass-production process of the targets for a fusion power plant. Two fuel-loading methods are proposed for the fast ignition target with the cone. Preliminary experiments of injection and tracking of real size targets have started showing promising results.

An important approach is to control the fuel shape by wicking it into a supporting foam structure. Conceptually the separation of layer shape from the ambient isotherms allows considerable freedom in target design. Practically, there are still difficulties. First among them attaining a foam density that won't invalidate the experiments. Calculations (see Fig. 1(a)) show that in a full scale reactor a target using 30 mg/cc foam could have some gain, and would have excellent performance when its density is below ~10mg/cc. Such a foam shell is not feasible yet, but neither is ignition our initial goal. Foam method is the primary candidate to produce the hollow solid DT layer in the FI target with the cone. Basic elemental technologies to make both targets already exist. Future reactor size targets might be fabricated by improving existing technologies but demonstration is necessary using actual material and size. The thermal cavitation technique or feeder pipe method (Fig. 1(b)) can be applied for a future mass-production process of the FI target with cone.



(a) (b)

Fig. 1 The gain curve of fast ignition target with foam (a) and the way of fuel loading by a tube (b).

In both the cone target and cone-less target approaches to fast ignition target design, fusion fuel must be compressed "cold" (along a low isentrope curve) to a high density exceeding >1000 times solid density before the compressed fuel core is heated to >10 keV with a fast ignitor beam. The techniques being demonstrated for fabrication and handling of direct drive targets will be directly applicable to cone-less fast ignition targets.

The OMEGA Cryogenic Target Handling System (CTHS) provides cryogenic targets for direct-drive implosion experiments on the OMEGA laser at the University of Rochester Laboratory for Laser Energetics. The OMEGA direct drive targets are 0.9 mm in diameter with a 3-μm-thick outer plastic ablator and an inner ice layer that ranges from 80 to 100 μm thick.

The inner-ice-surface nonuniformities are characterized using a shadowgraphic technique as shown in Fig. 2. The parallel rays from a light source are refracted at the plastic shell and reflected by total internal reflection from the inner ice surface, thus forming a virtual bright ring. The bright ring in the recorded image is unrolled using the center of the shadow of the plastic shell as a reference point, providing a graph with the distance of the inner ice surface from the center of the shell as a function of angle. The difference in the measured distance of the ice surface from a perfect circle is then decomposed into cosine modes, resulting in a nonuniformity spectrum of the inner ice surface. These measurements provide a 2-D representation of the inner-ice-surface nonuniformity along one circular cut through the sphere. It is possible to fully map a 3-D nonuniformity spectrum by rotating the target and acquiring 2-D power spectra for different slices through the ice.

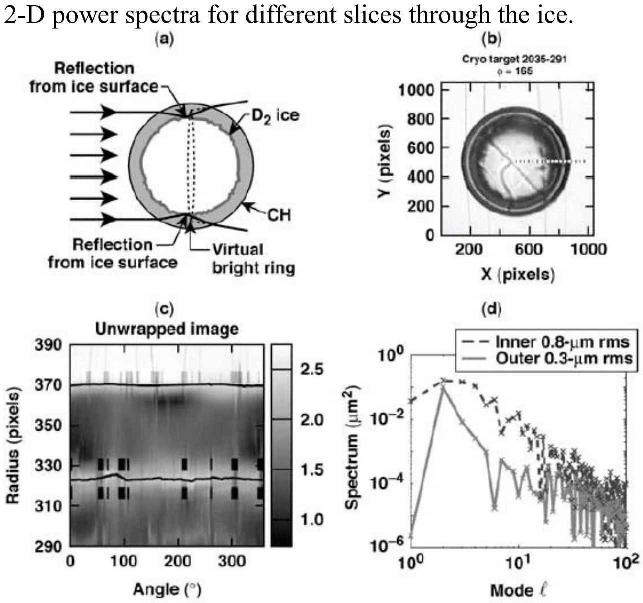


Fig. 2 Quality of solid Dr layer for corn-less fast ignition target at Rochester University

[1] T. Norimatsu et al., Fusion Sci. Technol., 49 p483 (2006)

Robust fusion energy release from a fuel pellet in heavy-ion inertial confinement fusion

Category: High Energy Density Science
Year-Number: 2000-FP5-1, 2001-FP5-19, 2004-FP5-17, 2005-FP5-1, 2006-FP5-10, 2007-FP6-3, 2008-FP6-1
Name: *S. Kawata, *1M. Ogawa, *1K. Horioka, *1Y. Oguri, *2M. Murakami, *3K. Takayama, *4H. Yoneda, *5G. Logan, *5J. Barnard, *5, *6R. Davidson
Affiliation: *Utsunomiya Univ., *1Tokyo Inst. Tech., *2Osaka Univ., *3KEK, *4Tokyo University of Electro Communications, *5HIF-VNL, Lawrence Berkeley National Lab., *6Princeton University

In our collaborations with collaborators in the U.S. Virtual National Lab. for Heavy Ion Fusion, we have studied for many years on heavy-ion-beam (HIB) accelerators, HIB propagation, HIB-target interaction and HIF fuel target implosion study, including new approaches to warm dense matter physics (WDMP), Rayleigh-Taylor instability growth control, etc.[1-3] HIB has unique features for inertial fusion: 1) A precise control of HIB, including HIB pulse shape, particle energy, HIB axis control, ion species, etc. 2) HIB energy deposition is well defined precisely by a well-known physics inside matter. The HIB energy is deposited inside matter, and this feature can be utilized for WDMP. The HIB energy deposition area is rather wide and thick inside a matter. 3) HIB generation energy efficiency is rather high, that is, about 30~40% from electricity to HIB energy.

Nonuniformity of HIB illumination is one of key issues in the HIB inertial confinement fusion (ICF): implosion symmetry should be less than a few percent in order to compress a fuel sufficiently and release fusion energy effectively. In this collaboration a new HIB illumination scheme (see Fig. 1) was persued in order to realize a robust illumination scheme against a displacement of a direct-driven fuel pellet in an ICF reactor. It is known that the HIB illumination nonuniformity is sensitive to a little pellet displacement from a reactor chamber center; a pellet displacement of only 50–100 μm [1] was tolerable in the conventional beam illumination schemes. In this work by three-dimensional computer simulations a new robust HIB illumination scheme was found, in which a 200–300 μm displacement is allowed as shown in Fig. 2.

A new mitigation method of the Rayleigh-Taylor (R-T) instability growth was also studied in order to make a HIF target robust against a non-uniform implosion. In this study a new mitigation method of the R-T instability growth is proposed based on an oscillating perturbed acceleration, which can be realized by a rotating or oscillating HIB illumination onto a fuel pellet. The R-T instability analyses and fluid simulations demonstrate that the oscillating acceleration reduces the R-T instability growth significantly. In this paper a baseline steady acceleration g_0 is perturbed by a perturbed oscillating acceleration δg, which is spatially non-uniform and oscillates in time ($g_0 >> \delta g$). An example result shows 84% reduction of the R-T instability growth (see Fig. 3).

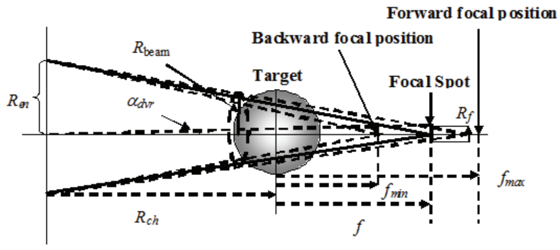


Fig. 1. The relationship between a beam emittance and the divergence angle. The HIB illumination is precisely computed.

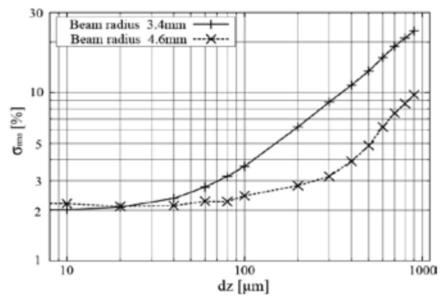


Fig. 2. The rms nonuniformity versus the pellet displacement *dz* in a reactor chamber for the beam radius of 3.4 mm and 4.6 mm, a pellet of the Al layer structure, the external pellet radius of 4.0 mm and the 32 HIBs system. $\Delta\theta = 2$ degree.

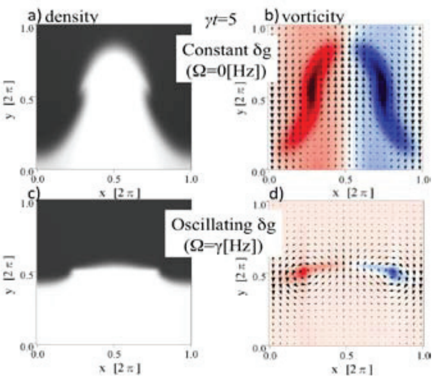


Fig. 3 The Rayleigh-Taylor (R-T) instability control example results under the oscillating acceleration. The R-T instability growth is controlled and reduced significantly by the oscillating acceleration perturbation, induced by the HIB axis wobbling.

1) T. Someya *et al.*, Phys. Rev. ST-AB **7** (2004) 044701.
2) S. Kawata *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A, **606** (2009) 152.
3) K. Horioka *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A, **606** (2009) 1.

CHAPTER 4　Joint Institute for Fusion Theory (JIFT)

4.1 Objectives

The distinctive objectives of the JIFT program are (1) to advance the theoretical understanding of plasmas, with special emphasis on stability, equilibrium, heating, and transport in magnetic fusion systems; and (2) to develop fundamental theoretical and computational tools and concepts for understanding nonlinear plasma phenomena. These objectives are pursued through collaborations between U.S. and Japanese scientists by means of two types of exchange program activities — namely, workshops and exchange visitors.

4.2 Activities

Each year the JIFT program usually consists of four topical workshops (two in each country) and six exchange scientists (three from each country). So far, during its 28 years of successful operation, JIFT has sponsored 166 long-term visits by exchange scientists and 102 topical workshops.

- The *workshops* typically have an attendance of 15–30 participants, of whom usually three to seven scientists (depending on the particular workshop) travel to the workshop from the non-host country. Scientists from countries other than the U.S. and Japan are also often invited to participate in JIFT workshops, either as observers or multi-laterals.
- Of the approximately three *exchange visitors* in each direction every year, one—called the "JIFT Visiting Professor"—is supported by the host country, while the others—called "Exchange Scientists"—are supported by the sending country. The visits of the Exchange Scientists usually last from several weeks to two or three months in duration, whereas the Visiting Professors normally stay for the period of three months.

Participants at the JIFT Workshop on Advanced Simulation Methods in Plasmas (December 2009, National Institute for Fusion Science).

The topics and also the participating scientists for the JIFT exchange visits and workshops are selected so as to have a balanced representation of critical issues in magnetic fusion research, including both fundamental problems as well as questions of near-term significance, and also to take into account the specific capabilities and interests of both countries. The Japanese and US members of the JIFT Steering Committee agree together on the appropriateness of proposed topics before recommending them.

Participants at the JIFT Workshop on Theory and Simulation on Ultra-Intense Laser Plasmas (November 2008, University of Texas at Austin).

The category of JIFT exchange activities called Joint Computational Projects program was instituted in 1985 to take advantage of the dedicated data link between the MFE Computer Center at LLNL (now called NERSC and located at LBNL) and the computer center of the Institute of Plasma Physics in Nagoya. In the early days of the US-Japan fusion collaboration, this JIFT data link was about the only of its kind, allowing data sets to be transferred back and forth and even allowing remote usage of computational facilities in one country by physicists in the other. However, the regular Internet now provides a sufficiently fast communication tool for scientists who wish to access their institution's computers remotely and exchange data through low- and medium-bandwidth lines. After discussions between the US and Japanese JIFT partners, it was decided at the annual meeting of the JIFT Steering Committee held at Dallas (Nov. 19, 2008) to terminate the Joint Computational Projects category of JIFT exchange activities at the end of Japanese Fiscal Year 2008 in accordance with the expiration of the Annex II document on a Data Link and Data link projects for fusion. The JIFT Steering Committee wrote a 30-page report about the history and achievements of the Data Link and the Joint Computational Projects (http://peaches.ph.utexas.edu/ifs/jift/references.html).

Information about the JIFT program, including annual schedules of exchange activities, can be found on the US JIFT web site at http://peaches.ph.utexas.edu/ifs/jift/ on the US side. A corresponding Japanese JIFT web site at http://www-nsrp.nifs.ac.jp/JIFT/ was set up in 2008, with information such as previous JIFT annual reports and JIFT meetings in Japan.

4.3 Administration

JIFT has a Steering Committee consisting of eight members, four from each country. Two of these members are the Japanese and US co-chairmen. Two other members of the Steering Committee, the US and Japanese co-executive secretaries, are responsible for the ongoing daily oversight of the progress of JIFT activities. The co-chairman and co-executive secretary on the US side are, respectively, the director and associate director of the Institute for Fusion Studies (IFS) of The University of Texas at Austin. The Japanese co-chairman is the executive director of the Numerical Simulation Research Project at the National Institute for Fusion Science, and the Japanese co-executive secretary is the director of the Fusion Theory and Simulation Research Division in the Department of Helical Plasma Research at the National Institute for Fusion Science. Furthermore, on the Japanese side there is an Advisory Committee comprised of several members representing a spectrum of Japanese universities and the Japan Atomic Energy Agency; and on the US side there is an Advisory Committee comprised of several members representing a spectrum of US universities and national laboratories.

The JIFT Steering Committee attempts to schedule workshops in such a way as to dovetail with other meetings. It also encourages participation at workshops by interested experimentalists and invites relevant available scientists from other countries to attend workshops.

As the principal program for fundamental theoretical exchanges in the US-Japan Fusion Research Collaboration, JIFT operates alongside the Fusion Physics Planning Committee (FPPC) and the Fusion Technology Planning Committee (FTPC). In particular, the JIFT activities are coordinated with the four FPPC areas of activity, viz., core plasma phenomena, edge behavior and control, heating and current drive, and new approaches and diagnostics.

Participants at the JIFT Steering Committee Meeting (November 2004)

4.4 Accomplishments and Highlights

A number of general benefits have resulted over the years from the JIFT program. In particular, the following may be cited: JIFT has provided efficient communication channels for the latest theoretical research results, techniques, and directions; JIFT activities have attracted serious participation from allied fields such as fluid turbulence, statistical physics, computational science, and space plasma physics, which brings new scientific tools into the fusion program and enhances the stature of fusion physics; JIFT exchanges have contributed to efficient utilization of international research facilities; and, JIFT emphasis on large-scale computational studies has reaped significant mutual benefits from the supercomputer resources and code-building expertise of both countries.

Through JIFT, close and long-lasting scientific connections have been established between the U.S. and Japanese fusion theory communities. Not only have senior scientists profited from these collaborations, but also young scientists—and even, on occasion, advanced graduate students—have had many opportunities to enhance their research careers. Some of highlights of achievements are shown hereafter.

JIFT activities have led to the publication of numerous scientific papers, as well as review articles and books. JIFT research has also been featured in a number of invited talks at major international meetings (e.g., the biennial IAEA Fusion Energy Conference.) A list of JIFT-related publications is attached.

Simulation Studies of Alfvén eigenmodes

Category : Joint Institute for Fusion Theory
Year-Number : 2000-JF1-9, 2004-JF1-12, 2006-JF1-4
Name: Y. Todo, D. A. Spong*, H. L. Berk**, B. N. Breizman**
Affiliation: National Institute for Fusion Science (NIFS), *Oak Ridge National Laboratory (ORNL), **Institute for Fusion Studies, University of Texas at Austin (IFS)

Toroidal Alfvén eigenmode (TAE) bursts and nonlinear MHD effects on the TAE evolution were studied while Y. Todo visited IFS in the years 2000 and 2005. The TAE bursts are phenomena where multiple TAE's are recurrently destabilized by the neutral beam injection. The behaviors of the multiple TAE's are synchronized and the fast ion losses take place associated with the TAE destabilization. The TAE bursts are observed in many toroidal magnetic confinement devices. The first numerical demonstration of TAE bursts was performed with parameters similar to a TFTR experiment and many of the experimental characteristics were reproduced[1]. These include: (a) the synchronization of multiple TAE's taking place at time intervals fairly close to the experimental value; (b) the modulation depth of the drop in the stored beam energy that closely matches the experimental value; (c) the stored beam energy saturating at about one-half to one-third of that predicted for a classical slowing down distribution. Figure 1 shows the time evolution of the dominant two modes (2 and 5) and the density of the co-injected beam ions. To understand the beam ion loss mechanism, we studied surface of section plots where only one eigenmode is taken into account and the amplitude of the eigenmode is at a constant value. It was found particle loss is due to: (1) the resonance overlap of different eigenmodes; (2) the disappearance of KAM surfaces in phase space due to overlap of multiple nonlinear islands created by a single eigenmode. The synchronization of the multiple TAE's takes place due to the resonance overlap.

However, the saturation amplitude was $\delta B/B{\sim}10^{-2}$ which is higher by one order of magnitude than the value inferred from the experimental plasma displacement measurements. Then, we investigated the nonlinear MHD effects comparing two types of simulations. In the standard simulation, the full nonlinear dynamics of both the MHD fluid and the energetic particles is simulated. In the other version of the simulation, only linear MHD equations are used while the nonlinear particle dynamics is retained. In the results of the two codes[2], no significant difference was found for low saturation levels, $\delta B/B{\sim}10^{-3}$. In contrast, when the TAE saturation level predicted by the linear code is $\delta B/B{\sim}10^{-2}$, the saturation amplitude in the fully nonlinear simulation was reduced by a factor of 2 due to the generation of zonal (n=0) and higher-n modes. This reduction is attributed to the increased dissipation arising from the non-linearly generated modes. The fully nonlinear simulations also show that geodesic acoustic mode is excited by the MHD nonlinearity after the TAE mode saturation.

D. A. Spong studied Alfvén eigenmodes in several stellarator configurations including LHD during his visit to NIFS in the year 2007. The shear Alfvén spectrum in three-dimensional configurations, such as stellarators and rippled tokamaks, is more densely populated due to the larger number of mode couplings caused by the variation in the magnetic field in the toroidal dimension. A new algorithm based on the Jacobi–Davidson method was developed and applied for a reduced MHD model[3]. This technique focuses on finding a subset of eigenmodes clustered about a specified input frequency. A three-dimensional structure for a TAE mode in LHD is shown in Fig. 2.

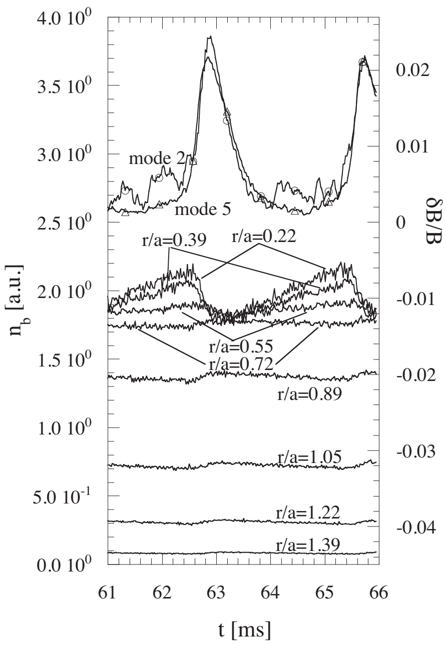


Fig.1. Time evolution of the dominant two modes and the co-injected beam ion density at various minor radius[1].

Fig.2. Three-dimensional eigenmode structure for a TAE mode in LHD[3].

1) Y. Todo, H. L. Berk, and B. N. Breizman, Phys. Plasmas **10**, 2888 (2003).
2) Y. Todo, H. L. Berk, and B. N. Breizman, to appear in Nucl. Fusion **50** (2010).
3) D. A. Spong, E. D'Azevedo, and Y. Todo, Phys. Plasmas **17**, 022106 (2010).

Gyrokinetic simulation of drift wave turbulence in magnetically-confined plasmas

Category : Fusion Physics/ Theory
Year-Number : 2002-JF1-10, 2008-JF1-12
Name: T.-H. Watanabe, *)W. Horton
Affiliation: National Institute for Fusion Science, *)Institute for Fusion Studies, University of Texas at Austin (USA)

The present research collaboration started since Dr. Watanabe stayed at Institute for Fusion Studies (IFS), University of Texas at Austin, in November 2002 as a visiting researcher supported by the US JIFT program. Then, the collaboration studies have been continued in various ways. In 2008, Prof. W. Horton (IFS) visited National Institute for Fusion Science (NIFS), and stayed three months. During this opportunity, we could effectively conduct research collaborations on simulation of drift wave turbulence in magnetized plasmas. Here, we report two major results obtained under the JIFT program.

i) Research collaborations using GKV code

Gyrokinetic simulation code, GKV, which solves the gyrokinetic equation as a nonlinear partial differential equation in the five-dimensional phase space, has been developed at NIFS, with the aim of analyzing the drift wave turbulence in magnetically-confined toroidal plasmas. By means of GKV code, we have intensively investigated the ion temperature gradient (ITG) driven turbulent transport and zonal flows in a tokamak and the Large Helical Device (LHD).

Since numerical simulations dealing with the five-dimensional phase space demand huge amount of computer resources, their successes largely rely on realization of efficient computing on massively-parallel supercomputers. We revised GKV and MEGA codes (the latter is developed by Prof. Todo at NIFS for analysis of high-energy particle confinement) so as to be executed on Franklin at NERSC and Ranger at University of Texas, and compared their performances with those of supercomputers available at Japanese sites [1]. The both codes newly installed in Franklin and Ranger show good scalability over 10,000 processor cores (see Fig.1).

ii) Simulation of electron temperature gradient turbulence

The electron temperature gradient (ETG) turbulence has been considered as one of possible causes for the anomalous electron heat transport in magnetized plasmas. Prof. Horton and his collaborators have investigated the ETG turbulence by means of the two-dimensional fluid simulations. In Japan, Mr. Nakata, the Graduate University of Advanced Studies (Sokendai), has carried out gyrokinetic simulations of the slab ETG turbulence. Utilizing the opportunity of the Prof. Horton's stay at NIFS, we conducted the research collaborations on the ETG turbulent transport [2].

Color contours for fluctuations of the electrostatic potential and the electron temperature are shown in Fig.2. It is found that a coherent vortex structure (right) with a low transport level is spontaneously formed after the ETG turbulence (left).

The present research collaboration has recently been extended for the ETG turbulence and zonal flows in a tokamak and a linear magnetic confinement device.

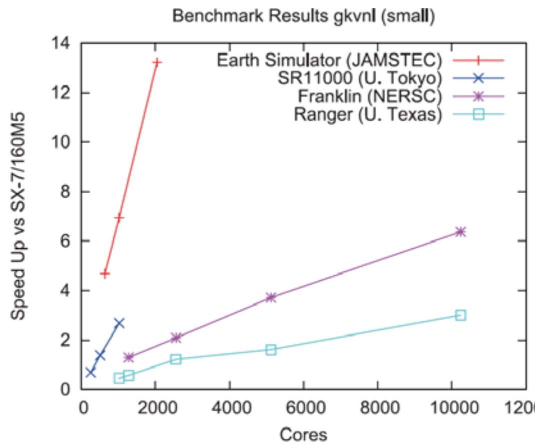


Fig. 1. Computational performance of GKV code on several massively-parallel supercomputers. Horizontal axis is normalized by the computation speed measured by using the NEC SX-7/160M5 system (after Ref. [1]).

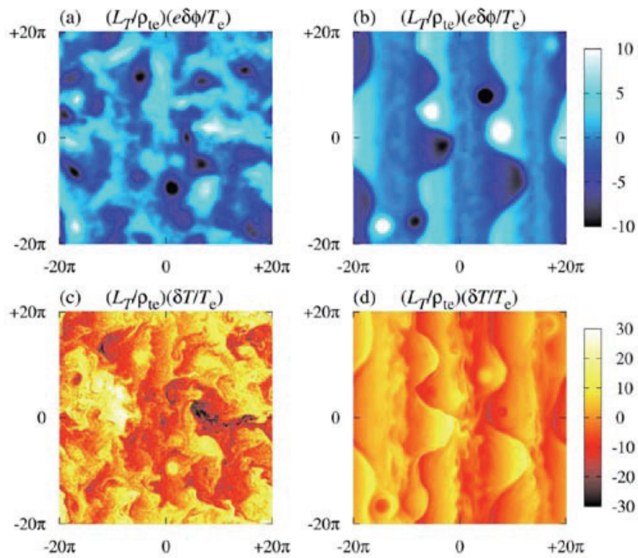


Fig. 2. Potential [(a) and (b)] and temperature [(c) and (d)] fluctuations found in the slab ETG mode simulation during turbulent [(a) and (c)] and quiescent [(b) and (d)] phases (after Ref. [2]).

1) T.-H. Watanabe, Y. Todo, and W. Horotn, Plasma Fusion Res. **3**, (2008) 061.
2) M. Nakata, T.-H. Watanabe, H. Sugama, and W. Horton, Phys. Plasmas **17**, 042306 (2010).

JIFT Workshops on Theoretical Analyses in Helical Plasmas

Category: JIFT
Year/Number: 2004-JF1-01
Names: D. Monticello (PPPL), N. Nakajima (NIFS)

Dr. Monticello and Dr. Nakajima organized a series of two workshops on theoretical physics issues in 3D toroidal magnetic confinement systems.

1. *First workshop (Princeton, 2002)*

A workshop entitled "Theoretical Consideration on Helical Plasmas" organized by Dr. Nakajima (NIFS) and Dr. Monticello (PPPL) was held in Princeton on November 18-21, 2002. Sixteen talks were presented. The talks focused mostly on stellarator experiments that were operating at the time of the conference (LHD, Heliotron-J, W7-AS, and HSX) and on proposed experiments such as QPS, W7-X, and NCSX. A synopsis of all the talks was prepared by Nakajima and Monticello and published in the May 2003 edition of *Stellarator News* [1]. The talks were posted on the workshop website [2]. Several results from this workshop are shown in Figs. 1-3 here.

2. *Second workshop (Kyoto, 2005)*

A follow-on workshop, entitled "Progress of theoretical analyses in three dimensional configurations," with the same two organizers, was held in Kyoto on January 25-27, 2005. There were five participants from the US and seventeen from Japan. The US representatives were A. Boozer (Columbia), C. Hegna (Wisconsin), L. Sugiyama (MIT), A. Ware (Montana), and D. Monticello (PPPL). The talks covered a wide range of stellarator physics, including equilibrium, MHD stability, kinetic stability, pellet ablation, and edge physics. Probably most interesting were the details of theoretical analyses of the experiments on the Large Helical Device (NIFS) that attained plasma beta of 4.2%. A report on the workshop, with a synopsis by the US participants, was presented to the US stellarator physics community on February 10, 2005, as part of the National Stellarator Theory seminar series. The talks were posted on the workshop website [3]. This information was also announced in *Stellarator News*.

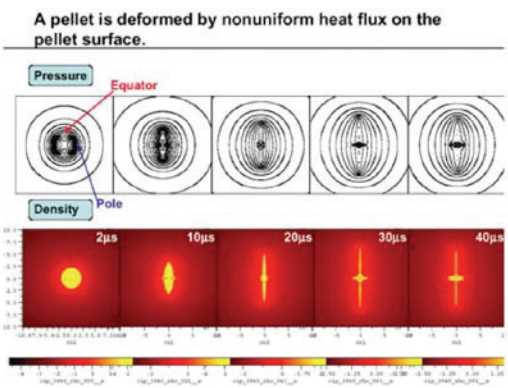


Fig. 1. Pellet deformed by non-uniform heat flux [from a talk by R. Ishizaki, R. Nakajima, and P. B. Parks)]

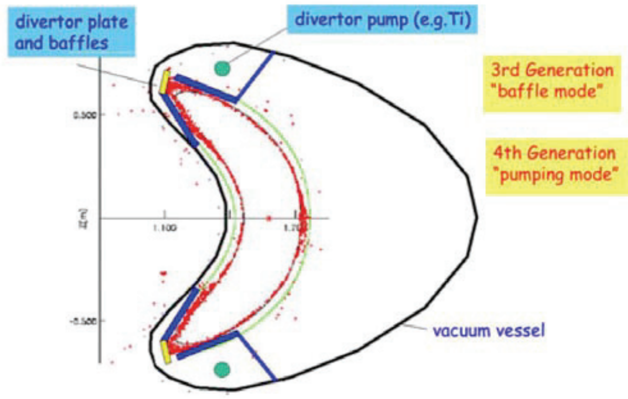


Fig. 2. NCSX divertor model with field line traces [from talk by A. Grossman et al.)]

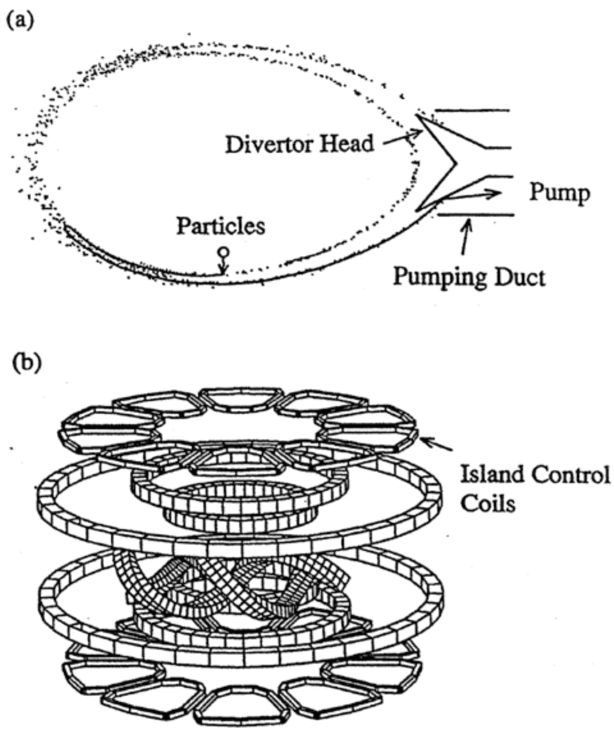


Fig. 3. Local Island Divertor (LID) using m/n = 1/1 [from talk by R. Kanno]

[1] http://www.ornl.gov/sci/fed/stelnews.
[2] http://www.pppl.gov/ncsx/Scientificconf/JIFT/JIFT.html
[3] http://www.center.iae.kyoto-u.ac.jp/kondok/meetings/jift/presentations.html

Micro-Instability Analysis of Toroidal Confinement Devices

Category: JIFT
Year/Number: 2004-JF1-04
Names: G. Rewoldt (PPPL), H. Shirai (JAEA), N. Nakajima (NIFS)

Dr. Rewoldt has been involved in three general areas of work for the Joint Institute for Fusion Theory program. He made many trips to Japan under its auspices. These areas of research were:

(1) Ideal MHD equilibrium and stability analysis of stellarator/heliotron devices, in particular Heliotron-E, using the STEP code, a modified version of the PEST code, which implements the so-called stellarator expansion. This work was done in collaboration with J.L. Johnson (PPPL), M. Wakatani and Y. Nakamura (Kyoto University Plasma Physics Laboratory), and others, over the period from 1985 to 1991.

(2) Linear and quasi-linear gyro-kinetic micro-instability analysis of the JT-60U tokamak using the FULL code, in collaboration with K.W. Hill, W.M. Tang, and others (PPPL) and H. Shirai, Y. Kishimoto, and many others (JAERI). This work involved calculations of linear growth rates and real frequencies and ratios of quasi-linear fluxes, using realistic experimental density and temperature profiles and MHD equilibria, over the period from 1999 to 2005.

(3) Linear gyrokinetic micro-instability analysis of the LHD stellarator using the FULL code, in collaboration with L.-P. Ku and W.M. Tang (PPPL), W.A. Cooper (CRPP-EPFL), and H. Sugama, N. Nakajima, K.Y. Watanabe, S. Murakami, H. Yamada, and many others (NIFS), over the period from 2000 to 2003. In these calculations, modes such as trapped-electron modes and ion temperature gradient modes can be unstable, with contributions from both toroidal curvature and helical curvature to resonances of both toroidally trapped and helically trapped electrons.

Numerous publications resulted from these joint collaborations. Selected papers are listed below [1-5].

[1] R. Nazikian, K. Shinohara, G.J. Kramer, E. Valeo, K. Hill, T.S. Hahm, G. Rewoldt, S. Ide, Y. Koide, Y. Oyama, H. Shirai, W. Tang, "Measurement of Turbulence Decorrelation during Transport Barrier Formation in a High Temperature Fusion Plasma," Phys. Rev. Lett. **94**, 135002 (2005).

[2] H. Takenaga, S. Higashijima, N. Oyama, L.G. Bruskin, Y. Koide, S. Ide, H. Shirai, Y. Sakamoto, T. Suzuki, K.W. Hill, G. Rewoldt, G.J. Kramer, R. Nazikian, T. Takizuka, T. Fujita, A. Sakasai, Y. Kamada, H. Kubo, and JT-60 Team, "Relationship between particle and heat transport in JT-60U plasmas with internal transport barrier," Nuclear Fusion **43**, 1235-1245 (2003).

[3] G. Rewoldt, L.-P. Ku, W. M. Tang, H. Sugama, N. Nakajima, K. Y. Watanabe, S. Murakami, H. Yamada, and W. A. Cooper, "Microinstability Studies for the Large Helical Device," Nuclear Fusion **42**, 1047-1054 (2002).

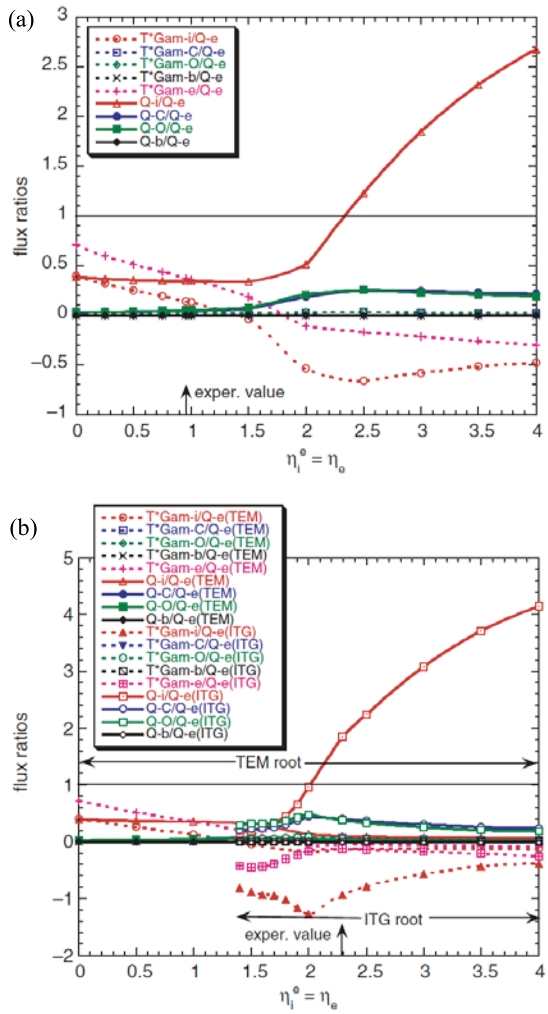


Fig. 1. Quasilinear particle flux Γ and energy flux Q as functions of the electron temperature gradient parameter, compared to experimental values. [from Ref. 3]

[4] G. Rewoldt, L.-P. Ku, W.M. Tang, H. Sugama, N. Nakajima, K. Y. Watanabe, S. Murakami, and H. Yamada, "Drift Mode Calculations for the Large Helical Device," Phys. Plasmas **7,** 4942-4947 (2000).

[5] Y. Sakamoto, T. Suzuki, S. Ide, Y. Koide, H. Takenaga, Y. Kamada, T. Fujita, T. Fukuda, T. Takizuka, H. Shirai, N. Oyama, Y. Miura, K.W. Hill, G. Rewoldt, and JT-60 Team. "Properties of Internal Transport Barrier Formation in JT-60U," presented at 19th IAEA Fusion Energy Conference 2002; Nucl. Fusion **44,** 876-882 (2004).

Effect of Resistive Wall on External Kink Modes

Category: JIFT
Year/Number: 2004-JF1-06
Names: M.S. Chu (GA), K. Ichiguchi (NIFS)

Dr. Chu from General Atomics spent three months at NIFS as the JIFT Visiting Professor (September 1–November 31, 2004). During this time, he performed research in collaboration with Dr. K. Ichiguchi concerning the possibility of resistive wall modes in 3D magnetic confinement configurations.

The external kink mode is one of the most serious instabilities that affect plasma confinement. Its growth rate is usually fast, outside the range of feasibility for plasma control. The external kink mode can be stabilized by the presence of a nearby perfect conducting wall. When the resistivity of the wall is taken into account, the external kink mode is changed into the resistive wall mode (RWM). Its growth rate then reduces to the inverse of the flux diffusion time through the resistive wall. The RWM with its slower growth rate can be stabilized either by plasma rotation or magnetic feedback. In configurations without toroidal symmetry, plasma rotation is relatively small and not expected to stabilize the RWM. Therefore, magnetic feedback must be relied upon to stabilize the RWM in non-axisymmetric configurations. As preparation for the design for feedback control of the RWM, the growth rate of the RWM in these configurations was investigated.

A method was formulated for the systematic computation of the growth rate of the RWM in weakly unstable 3D configurations by using results from ideal stability codes. It was shown that the growth rate of the RWM is given, approximately, by the rate at which the available free energy for the ideal external kink mode (with the wall at infinity) can be dissipated by the resistive wall. By relying on the concepts of energy and dissipation, the method is readily connected with other MHD codes and provides an independent and useful method of studying the physics of RWM.

This formulation was demonstrated by coupling to the ideal MHD code KSTEP to study the stability of the RWM in LHD plasmas. It is found that in terms of plasma current, a very limited range of the plasma equilibria can have its external kink mode affected by the presence of the resistive wall, i.e., the plasma quickly transits from being stable with respect to the external kink mode to being unstable even when the wall is upon on the plasma. Nevertheless, it was demonstrated that the proposed method can be used to evaluate the growth rate of the RWM in any 3D configurations readily. The growth rate in the advanced stellarators can also be calculated by employing full 3D codes such as CAS3D and TERPSICHORE instead of the KSTEP code.

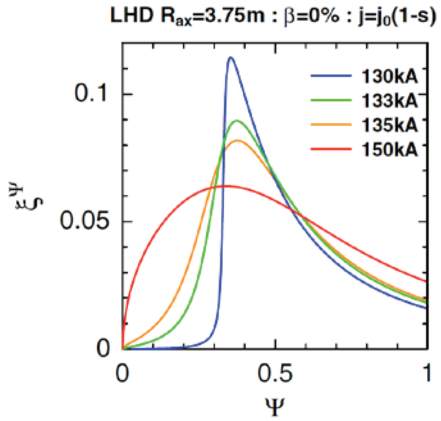


Fig. 1. Radial profile of the plasma displacement of the unstable ideal kink mode across the flux surfaces.

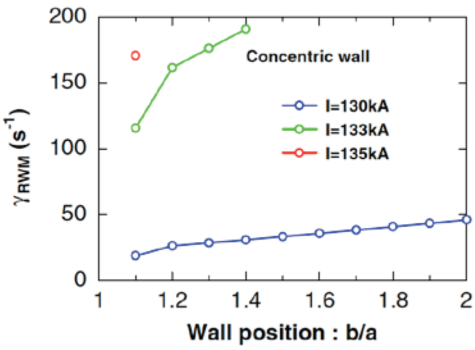


Fig. 2. Computed growth of the Resistive Wall Mode (RWM) as a function of the wall position [from Ref. 1].

[1] M. S. Chu and K. Ichiguchi, "Effect of the resistive wall on the growth rate of weakly unstable external kink mode in general 3D configuration," Nucl. Fusion **45**, 804 (2005).

Particle acceleration and parallel electric field in collisionless shock waves

Category : JIFT
Year-Number : 2004-JF1-14, 2009- JF-3,
Name: Y. Ohsawa, W. Mori*, J. Van Dam**, W. Horton**
Affiliation: Nagoya University, *UCLA, **IFS

With the JIFT personnel exchange program, I visited The University of California at Los Angeles (UCLA) and Institute for Fusion Studies (IFS), The University of Texas at Austin, in 2004 and the IFS in 2009. With plasma physicists at these institutions I discussed particle acceleration, nonlinear wave structure, and simulation methods. I was happy that I was able to collaborate with outstanding American plasma physicists, such as W. Mori, J. Leboeuf, V. Decyk, W. Horton, C. Chiu, J. Van Dam, and H. Berk. In particular, the electric field parallel to the magnetic field, $E_{\parallel}$, in nonlinear magnetosonic waves was one of the main topics we worked on together [1].

In the ideal MHD, the parallel electric field $E_{\parallel}$ is zero, and it was generally thought that $E_{\parallel}$ is quite weak in low-frequency phenomena in high-temperature plasmas. We have found out, however, that it can be strong in magnetosonic shock waves [2,3]. Our theory and relativistic, electromagnetic, particle simulations show that the magnitude of the parallel pseudo potential F, which is the integral of $E_{\parallel}$ along the magnetic field $\boldsymbol{B}$, in a small-amplitude (ε<<1) magnetosonic wave is $eF \sim \varepsilon\Gamma_e T_e$ in a high beta plasma, where Γ_e is the specific heat ratio of electrons, and is $eF \sim \varepsilon^2 m_i v_A^2$ in a low beta plasma. For large-amplitude waves with $\varepsilon \sim O(1)$ (shock waves), it is $eF \sim \varepsilon(m_i v_A^2 + \Gamma_e T_e)$, which is valid for both high and low beta cases. Figure 1 compares the theory and simulation results for the case of shock waves [2]. Furthermore, this work has been extended to electron-positron-ion (e-p-i) plasmas; positrons act to decrease the magnitude of F, and in a pure electron-positron plasma it becomes zero [3]. This explains the simulation result that the positron acceleration along the magnetic field in e-p-i plasmas becomes weak as the positron density decreases [4].

The parallel electric field plays an essential role in the acceleration of electrons [5] and of positrons [4] in shock waves, while it was ignored in the theory of the incessant acceleration of relativistic ions [6]. Having obtained the above quantitative theory for $E_{\parallel}$, we have revisited the effect of $E_{\parallel}$ on these acceleration mechanisms with use of particle simulations and two types of test particle calculations: In one method we have used the total electric field in the relativistic equation of motion for test particles, while in the other method we have used the electric field perpendicular to $\boldsymbol{B}$.

This study [1] indicates that without $E_{\parallel}$, electron reflection near the end of the main pulse of a shock wave, which triggers electron acceleration and trapping, does not occur, and thus the acceleration mechanism reported in Ref. [5] does not operate (see Fig. 2). The positron acceleration in an e-p-i plasma discussed in Ref. [4] is nearly along the magnetic field. If $E_{\parallel}$ =0, therefore, this type of acceleration cannot take place either. The effect of $E_{\parallel}$ on relativistic ions becomes small as the particle energy goes up; thus, the theoretical treatment ignoring $E_{\parallel}$ [6] is justified.

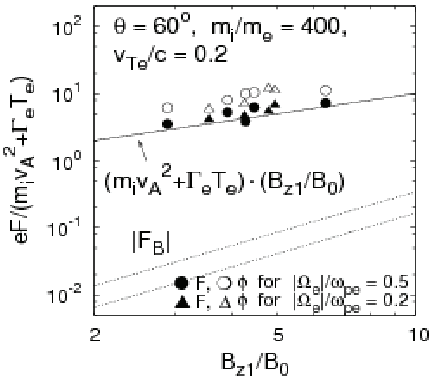


Fig. 1 Parallel pseudo potential F versus shock amplitude. The closed circles and triangles show F while the open ones represent electric potential formed in shock waves [2].

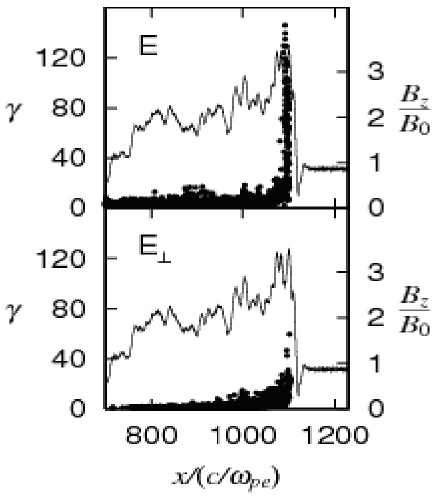


Fig. 2 Phase spaces (x, γ) of test electrons. The upper and lower panels, respectively, show test electrons calculated with total and perpendicular electric fields. There are many ultrarelativistic (γ>100) electrons in the upper panel [1].

1) S. Takahashi, H. Kawai, Y. Ohsawa, S. Usami, C. Chiu, and W. Horton, Phys. Plasmas **16**, 112308 (2009).
2) S. Takahashi and Y. Ohsawa, Phys. Plasmas **14**, 112305 (2007).
3) S. Takahashi, M. Sato, and Y. Ohsawa, Phys. Plasmas **15**, 082309 (2008).
4) H. Hasegawa and Y. Ohsawa, Phys. Plasmas **12**, 012312 (2005); H. Hasegawa, K. Kato, and Y. Ohsawa, *ibid.* **12**, 082306 (2005).
5) N. Bessho and Y. Ohsawa, Phys. Plasmas **6**, 3076 (1999); *ibid.* **9**, 979 (2002).
6) S. Usami and Y. Ohsawa, Phys. Plasmas **9**, 1069 (2002); *ibid.* **11**, 3203 (2004).

Analysis of Axisymmetric Equilibria with Flows in Non-Ideal Fluid Models

Category: JIFT
Year/Number: 2005-JF1-05
Names: A. Ito (NIFS), N. Nakajima (NIFS), J.J. Ramos (MIT)

Dr. Ramos visited NIFS in the summer of 2005 and carried out theoretical studies in collaboration with Dr. Ito and Prof. Nakajima to investigate properties of axisymmetric plasma equilibria with mass flows, within the framework of several non-ideal fluid models.

1. *Ellipticity of Axisymmetry Equilibria with Flow and Pressure Anisotropy*

The first part of the work was based on a Hall-MHD model with cold ions, zero-mass electrons and finite electron pressure anisotropy [1]. This model included a closure consistent with dynamical evolution equations for the parallel heat fluxes and yielded a homogeneous plasma dispersion relation identical to the one derived from kinetic theory. The ellipticity criteria for the partial differential equations of axisymmetric single-fluid and Hall magnetohydrodynamic (MHD) equilibria with flow and pressure anisotropy are investigated. In the limit of vanishing ion skin depth, it reduces to a single-fluid model with anisotropic pressure, which predicts mirror and firehose instability thresholds in agreement with kinetic theory. In the single-fluid description of plasmas, axisymmetric toroidal equilibria with flow are obtained by solving the so-called generalized Grad-Shafranov (GS) equation and the Bernoulli law. In the absence of poloidal flow, the equilibrium is elliptic if the kinetic stability conditions for the firehose and mirror modes are satisfied. Conditions for ellipticity of the axisymmetric toroidal equilibria with flows were derived and shown to be related to the velocities of waves in the kinetic-consistent dispersion relation. These conditions are different from those for the double-adiabatic Chew-Goldberger-Low model. For anisotropic Hall MHD, a set of anisotropic-pressure equilibrium equations has been derived. It consists of the coupled GS equations for the magnetic flux and the ion stream function and the Bernoulli law for ions. Unlike the isotropic case, in the presence of pressure anisotropy, the characteristic determinants for each GS equation are coupled and cannot be examined their ellipticity separately. One can find the conditions for ellipticity of such systems involving higher order derivatives by examining the existence of wave type solutions, a method also applicable to second order differential equations. If we consider a wave propagating in one-dimensional space and time and having discontinuity across the wave front, ellipticity of the coupled GS equations requires the non-existence of real values of the velocity of the wave front. A sufficient condition for ellipticity was obtained that corresponds to a poloidal flow velocity slightly smaller than the sound velocity.

2. *High-Beta Axisymmetric Equilibria with Flow*

The second part of the work was devoted to reduced-MHD models with high-beta and large-aspect-ratio orderings [2]. In improved confinement modes of magnetically confined plasmas where high-beta is achieved, equilibrium flows play important roles like the suppression of instability and turbulent transport. At the sharp boundary of a well-confined region, the scale lengths characteristic of microscopic effects not included in single-fluid magnetohydrodynamics (MHD) cannot be neglected. Small scale effects on flowing equilibria due to the Hall current have been studied with two-fluid or Hall MHD models. However, these models are consistent with kinetic theory only for cold ions [1]. In order to include the hot ion effects that are relevant to fusion plasmas, an extension of the model is necessary. A consistent treatment of hot ions in a two-fluid framework must include the ion gyroviscosity and other finite Larmor radius (FLR) effects. A two-fluid equilibrium system including Hall and finite ion Larmor radius effects was derived for flows comparable to the poloidal Alfven velocity, showing that the ion gyroviscosity produces a shift of the Alfven singularity. A single-fluid system was derived for flows comparable to the poloidal sound velocity, a case that requires keeping higher-order terms in the aspect ratio expansion before the singular velocity points can be shown. Since the formulation of higher-order equations is involved, here we restricted our analysis of the poloidal-sonic flow to the single-fluid case, planning to extend our present results with the inclusion of two-fluid, hot ion effects in future work. The singularity at a poloidal flow velocity equal to the poloidal sound velocity was recovered in the higher order equations. The orderings in this study provide the simplest models that include ion FLR effects on toroidal equilibria with flow. As such, they should be just considered as convenient working hypotheses that allow our analytic study of such effects. The resulting equations can be easily solved numerically to yield flowing equilibria without singularity and their solutions can be used as initial states or for comparison with saturated states of reduced model nonlinear simulations.

[1] A. Ito, J.J. Ramos and N. Nakajima, "Ellipticity of axisymmetric equilibria with flow and pressure anisotropy in single-fluid and Hall magnetohydrodynamics," Phys. Plasmas **14**, 062502 (2007).

[2] A. Ito, J.J. Ramos and N. Nakajima, "High-Beta Axisymmetric Equilibria with Flow in Reduced Single-Fluid and Two-Fluid Models," Plasma Fusion Res. **3**, 034 (2008).

Study of ballooning instability of LHD by high-accuracy numerical simulation

Category : JIFT
Year-Number : 2005-JF1-11,2009-JF-4,
Name: Hideaki Miura, *S. Mahajan, *W. Horton
Affiliation: National Institute for Fusion Science, *Institute for Fusion Studies (U.S.A.)

We have been studying the pressure-driven instability of the Large Helical Device (LHD) of National Institute for Fusion Science, Japan, by means of numerical simulations of MHD / extended MHD. The pressure-driven instabilities of LHD were considered to be saturated due to the nonlinear pressure flattening mechanism of MHD. However, the understanding was base on simulations of the reduced MHD equations with the averaging method, in which roles of high toroidal wavenumber unstable modes and other three-dimensional natures were omitted.

In order to understand contributions of these factors, we developed a numerical code for fully three-dimensional compressible MHD equations, MHD In the Non-Orthogonal System (MINOS). Simulations with the MINOS code have revealed that there can be at least three mechanisms to suppress the pressure-driven instability: the pressure flattening, the compressibility effect which works to reduce the growth rates of the unstable modes, and the parallel flow generation which releases the free energy into the direction parallel to the magnetic field lines.[1,2)] In the JIFT-JF1-11 program, we investigated these suppression mechanisms. By the most recent numerical simulations, we have shown that the parallel heat conduction can be much more significant to suppress the high wave number ballooning modes than the three mechanisms in the above.[3)] (In Fig.1, the isosurfaces of the pressure which are distorted by the ballooning modes are shown with the LHD CAD image. See Ref.3.)

Recently, we have started studies on the Large Eddy Simulation (LES) of the MHD / extended MHD system in order to enable two requirements which contradict to each other: taking the two-fluid effects into our simulation and shortening a computational time. In the LES approach, physical variables are filtered by an appropriate low-pass filter so that we can solve the coarse-grained equations with small computational costs. However, we have to develop models of many nonlinear couplings for the purpose, especially associated with many two-fluid effects. Furthermore, we may need to take the effects of the particle-field interactions into the simulation for the purpose of numerical experiments. Because o these reasons, there are many subjects to be solved for the purpose of numerical experiments with the LES approach. Some of these subjects are studied with the help of the JIFT program (2009-JF-4). (See Fig.2.) Some of preliminary efforts have been reported in Refs. 4) and 5).

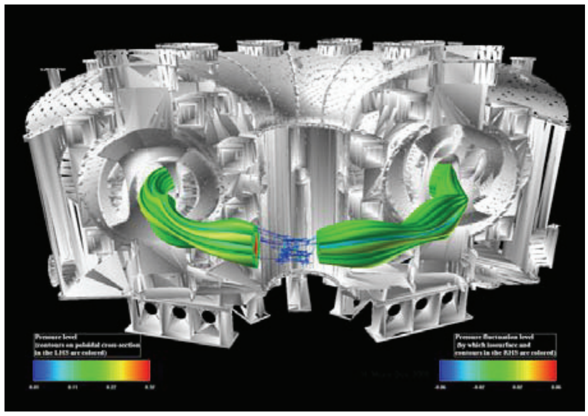


Fig.1: Isosurface of the pressure in the MHD simulation of LHD. The flute-like structures represent growth of the ballooning-modes.

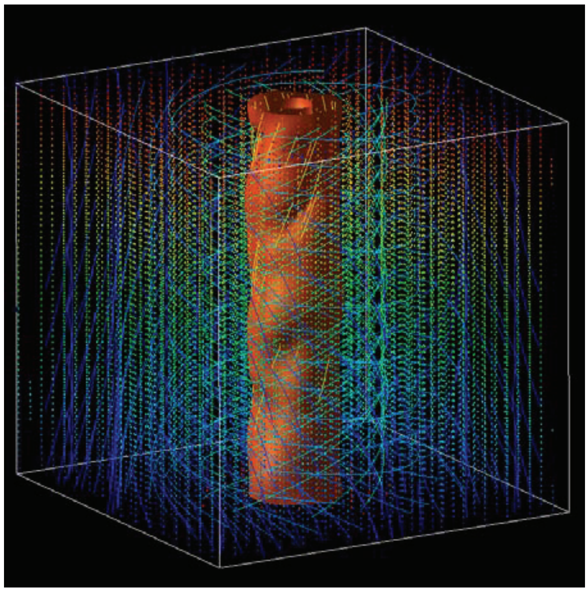


Fig.2: Test particle simulations with a vortex.

1) H. Miura et al, Fusion Sci. & Tech. Vol.51 (2007) 8-19.
2) H. Miura et al. AIP Conference Proceedings Vol.871 (2007) pp.157-168
3) H. Miura and N. Nakajima, to appear in Nuclear Fusion (2010).
4) H. Miura and N. Nakajima, submitted to 23rd IAEA FEC (Oct. 2010, Dajeon, Korea)
5) W. Horton, C. Correa, H. Miura, B. Rodenborn, Bull. 2009 APS April Meeting Vol.54 .

Energy Conversion in Magnetic Reconnection with Chaos Diffusion

Category : Fusion Physics/ Theory
Year-Number : 2006-JF1-12
Name: H. Ohtani, W.Horton[*)], T.Petrosky[**)], R.Horiuchi
Affiliation: National Institute for Fusion Science, [*)]Institute for Fusion Studies, University of Texas at Austin, [**)]Center for Complex Quantum Systems, University of Texas at Austin

The present research collaboration started since Dr. Petrosky (Center for Complex Quantum Systems, University of Texas at Austin) stayed at National Institute for Fusion Science (NIFS), from October 2005 to January 2006 as a visiting professor. Then, the collaboration studies have been continued in various ways. In 2007, H. Ohtani (NIFS) visited Institute for Fusion Studies (IFS), University of Texas at Austin, and stayed two months supported by the JIFT program. In this stay, Prof. W. Horton (IFS) joined in the collaboration studies. During this opportunity, we could effectively conduct research collaborations on simulation of magnetic reconnection. Here, we report one major result obtained under the JIFT program.

Role of meandering particles in break of frozen-in condition.

The three-dimensional particle simulation code for magnetic reconnection in an open system, PASMO, has been developed at NIFS. By using PASMO code, we have intensively investigated the dynamics and plasma instabilities in collisionless driven reconnection.

The plasma inflow and magnetic flux go from the upstream toward the center region because of the driving electric field imposed at the upstream boundary. The driving field penetrates into the current sheet owing to particle kinetic effects, and triggers magnetic reconnection when it reaches the center.

In the ion dissipation region around the central reconnection point at which collisionless reconnection sets under the influence of driving flow, the frozen-in condition is broken by the pressure tensor term $\frac{1}{qn}\frac{\partial \Pi_{yz}}{\partial y}$ (Fig.1), where q is charge, n is number density, Π_{yz} is pressure tensor. Pressure tensor term originates from the stochastic thermal motion called meandering in the vicinity of reconnection point. We examined the relationship between the meandering motion and the pressure tensor based on a simple model (Ref.(1)). In the approximations of the model, (i) the average orbit amplitude of the meandering motion is determined from the location and the local ion Larmor radii, (ii) the magnetic field changes linearly, (iii) the size of the dissipation region is equal to the meandering amplitude, and (iv) the pressure tensor is given under a type of semi-cold plasma approximation. Under the model, the pressure tensor term is written as

$$\frac{1}{qn}\frac{\partial \Pi_{yz}}{\partial y} = -\frac{1}{qn}\frac{mnE_z B'_x v_{th}\left(B'^2_x y^2 - B^2_y\right)}{\left(B'^2_x y^2 + B^2_y\right)^2} \quad (1)$$

where m is mass, B'_x is a constant parameter of linear change of B_x. Figure 1 shows spatial profiles of terms of the force balance equation

$$E_z + (u \times B)_z = \frac{m}{q}\left\{\frac{\partial}{\partial t} + (u \cdot \nabla)\right\}u_z + \frac{1}{qn}\left(\frac{\partial \Pi_{xz}}{\partial x} + \frac{\partial \Pi_{yz}}{\partial y}\right) \quad (2)$$

and analytic solution (Eq.(1)). *u* is flow velocity. The tendency of the solution (orange line) is in agreement with the pressure tensor term $\frac{1}{qn}\frac{\partial \Pi_{yz}}{\partial y}$ (a sky blue line) of the simulation result. This result supports that the meandering motion plays an important role in collisionless reconnection.

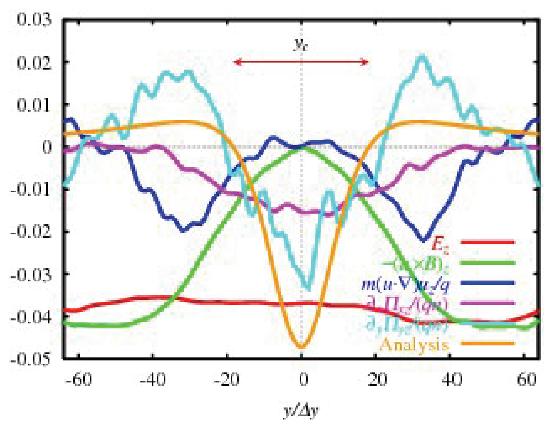


Fig. 1. Spatial profiles of terms of the force balance equation (Eq.(2)) for ion and analytic solution (Eq.(1)) of $\frac{1}{qn}\frac{\partial \Pi_{yz}}{\partial y}$ along y direction through the reconnection point. Red, green, blue, magenta, sky blue and orange lines show E_z, $-(u \times B)_z$, $m(u\nabla)u_z/q$, $\frac{1}{qn}\frac{\partial \Pi_{xz}}{\partial x}$, $\frac{1}{qn}\frac{\partial \Pi_{yz}}{\partial y}$ in the simulation result, and analytic solution of $\frac{1}{qn}\frac{\partial \Pi_{yz}}{\partial y}$, respectively.

1) H.Ohtani, W.Horton, T.Petrosky and R.Horiuchi: J. Plasma Fusion Res. SERIES, Vol.8, (2009), pp.203-207.

Plasma rotation effects on resistive wall mode stability and magnetic island formation by error fields

Category: Joint Institute for Fusion Theory
Year-Number: 2006-JF1-11, 2007-JF1-5, 2008-JF1-6
Name: Masaru Furukawa[1)], Linjin Zheng[2)]
Affiliation: [1)] Grad. Sch. Frontier Sci., Univ. Tokyo, [2)] Inst. Fusion Studies (IFS), Univ. Texas at Austin

High-beta and long-pulse discharges of tokamak plasmas have introduced serious problems of disruption and confinement degradation due to relatively slow MHD phenomena such as resistive wall mode (RWM) and neoclassical tearing mode (NTM). These are important issues not only as the nuclear fusion development, but also as physics problems. It was shown experimentally that the RWM can be stabilized if the plasma is rotating toroidally and that the critical rotation speed for the stabilization is closely related to externally given error fields. In addition, this error field penetrates and can be amplified in the plasma, which generates magnetic islands at the rational surface. Thus the error field is also closely related to NTM. Therefore, these problems cannot be divided into elements. The motivation of our study is therefore to develop theoretical models and analysis methods on the RWM stability and the generation of magnetic islands due to the error fields under the presence of plasma rotation, and to verify the models by numerical simulations.

We have studied the effect of plasma rotation on the penetration of error fields into the plasma by low-beta reduced MHD simulation in a cylindrical configuration.[1)] The plasma rotation and the error field at the plasma edge are kept unchanged, and we observed stationary states after transient dynamics. If the equilibrium rotation changes slowly, the plasma may follow a sequence of the quasi-stationary states obtained in the simulation. Figure 1 shows the magnitude of the penetrated magnetic flux $|\psi_{2/1}(r_s)|$ versus the rotation speed $v_{\theta s}$ at the rational surface. We see that $|\psi_{2/1}(r_s)|$ or the island width begins to decrease rapidly as $v_{\theta s}$ is increased above some critical value, and that the critical value is lower for smaller resistivity η. This is because two current sheets, generated at the Alfvén resonances which are at both sides of the rational surface in the presence of plasma rotation, have enough shielding effect on the penetration of error field if the current sheets do not overlap the rational surface when the rotation speed is fast enough. This situation occurs at lower rotation speed for smaller η. We also calculated the electromagnetic torque generated by the penetrated error fields, which brakes the plasma rotation. In the range of fast rotation, the torque is proportional to $v_{\theta s}$, and does not depend on η.

It is difficult actually to apply the conventional asymptotic matching method to the situation where the current sheet splits fully into two sheets. In order to resolve this, in addition to some practical difficulties inherent in the asymptotic matching method, we have developed a new matching technique[2)]. Our new technique is a direct matching using the inner layer with a finite width. In the matched asymptotic expansion, on the contrary, the inner layer has an infinitely thin width. Advantages are: i) it is applicable to reversed magnetic shear configuration with its minimum safety factor being a rational number, ii) high accuracy can be obtained because of the avoidance of numerical treatment of singularity, iii) it can be formulated easily as an initial-value problem and so on. Our technique has been applied to well-known results of single and double tearing, internal kink and interchange modes in a cylindrical geometry, and the results have shown its good performance.

We have also discovered a new instability, "current-interchange tearing mode", in the presence of resistivity gradient[3)]. Figure 2 shows the mode structure. We see that $\psi_{2/1}$ is finite at the rational surface r=0.5, i.e., magnetic islands are generated.

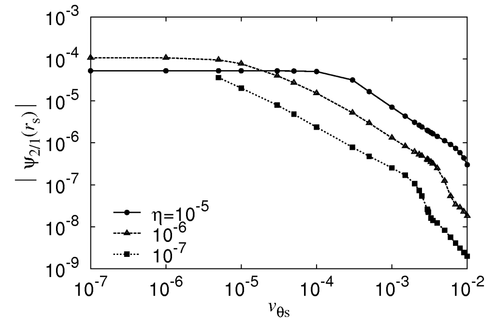


Fig.1. Magnetic flux of the penetrated error field $|\psi_{2/1}(r_s)|$ versus the rotation velocity at the rational surface.

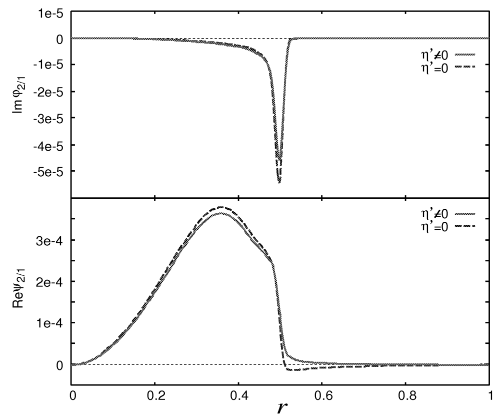


Fig.2. Mode structure of newly-discovered "current-interchange tearing mode".

1) M. Furukawa and L. –J. Zheng, Nucl. Fusion **49** (2009) 075018; The 22th IAEA Fusion Energy Conference, TH/P9-13 (2008).

2) M. Furukawa, S. Tokuda and L. –J. Zheng, submitted to Phys. Plasmas (2009); The 50th Ann. Meeting Div. Plasma Phys., American Phys. Soc., CP6.73 (2008).

3) L. –J. Zheng and M. Furukawa, Phys. Plasmas (accepted, 2010) ; L. –J. Zheng and J. W. Van Dam, The 51th Ann. Meeting Div. Plasma Phys., American Phys. Soc., UP8.84 (2009).

JIFT Workshop on Gyrokinetic Simulation of Plasma Transport

Category: JIFT
Year/Number: 2007-JF1-1
Names: T. S. Hahm (PPPL), H. Sugama (NIFS)

This workshop was held at the High Temperature Plasma Center, Kashiwa Campus, The University of Tokyo, September 24 and 25, 2007.

The workshop consisted of 4 sessions: (I) Recent Progress in Gyrokinetic Simulation, (II) Theory and Experiments on Momentum Transport, (III) Theory and Simulation of Electric Fields and Flows, and (IV) Multi-Scale Physics, New Fluid Simulation.

In addition, there was a special lecture entitled "Plasma Waves and Instabilities in Shear Flow–A Frontier of Functional Analysis beyond von Neumann's Theorem." Talks were presented by 11 scientists from Japan, 2 from US, and 2 from EU. Recent results from theoretical and simulation studies about plasma transport based on gyrokinetic and gyrofluid models were reported. Comparative studies of theoretical modeling and experimental results of toroidal momentum transport in tokamaks and helical systems were made. Also, topics such as zonal flows, geodesic acoustic modes, and multi-scale interactions in ion temperature gradient (ITG) turbulence were discussed.

Several papers that were subsequently published acknowledged simulating scientific exchanges during this workshop. One such paper [1] presented a refined formulation of the gyrokinetic equations for plasmas with large flow shears caused by an equilibrium electric field. Through the choice of a more suitable equilibrium drift velocity for the reference frame of a charge particle, the accuracy of the gyrokinetic equations can be significantly improved. Another paper [2] showed the derivation of an energy conserving set consisting of the fully electromagnetic nonlinear gyrokinetic Vlasov equation and Maxwell's equations, where this set of equations is applicable both to L-mode turbulence with large amplitude and to H-mode turbulence in the present of large ExB shear. A third paper [3] described how plasma parameter scans—such as the plasma current, neutral beam heating power, and electron density—had been used to obtain properties of the toroidal momentum diffusivity and the convection velocity in H-mode plasmas in the JT-69U experimental facility.

[1] G. Kawamura and A. Fukuyama, "Refinement of the gyrokinetic equations for edge plasmas with large flow shear," Phys. Plasmas **15**, 042304 (2008).
[2] T.S. Hahm, Lu Wang, and J. Madsen, "Fully electromagnetic nonlinear gyrokinetic equations for tokamak edge turbulence," Phys. Plasmas **16**, 022305 (2009).

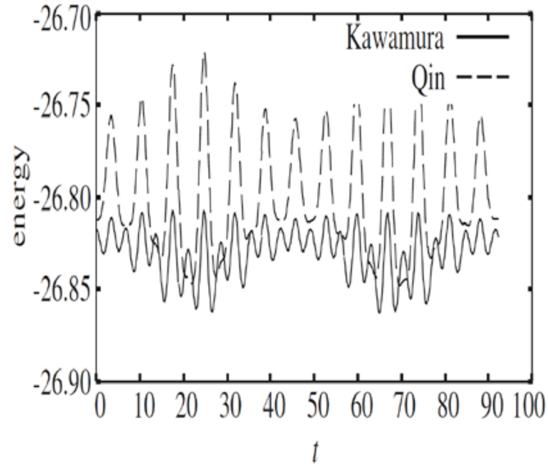


Fig. 1. Time evolution of the particle energy as calculated with a refined version of the gyrokinetic equations for large flow shear, compared to the previous analysis of Qin [from Ref. 1]

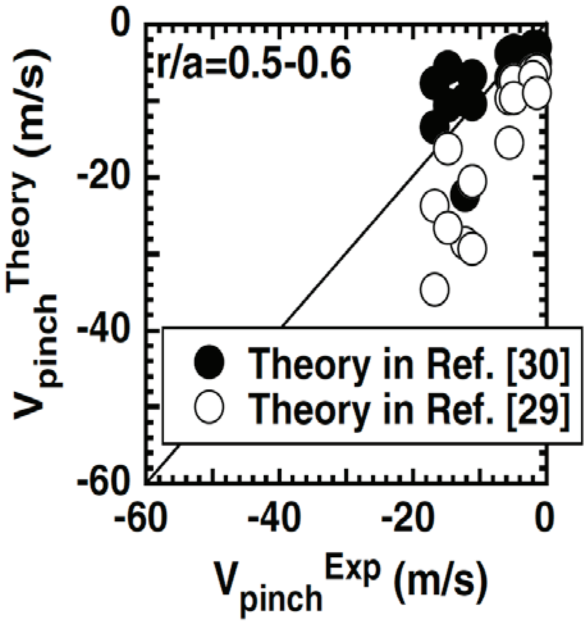


Fig. 2. Comparison of the pinch velocity from modulation experiments in JT-60U with that calculated from two theories [from Ref. 3]

[3] M. Yoshida, Y. Kamada, H. Takenaga, et al., "Characteristics of momentum transport in JT-60U H-mode plasmas," Nucl. Fusion **49**, 115028 (2009).

Relativistic Fast Electron Transport in Fast Ignition Targets

Category : Joint Institute for Fusion Theory
Year-Number : 2007-JF1-10
Name: T. Johzaki, Y. Sentoku*
Affiliation: Institute of Laser Engineering, Osaka University, *University of Nevada, Reno

In Fast ignition using cone-guide targets, the core heating is done by the energy transport of fast electrons generated at the cone inner surface. In Fast Ignition Realization Experiments phase-I (FIREX-I), the heating laser energy is 10kJ and it will be 100kJ in the fusion reactor. When using such a high energy heating lasers, the bulk electron temperature in the cone tip becomes higher than 10keV due to laser irradiation and fast electron heating, and Au atoms reach highly-ionized state. In such a situation, the fast electron generation and its transport will be affected by the collisional processes in cone tip. So we have estimated the dependence of core heating properties on the cone tip material on the basis of coupled 1D simulations; collisional/ionization particle-in-cell (PIC) simulations for intense-laser plasma interactions and Fokker-Planck (FP) simulations for fast electron transport and core heating.

The fast electron profiles obtained from the PIC simulations for Au and CH cone tips are shown in Fig.1. It is found that a high-*Z* Au has disadvantages as a cone material in the long-duration and high-intensity laser case. The atoms rapidly reach highly-ionized states. In particular, the ions around the interaction region reach nearly full-ionization within a few hundreds fs. Because of the density profile steepening and the resistive damping of return current after reaching highly-ionized state, the conversion efficiency of laser to hot electrons decreases. In addition, the electron beam quality deteriorates due to the collisional and resistive drags and the scattering by the ions even for 10μm propagation in the Au cone tip. As a possible way to improve the energy coupling and to reduce the collisional effects, we propose to use a low-Z material (CH) as a cone tip material. The resistive damping of return current is weak for the CH case and the energetic electrons are continuously supplied into the LPI region. Thus the high beam intensity is kept even after the density steepening occurs. In addition, the scattering of fast electron beam is almost negligible. Therefore, twice higher energy coupling of laser to fast electron is obtained.

Using the fast electron profiles obtained from the PIC simulations, the core heating properties were evaluated with the FP simulations, where the cone tip thickness is 10μm (20μm) for Au cone (CH cone). The temporal evolution of core temperature is shown in Fig.2, and the core heating properties are summarized in Table I. Compared to the Au cone case, the energy coupling of the heating laser to the fast electron is twice higher in the CH cone. Though the propagation length is twice longer in the CH case, the energy ratio of the deposition in the cone to the beam source is comparable between the CH and Au cases. The energy ratio of the deposition in the core to the beam source is also comparable. Thus, the increases in electron and ion temperatures in the core ($\Delta\langle T_e\rangle$ and $\Delta\langle T_i\rangle$) are twice larger in the CH cone case because of larger conversion efficiency from laser to hot electrons.

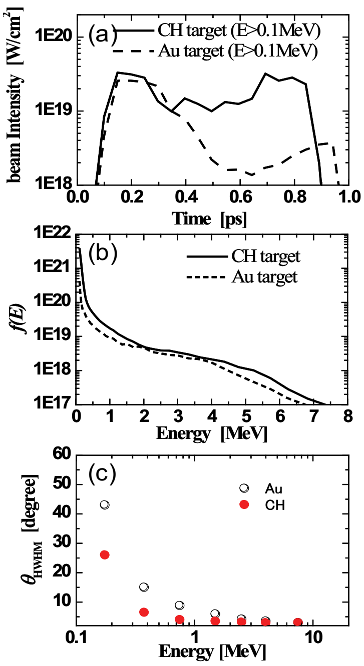


Fig.1. Comparison of observed fast electron profiles between Au and CH cone tips. (a) Beam intensity, (b) energy spectrum and (c) angular spread (full width at half maximum of angular distribution). In both cases the ionization is considered.

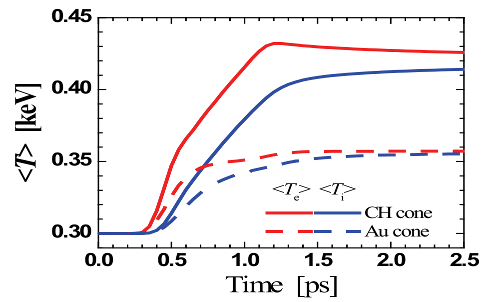


Fig.2. Temporal evolution of averaged electron (red) and ion (blue) temperatures in the core region (ρ > 1 g/cm^3). The solid lines stand for the CH cone case, the dashed lines for the Au cone case..

Table I. Comparison of core heating properties

	Au cone	CH cone
Source energy [MJ/cm^2]	7.34	15.26
E_{dep} in cone* [MJ/cm^2]	0.78	1.53
E_{dep} in core* [MJ/cm^2]	1.62	3.57
$\Delta\langle T_e\rangle$ [keV]	0.057	0.13
$\Delta\langle T_i\rangle$ [keV]	0.055	0.11

*E_{dep} is deposited energy of fast electrons

Simulation Study of the ICRF Minority Heating in the Quasi Helically Symmetric Plasma

Category : JIFT
Year-Number : 2008-JF1-7
Name: S. Murakami, K. Likin*, J. Talmadge*
Affiliation: Dpt. of Nuclear Eng., Kyoto Univ.
*HSX Plasma Laboratory, Univ. of Wisconsin

In HSX plasma the ECH experiments have been performed and a clear improvement of the electron temperature in the quasi-helically symmetric (QHS) configuration is observed because of the reduction of the neoclassical transport. Also the trapped particle orbit is improved in the QHS configuration. However, when the energy of particle increases the orbit of the trapped ion becomes complex due to the finite ripple field and finite orbit effect; e.g. the ion orbit of 10keV shows a stochastic trajectory. On the other hand ICRF heating is considered as an additional heating method in HSX to heat both of electrons and ions. Thus the detail analysis of the ICRF heating efficiency is necessary to set up the ICRF heating system.

We study the ICRF minority heating in the QHS configuration of HSX applying GNET code[1]. The efficiency is evaluated assuming the heating power of 100kW. We consider the ICRF sustained plasma and the plasma parameters are as follows: the electron and ion temperature: $T_{e0} = T_{i0} = 200\text{eV}$, the plasma density: $n_{e0} = 2 \times 10^{19}\text{m}^{-3}$, and magnetic field strength: $B_0 = 2.0\text{T}$.

First we run the GNET with a relatively large RF wave electric field (about 2.5kV/m) and heating efficiencies are evaluated after a short time changing the resonance magnetic field strength. It is found that the obtained heating efficiency show an optimum when $B_{res}/B_0 \sim 1.02$. We apply the effective confinement region and results are shown in Fig. 1. We can also see an optimum point in B_{res} space in both confinement region cases ($r_{eff}/a = 0.66$ and 0.8).

Next we study the ICRF heating in HSX running the full simulation assuming the optimum B_{res}. Figure 2 shows the evaluated minority ion distribution in the velocity space at the three r/a points; $r/a = 0.1 - 0.25$ (left), $r/a = 0.5$ (center) and $r/a = 0.75$ (right). Large tail formation is observed in the resonance surface region and Up to 40keV energetic ions are obtained. Lost ion distribution shows broad profile in the pitch angle space compared with that of the LHD. This indicates that the loss mechanism is different from that of LHD, where the transition between the trapped and passing particles plays important role.

Radial profiles of the power absorption shows a strong peak near the resonance layer but the energetic ion pressure and the heating deposition show broader profile due to the finite orbit effect. This also indicates the existence of a large radial diffusion due to the finite orbit effect.

As a results we obtain the following heating efficiency, η,; $P \sim 58\text{kW}$ $\eta = 0.47$ and $P \sim 97\text{kW}$, $\eta = 0.34$. Also we found that the neutral density changes the heating efficiency about 10% and more detail simulation should be done to evaluate the heating efficiency correctly.

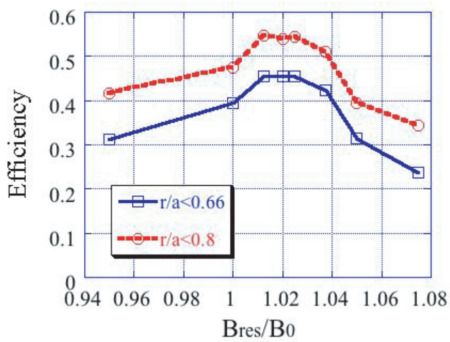


Fig. 1: Heating efficiencies assuming the effective confinement minor radius in the HSX.

[1] S. Murakami, et al., Nucl. Fusion **46**, S425 (2006).

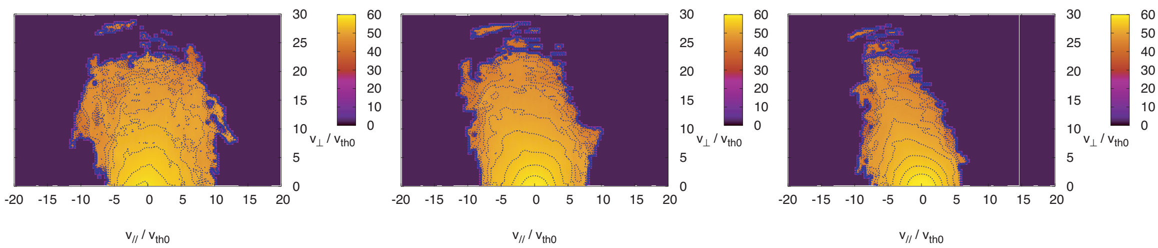


Fig. 2: Minority ion distribution in the velocity space in the HSX at the three minor radius points; $r/a = 0.1 - 0.25$ (left), $r/a = 0.5$ (center) and $r/a = 0.75$ (right).

Simulation study of neoclassical transport in non-axisymmetric plasmas using the δf method

Category : JIFT
Year-Number : 2008-JF1-8
Name: Shinsuke Satake, Weixing Wang*
Affiliation: National Institute for Fusion Science, Princeton Plasma Physics Laboratory*

Neoclassical transport theory describes the irreducible level of particle and heat transport in torus plasma and constitutes the basis of transport analysis in fusion devices. Compared with that in axisymmetric tokamaks, neoclassical transport in non-axisymmetric configuration as LHD in NIFS is more complicated owing to these two effects as follows; the one is the enhancement of radial drift of the particles which are trapped in local magnetic ripples, and the other is the effect of the radial electric field. Different from the tokamak cases in which the neoclassical particle flux is intrinsic ambipolar, the radial drift of ripple-trapped particles is strongly affected by the ExB rotation, and the radial electric field develops spontaneously so that ion radial particle flux balances that of electrons. This ambipolar electric field condition has multiple roots in some cases, depending on the magnetic configuration and profiles of plasma density and temperature. The neoclassical transport level largely changes according to which ambipolar root is realized in plasma.

In order to solve neoclassical transport in non-axisymmetric plasmas with high accuracy, it is required to calculate the guiding-center motion with precise magnetic field description in magnetic coordinates, to introduce a Coulomb collision operator which satisfies its conservation low, to consider the radial electric field profile which satisfies the ambipolar condition, and so on. Satake has developed a simulation code FORTEC-3D[1] which solves neoclassical transport and evolution of radial electric field for non-axisymmetric configuration. To improve the numerical schemes in the code and to promote neoclassical transport analysis using FORTEC-3D in other devices than LHD, Satake visited Dr. Weixing Wang in PPPL, who had developed the original δf method, from Oct. 22 to Dec. 22, 2008.

When Satake applied for the JIFT program, the non-axisymmetric plasma confinement device NCSX was under construction in PPPL. Therefore, one of the main subject was the application of FORTEC-3D code to NCSX magnetic configurations. However, the NSCX project was suspended just before the visit. Then at the beginning of visit, Satake discussed with Dr. Wang about the numerical scheme of the δf method. FORTEC-3D is a global transport code which solves the drift-kinetic equation in the whole plasma confinement region at once. And it includes the higher-order terms of the finite-orbit-width effect, which stems from the radial excursion of guiding-center orbits. However, to compare with conventional local analyses of neoclassical transport or to evaluate the electron neoclassical transport coefficients in which the finite-orbit-width effect is unimportant, it is profitable to make a numerical way of solving the drift-kinetic equation using the δf method in the zero-orbit-width limit. Satake had found the accumulation of numerical error in simulation marker energy when the numerical scheme of zero-orbit-width limit calculation, which Dr. Wang had demonstrated in tokamak cases, was applied to non-axisymmetric configurations. They discussed about how to improve the numerical scheme, and the result of the study was finally presented at the JPS meeting[2] 2009.

While visiting PPPL, Satake had a proposal of applying FORTEC-3D to calculate neoclassical toroidal viscosity (NTV) of NSTX, a spherical tokamak device in PPPL. At that time, ELM control experiments in some tokamaks including NSTX by means of external non-axisymmetric magnetic field perturbation had attracted attention. However, it was concerned that the neoclassical viscosity that arises from the break of symmetry might affect the MHD stability such as resistive wall mode, and a quantitatively reliable method to calculate NTV in weakly-perturbed tokamaks had been required. Then, Satake began discussion and collaboration with Drs. W. Wang, A. Boozer, J.-K. Park and S. Sabbagh, and a new numerical formulation to calculate NTV directly from FORTEC-3D code had developed. This research has continued since then, and preliminary benchmark result was presented at the ISHW 2009 workshop held in PPPL[4]. The collaborative research activity of NTV simulation with PPPL researchers is still going on. Visiting PPPL as a JIFT program was really a good opportunity to start a new collaboration.

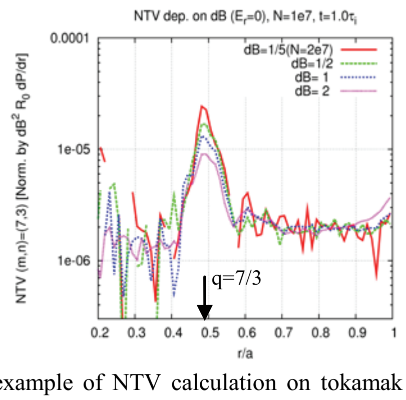


Fig.1 : An example of NTV calculation on tokamak with small perturbation magnetic field. On the q=7/3 surface where the perturbation field resonates with background magnetic field, peaking of NTV is found. And the magnitude of NTV is found to be proportional to the square of the magnitude of field perturbation, δB^2 .

1) S. Satake et al, Plasma Fusion Res. **3**, S1062 (2008).
2) S. Satake et al, oral presentation at the 64th annual meeting of the Physical Society of Japan, Mar. 27th, 2009.
3) W. Zhu et al, Phys. Rev. Lett. **96**, 225002 (2006)
4) S. Satake et al, "Calculation of Neoclassical Toroidal Viscosity in Tokamaks with Broken Toroidal Symmetry", ISHW2009 , PPPL Oct. 13, P02-21.

Reduced Nonlinear Dynamics for Turbulent Transport In Toroidal Confinement Devices

Category: JIFT
Year/Number: 2008-JF1-12
Names: W. Horton (IFS Texas), H. Sugama (NIFS), T.-H. Watanabe (NIFS)

In about 2000, we became interested in new techniques to analyze ion temperature gradient (ITG) driven turbulence. For the infinite chain of linked fluid transport equations, we wanted to find a fluid closure that would reproduce the most important aspects of the full gyrokinetic equations. In the 1990s, we had completed a series of studies of fluid turbulence theory and simulations for the resistive-g mode and the Hasegawa–Wakatani drift wave model. Our fluid simulations showed that nonlinear interactions in the unstable spectrum produced sheared azimuthal ExB flows and an oscillation in the parallel thermal flux. The question was how to find an accurate ITG gyrofluid model.

We wanted a new closure procedure with parallel heat fluxes that would give accurate nonlinear energy conservation laws and correct entropy production functions. Using the unstable Vlasov-Poisson ion temperature gradient (ITG) modes, we searched for closures that reproduced the unstable and stable spectra. This implied preserving the time-reversal symmetry of the collisionless kinetic equation. After studying the closure of Mattor and Parker (1997), we eventually found a closure that preserves time reversibility and whose unstable-stable spectrum agrees fairly well with that from the plasma dispersion function of the exact kinetic equation. The key point is that the new non-dissipative collisionless closure method enabled the very accurate calculations of the parallel thermal flux driven by temperature fluctuations that are required.

Our result [1] led to a series of simulations and derivations of reduced gyrofluid equations [2]. The most recent concerned zonal flows driven by turbulence [3], simulated with the GKV code.

The GKV code of Sugama and Watanabe is now widely used for turbulence simulations. It solves for the fluctuation distribution function directly on high-resolution parallel velocity grids, which allows accurate tracking of the phase and amplitude of higher order parallel velocity moments. Comparison with the Hammett-Perkins closure showed that the GKV solutions reproduce the radial turbulent thermal flux more accurately.

During Horton's three-month visit to NIFS in 2007 as the JIFT Visiting Professor, the GKV code was benchmarked on several large-scale parallel computers, including Ranger at the University of Texas and Blue Gene at ORNL. The code showed good linear scaling with the number of processors.

This joint work is continuing. The new closure models are now being used in the pseudo-spectral simulations with ion-temperature-gradient and electron-temperature-gradient turbulence gyrofluid models.

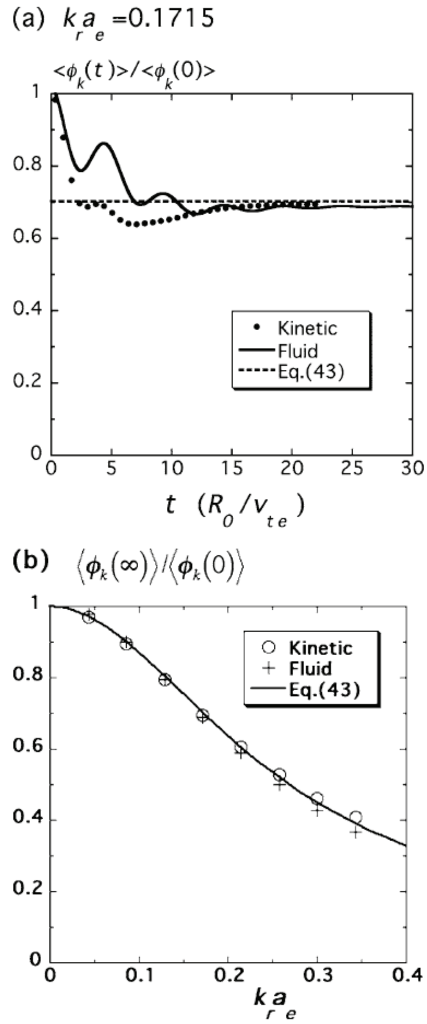


Fig. 1. Time evolution of the zonal flow potential, comparing kinetic and fluid results, as functions of (a) time and (b) wave number. [from Ref. 3]

[1] H. Sugama, T.-H.Watanabe, and W. Horton, "Collisionless kinetic-fluid closure and its application to the three-mode ITG system," Phys. Plasmas **8**, 2617 (2001).
[2] H. Sugama, T.-H.Watanabe, and W. Horton, "Comparison between kinetic and fluid simulations of slab ITG driven turbulence," Phys. Plasmas **10**, 726 (2003).
[3] H. Sugama, T.-H.Watanabe, and W. Horton, "Collisionless kinetic-fluid model of zonal flows in toroidal plasma," Phys. Plasmas **14**, 022502 (2007).

Anisotropic Pressure Diffusion in the HINT Code

Category: JIFT
Year/Number: 2009-JF-9
Names: S. Hudson (PPPL), N. Nakajima (NIFS)

Dr. Hudson from PPPL spent three months at NIFS as the JIFT Visiting Professor (summer 2009). During this time, he performed research in collaboration with Dr. N. Nakajima concerning how to realistically and efficiently compute MHD equilibria in the presence of chaotic magnetic fields.

Analyses of plasma behavior often begin with a description of the ideal magnetohydrodynamic equilibrium, this being the simplest model capable of approximating macroscopic force balance. For perfectly axisymmetric tokamaks this is a comparatively simple task, since a nested, continuous family of flux surfaces exists, i.e. the field is integrable. The ideal equilibrium equation can be reduced to the Grad-Shafranov equation, and equilibria can be found numerically. In contrast, for stellarators and perturbed tokamaks, the magnetic fields are generally non-integrable and a different approach is required.

Stellarators are designed to have good flux-surfaces, but without a continuous symmetry, perfectly integrable fields cannot be achieved. The HINT and HINT2 codes developed at NIFS, and the PIES code developed at PPPL, seek solutions to the ideal force balance equation in stellarator geometry without assuming a nested family of flux surfaces. HINT uses a relaxation algorithm, whereas PIES is based on an iterative scheme with magnetic coordinates. However, neither code adequately treats the fractal structure of pressure in a chaotic field.

A generally chaotic field will be a fractal mix of KAM surfaces, islands, and irregular field lines. Some field lines trace out structures that are infinitely complex, such as the unstable manifold. Interspersed between these irregular field-lines are periodic orbits; arbitrarily small, high-order island chains; and irrational field-lines, which may or may not trace out smooth flux surfaces. Generally, there is no region of space foliated with flux surfaces and magnetic islands and irregular field-lines will emerge at the infinitely many rational surfaces that exist between any pair of KAM surfaces. When the field is chaotic, it is extremely difficult to calculate the ideal MHD equilibrium.

In ideal force balance, the structure of the pressure is tied to the structure of the field. Thus, a continuous, nontrivial pressure has an uncountable infinity of discontinuities in the pressure gradient. The equilibrium solutions are pathological when the fields are chaotic and therefore unsuitable for numerical calculations.

If the pressure and magnetic field are continuous, the only nontrivial solutions have an uncountable infinity of discontinuities in the pressure gradient and current. The problems arise from the arbitrarily small length scales in the structure of the field, and the consequence of ideal force balance that the pressure is constant along the field-lines. A simple method to ameliorate the singularities is to include a small but finite perpendicular diffusion. A self-consistent set of equilibrium equations is then described. Some algorithmic approaches aimed at solving these equations were investigated.

There is nothing radical about approximating an ideal MHD equilibrium by a resistive steady state, but we have come to this conclusion by considering the impact of chaotic fields on MHD equilibria, and requiring that the pressure be continuous. Since the equilibrium solutions are pathological when the field is chaotic, a nearly-ideal, resistive steady state equilibrium is the simplest model capable of computing coherent, self-consistent MHD equilibria with continuous (and non-fractal) pressure. Work towards implementing the anisotropic pressure diffusion into the HINT code has begun. Our approach, which is both computationally efficient and consistent with the structure of the HINT code, is to use locally field aligned coordinates that separate the large parallel transport from the small perpendicular transport, and thus reducs so-called “numerical diffusion.” We hope to present computational results in the near future.

[1] S. R. Hudson and N. Nakajima, “Pressure, chaotic magnetic fields, and magnetohydro-dynamic equilibria,” Phys. Plasmas **17**, 052511 (2009).

CHAPTER 5　JUPITER-II・TITAN

5.1　Progress in US-Japan collaboration research

The US-Japan collaboration was started in FY 1981, and the first phase was the RTNS-II (Rotating Target Neutron Source-II) project, followed by the second phase known as the FFTF/MOTA (Fast Flux Test Facility/Materials Open Test Assembly) project from FY 1987. In the RTNS-II program, fusion neutron irradiation experiments using the D-T neutron source of the U.S.A. were carried out. Though the maximum irradiation dose was about 0.1dpa, Japanese advanced technologies on microstructure observation by electron microscopy and material strength evaluation by testing miniaturized specimens were utilized to obtain wide and highly precise data on the generation and accumulation processes of defects induced by the D-T neutrons as well as on the microstructure-strength correlation. The results from these experiments are still very valuable even now.

The main theme in the FFTF/MOTA project was to explore the effects of high-dose neutron irradiation up to 100dpa, which was the expected life time for fusion reactor materials. A more fundamental approach, compared to conventional irradiation tests, was promoted and a thorough understanding of the entire microstructural evolution process under irradiation covering low dose to high dose irradiation regimes was obtained.

The irradiation experiments in the above projects were performed under relatively simple and steady irradiation conditions. The JUPITER project focused on dynamic irradiation effects detectable only during irradiation and effects of variable and combined irradiation conditions. This included radiation-induced conductivity of ceramic insulators, varying temperature effects, and combined transmutation effects. These experiments extracted valuable information on materials response in fusion relevant environments.

5.2　Objectives, research subjects and facilities

5.2.1　JUPITER-II project　(FY2001-2006)

The projects before JUPITER-II focused on materials performance under irradiation and materials development based on the knowledge gained from the irradiation experiments. In fusion blankets, materials will be used as joined or coated materials (materials systems). In addition, the use of materials in blankets involves new issues associated with the interaction with breeders and coolants. Thus basic technological studies and their integration are essential. The issues are better specified with the progress in the blanket design.

JUPITER-II project aimed at (1) developing key technology for fabrication and operation of “self-cooled liquid blankets” and “high temperature gas-cooled blankets” which are combinations of low activation structural materials and breeder/coolants which are capable of high tritium breeding ratio and high coolant exit temperature, and (2) evaluation of the irradiation performance of the materials system which is a key feasibility issue for blanket development. Overall evaluation of blankets and materials systems based on modeling, and orientation of the development towards the commercialization of the system were also carried out in this project.

5.2.1.1 Research subject and task structure of JUPITER-II

Table 5-1 summarizes research subjects and task structure of JUPITER-II project.

5.2.1.2 US facilities used

(a) **STAR (Safety and Tritium Applied Research) [INL]**

STAR was established at the Idaho National Laboratory in 2001, having an allowable tritium inventory of 16,000 Ci. The site includes the Tritium Plasma Experiment (TPE) and various facilities for testing tritium behavior in blanket conditions. Unique features of the facility include use of large amounts of tritium, Be, and neutron-irradiated materials.

(b) **HFIR (High Flux Isotope Reactor) [ORNL]**

HFIR is a 100MW mixed spectrum research reactor, currently operated at 85MW, that is currently planned to remain in operation until 2035. Although the principal purpose of the reactor is to produce radioisotopes, it is actively used for materials irradiation and neutron scattering experiments utilizing the world's highest fast and thermal neutron fluxes. The HFIR is a unique irradiation facility with the potential for high environmental and temperature control during irradiation, and very low to high flux irradiation. Parts of the HFIR-irradiated specimens were shipped to Oarai Center of Tohoku University for Post Irradiation Examinations.

(c) **MTOR (Magneto-Thermofluid Omnibus Research Facility) [UCLA]**

The facility includes a magnet of homogeneous field to 2T in an area 15cm wide and 1m long, which can be used for testing the fluid dynamics of liquid metals and MHD flow for high Prandtl number stimulant fluids using electrolytes.

Table 5-1 Task structure of JUPITER-II project

Task		Subtask	Activity
Task1: Self-Cooled Liquid Blanket	1-1: FLiBe Cooled	1-1-A: FLibe Handling /Tritium Chemistry/Safety	Purification, transport, REDOX control and tritium behavior
		1-1-B: FLibe Termofluid Flow Simulation	Thermofluid of Flibe simulant
	1-2: Li Cooled with V Alloy Structure	1-2-A: Coatings for MHD Reduction	MHD insulator coating for Li/V blanket
		1-2-B: V Alloy Capsule Irradiation	Irradiation of vanadium alloys in Li capsule
Task2: High-Temperature Gas-Cooled Blanket	2-1: SiC Fundamental Issues, Fabrication, and Material Supply	Task2: High-Temperature Gas-Cooled Blanket	Fabrication technology of SiC/SiC
	2-2: SiC System Themomechanics		Thermomechanics of He cooled blanket
	2-3: SiC Capsule Irradiation		High temperature irradiation of SiC/SiC
Task3: Blanket System Modeling	3-1: Design-based Integration Modeling	Task3: Blanket System Modeling	Integration model for advanced blankets
	3-2: Material Systems Modeling		Multi-scale materials modeling

5.2.2 TITAN project (FY2007-2012)

Blankets are component systems whose principal functions are extraction of heat and tritium. Thus it is crucial to clarify the potentiality for controlling heat and tritium flow throughout the first wall, blanket and out-of-vessel recovery systems. The TITAN project continues the

Table 5-2 Task structure of TITAN project

Task	Subtask	Facility	Goal
Task 1 Transport phenomena	1-1 Tritium and mass transfer in first wall	TPE PISCES	Mass transfer and tritium inventory in first wall, and tritium transfer between first wall and blanket
	1-2 Tritium behavior in blanket systems	STAR	Tritium transfer in blanket elements
	1-3 Flow control and thermofluid modeling	MTOR	Thermofluid in high magnetic field and comparison between experiments and modeling
Task 2 Irradiation synergism	2-1 Irradiation-tritium synergism	HFIR STAR	Neutron irradiation effects on tritium transfer in first wall and structural materials
	2-2 Joining and coating integrity	HFIR	Radiation response of joint and coated materials, and synergistic tritium and helium effects
	2-3 Dynamic deformation	HFIR	Deformation of structural materials during irradiation, and effects of tritium and helium production
Common Task System integration modeling	MFE/IFE system integration modeling		Integrate modeling of mass and heat transfer in first wall, blanket and recovery system, and contribution to reactor system design

JUPITER-II activity but extends its scope including the first wall and the recovery systems with the title of "Tritium and thermofluid control for magnetic and inertial confinement systems". The objective of the program is to clarify the mechanisms of tritium and heat transfer throughout the first-wall, the blanket and the heat/tritium recovery systems under specific conditions to fusion such as irradiation, high heat flux, circulation and high magnetic fields. Based on integrated models, the breeding, transfer, inventory of tritium and heat extraction properties will be evaluated for some representative liquid breeder blankets and the necessary database will be obtained for focused research in the future.

5.2.2.1 Task structure and research subjects of TITAN project

The JUPITER-II project confined its scope to blankets and enhancement of key technologies. The TITAN project seeks to further enhance key technologies and to conduct system integration for tritium and heat transfer in the first-wall, blanket and recovery systems. Table 5-2 summarizes task structure of TITAN project.

5.2.2.2 US facilities used

The following facility is being used for the TITAN project in addition to the facilities used during the JUPITER-II project.

(d) **PISCES (Plasma Interactive Surface Component Experimental Station) [UCSD]**

A linear plasma simulator which can produce high-density plasmas with H, D, He and Be. Pulsed lasers are equipped for synergistic plasma exposure and pulse heating studies. Plasma diagnostics and surface characterization systems are furnished.

Table5-3　Administration structure of JUPITER-II project

Steering Committee

Japan	US
Representative K. Abe (Tohoku U.)	Representative S. Berk/G. Nardella (DOE)
Coordinator A. Kohyama (Kyoto U.) S. Tanaka (U. Tokyo)	Coordinator S.J. Zinkle (ORNL) D.K. Sze (UCSD)

Task			Japan TC	Japan Deputy	US TC	US Deputy
Task1: Self-Cooled Liquid Blanket	1-1: FLiBe Cooled	1-1-A: FLibe Handling /Tritium Chemistry/Safety	T. Terai	K. Okuno/ M. Nishikawa	D.A. Petti	R.A. Anderl
		1-1-B: FLibe Termofluid Flow Simulation	S. Toda/ T. Kunugi	T. Kunugi/ T.Yokomine	M.A. Abdou	N. Morley
	1-2: Li Cooled with V Alloy Structure	1-2-A: Coatings for MHD Reduction	T. Muroga	T. Muroga	R.J. Kurtz	B.A. Pint
		1-2-B: V Alloy Capsule Irradiation		H. Matsui		G.R. Odette
Task2: High-Temperature Gas-Cooled Blanket		2-1: SiC Fundamental Issues, Fabrication, and Material Supply	A. Hasegawa	T. Hinoki	R.H. Jones/ L.L. Snead	Y.Katoh
		2-2: SiC System Themomechanics		A. Shimizu		A. Ying
		2-3: SiC Capsule Irradiation		A. Hasegawa		L.L. Snead
Task3: Blanket System Modeling		3-1: Design-based Integration Modeling	A. Sagara	H. Hashizume	N.M. Ghoniem	D. Sze
		3-2: Material Systems Modeling		N. Sekimura		R.E. Stoller

Table 5-4　Administration structure of TITAN project

Steering Committee

Japan	US
Representative K. Okuno (Shizuoka U.)	Representative G. Nardella (DOE)
Coordinator T. Muroga (NIFS)	Coordinator D.K. Sze (UCSD)

Task	Subtask	TC (JP)	STC/Deputy (JP)	TC (US)	STC/Deputy (US)
Task 1 Transport phenomena	1-1 Tritium and mass transfer in first wall	T. Terai (U.Tokyo)	Y. Ueda (Osaka U.)/ N. Ohno (Nagoya U.) K. Tokunaga (Kyushu U.)	D. Sze (UCSD)	R. Doerner (UCSD)
	1-2 Tritium behavior in blanket systems		T. Terai (U. Tokyo)/ S. Fukada (Kyushu U.) S. Konishi (Kyoto U.)		P. Sharpe (INL)/ P. Calderoni(INL)
	1-3 Flow control and thermofluid modeling		T. Kunugi (Kyoto U.)/ T. Yokomine (kyushu U.)		N. Morley (UCLA)/ K. Messadek (UCLA)
Task 2 Irradiation synergism	2-1 Irradiation-tritium synergism	A.Kimura (Kyoto U.)	Y. Hatano (Toyama U.)/ Y. Oya (Shizuoka U.)	R. Kurtz (PNNL)	M. Sokolov (ORNL)/ Y. Katoh (ORNL) P. Calderoni (INL)
	2-2 Joining and coating integrity		A. Kimura (Kyoto U.)/N. Hashimoto (Hokkaido U.)		T. Yamamoto (UCSB)/ M. Sokolov (ORNL)
	2-3 Dynamic deformation		A.Hasegawa (Tohoku U.)/ T. Hinoki (kyoto U.)		Y. Katoh (ORNL)
Common Task System integration modeling	MFE/IFE system integration modeling	A.Sagara (NIFS)	A. Sagara (NIFS)/ H. Hashizume (Tohoku U) T. Norimatsu (Osaka U.)	R. Nygren (SNL)	R. Nygren (SNL)
Laboratory Liaisons	ORNL : INL : IMR-Oarai (Tohoku) :		R. Stoller (ORNL) P. Sharpe (INL) T. Shikama (Tohoku U.)		
IFE Liaisons		K. Tanaka (Osaka U.)	Kodama(Osaka U.) Yoneda(UTC)	M. Tillack (UCSD)	

5.3 Administration

The administative structure of the JUPITER-II and TITAN projects are summarized in Tables 5-3 and 5-4, respectively. A Steering Committee Meeting is held annually for summarizing annual achievements and planning activities for the following year.

References

[JUPITER-II project]

K. Abe, A. Kohyama, S. Tanaka, C. Namba, T. Terai, T. Kunugi, T. Muroga, A. Hasegawa, A. Sagara, S. Berk, S.J. Zinkle, D.K. Sze, D.A. Petti, M.A. Abdou, N.B. Morley, R.J. Kurtz, L.L. Snead, N.M. Ghoniem, "Development of advanced blanket performance under irradiation and system integration through JUPITER-II project", Fusion Engineering and Design, 83 (2008) 842-849

[TITAN project]

T. Muroga, D.K. Sze, K. Okuno, T. Terai, A. Kimura, R. Kurtz, A. Sagara, R. Nygren, Y. Ueda, R. Doerner, P. Sharpe, T. Kunugi, N. Morley, Y. Hatano, M. Sokolov, T. Yamamoto, A. Hasegawa, Y. Katoh, N. Ohno, K. Tokunaga, S. Konishi, S. Fukada, P. Calderoni, T. Yokomine, K. Messadek, Y. Oya, N. Hashimoto, T. Hinoki, H. Hashizume, T. Norimatsu, T. Shikama, R. Stoller, K.A. Tanaka, M. Tillack, "Midterm Summary of Japan-US Fusion Cooperation Program TITAN", 19th Topical Meeting on the Technology of Fusion Energy, Nov. 7-11, 2010, Las Vegas, submitted.

5.4 Accomplishments and Highlights

5.4.1 JUPITER-II

About 60 scientists in15 Universities from Japan and about 50 scientists in10 institutes from the US, including students, joined JUPITER-II project. Participants are listed in the following table.

Table 5-5 List of participants to JUPITER-II project

Task		Subtask	Japanese Participants	US Participants
Task1: Self-Cooled Liquid Blanket	1-1: FLiBe Cooled	1-1-A: FLibe Handling /Tritium Chemistry/Safety	T. Terai, S. Tanaka, A. Suzuki, H. Nishimura (U. Tokyo), M. Nishikawa, S. Fukada, K. Katayama (Kyushu U.), K. Okuno, Y. Oya (Shizuoka U.), Y. Hatano, M. Hara (Toyama U.), A. Sagara (NIFS)	D. A. Petti, G.R. Smolik, Michael F. Simpson, John P. Sharpe, R.A. Anderl (INL), Dai-Kai Sze (UCSD)
		1-1-B: FLibe Termofluid Flow Simulation	T. Kunugi, Z. Kawara (Kyoto U.), T. Yokomine, S. Ebara, H. Nakaharai (Kyushu U.), S. Satake (Tokyo U. of Science), S. Toda, H. Hashizume, K. Yuki (Tohoku U.)	M. A. Abdou, N. B. Morley, J. Takeuchi, R. Miraghaie, S. Smolentsev, H. Huang, Y. Tajima, , T. Sketchley, J. Burris (UCLA)
	1-2: Li Cooled with V Alloy Structure	1-2-A: Coatings for MHD Reduction	T. Muroga, T. Nagasaka, T. Tanaka (NIFS), T. Terai, A. Suzuki, Z. Yao, A. Sawada(U. Tokyo), K. Abe, M. Satou, M. Fujiwara (Tohoku U.)	B.A. Pint, M. Li, P. F. Tortorelli (ORNL), A. Jankowski (LLNL)
		1-2-B: V Alloy Capsule Irradiation	T. Muroga, T. Nagasaka (NIFS), K. Fukumoto (Fukui U.), H. Matsui, K. Abe, M. Satou, H. Kurishita (Tohoku U.), H. Watanabe, N. Yoshida, (Kyushu U.) S. Ohnuki (Hokkaido U.)	R.J. Kurtz, D.S. Gelles, M.B. Toloczko (PNNL) D.T. Hoelzer, M. Li, S.J. Zinkle (ORNL), G..R. Odette, T. Yamamoto (UCSB)
Task2: High-Temperature Gas-Cooled Blanket		2-1: SiC Fundamental Issues, Fabrication, and Material Supply	T. Hinoki, A. Kohyama, T. Nozawa, S. Kondo, H. Kishimoto、K. Shimoda (Kyoto U.) A. Hasegawa, (Tohoku University), T. Shibayama (Hokkaido U.)	Y.Katoh, L.L.Snead, B.A. Pint, S.J. Zinkle, E. Lara-Curzio, H-T. Lin, R.A. Lowden, G.C. McLaughlin (ORNL) C.H. Henager, Jr., G.E. Youngblood, R.H. Jones, C.A. Lewinsohn (PNNL)
		2-2: SiC System Themomechanics	A. Shimizu and T. Yokomine (Kyushu Univ.), A. Hasegawa (Tohoku Univ.), A. Kohyama, S. Konishi (Kyoto University)	A. Ying, M. Abdou, A. Abou-Sena, J. An and T. Sketchley (UCLA), Y. Katoh (ORNL)
		2-3: SiC Capsule Irradiation	A.Hasegawa, S.Nogami (Tohoku U.), T.Hinoki, A.Kohyama, T. Nozawa, S.Kondou, K. Ozawa (Kyoto U.) , T.Shibayama (Hokkaido U.)	Y.Katoh, L.L.Snead, B.A. Pint, S.J. Zinkle, J.L. McDuffee (ORNL), C.H. Henager, Jr., G.E. Youngblood (PNNL), N.B. Morley (UCLA)
Task3: Blanket System Modeling		3-1: Design-based Integration Modeling	A. Sagara, T. Tanaka (NIFS), S. Fukada, M. Nishikawa (Kyushu U.), S. Tanaka, T. Terai, A. Suzuki (U. Tokyo), S. Toda, H. Hashizume, K. Yuki, S. Chiba (Tohoku U.), S. Satake (Tokyo U of Science), T. Kunugi (Kyoto U.)	N.M. Ghoniem, S. Sharafat, M.Z. Youssef (UCLA), Da-Kai Sze (UCSD)
		3-2: Material Systems Modeling	N. Sekimura, T. Okita, H. Abe (U.Tokyo), K. Morishita, Y. Watanabe (Kyoto U.), M. Satou, N. Nita, H. Matsui (Tohoku University)	B.D. Wirth (UC Berkeley), T. Diaz de la Rubia, W.G. Wolfer (LLNL), N.M. Ghoniem, S. Sharafat (UCLA), H.L. Heinisch, F. Gao, R.J. Kurtz (PNNL), G.R. Odette (UCSB), R.E. Stoller (ORNL)

Task 1-1-A：Flibe Handling/Tritium Chemistry

Category: JUPITER-II
Task: 1-1-A
Name: T. Terai / D. Petti
Affiliation: U. Tokyo / INEEL

Based on the key issues associated with the use of Flibe (LiF and BeF_2) as a coolant in a fusion blanket, the objectives of our work are:

1) to develop the capability to fabricate and purify Flibe at the liter scale for use in the experiments;
2) to characterize tritium and deuterium behavior (e.g., solubility and diffusivity) in REDOX(reduction and oxidation)-controlled and non-controlled Flibe;
3) to characterize the magnitude and physio-chemical forms of material mobilized during an accidental spill of Flibe and to develop safe handling practices;
4) to develop a REDOX agent to control TF activities in Flibe in a fusion blanket;
5) to demonstrate the effectiveness of the redox agent in terms of structural material compatibility for fusion materials of interest using a simple dip specimens in small scale pot type experiments.

(a) Flibe purification

The Flibe in the JUPITER-II was prepared from reagent grade chemicals. Both the Be_2F and LiF were listed as 99.9% pure. Measurements of Be and Li in the final product ranged from 8.3 to 8.5 and 13.06 to 13.2 wt%, respectively. Although these are lower than the theoretical values of 9.04 and 14.14 wt%, Li to Be mole ratios of 2.01–2.06 are close to the targeted composition.

(b) Flibe mobilization experiment

A key safety issue associated with Flibe is the mobilization of vapors and aerosols from accidental introduction of air, moist air, or steam to the molten salt. Mobilization tests were performed with argon, air and moist air using a classical transpiration apparatus designed for vapor pressure determinations. Total measured pressures for BeF_2 and $LiBeF_3$ are two to three times lower than predicted values. The increasing contribution from the Li species in the INEEL data is apparent at 700 and 800C. Mass comparisons using probe interior ICP-AES measurements and sample loss for the argon test series in the nickel crucibles showed that about 22% of the material was deposited in the probe. Mass flux calculation obtained by adjusting ICP-AES measurements for the 22% factor generally agreed within a factor of two of the mass based determinations for individual tests.

(c) REDOX control and corrosion

A series of experiments was performed in which HF was bubbled through Flibe with varying concentrations of dissolved Be to investigate the viability of using Be as a redox agent in a molten Flibe (2LiF–BeF2) blanket. A mixture of H_2, He and HF gases was introduced into the test reactor, while the effluent passed through a quadrupole mass spectrometer (QMS) followed by an autotitrator. The reactor, shown in more detail in Fig. 1, was designed to provide a controlled reaction between Be and HF in the molten salt phase. Each experiment started with the HF–H2–He feed gas bubbled into the salt with the Be specimen pulled out of the salt. Once the HF concentration in the effluent stabilized close to the expected level, the Be specimen was inserted into the salt. After 10–60 min, the Be was lifted out of the salt and into its protective housing while HF in the effluent was continually monitored for times ranging from several hours up to a few days. Once the HF concentration in the effluent had again stabilized, the next experiment was run by re-inserting the Be into the salt for a different duration. The effluent HF concentration as measured by the QMS dropped rapidly usually within a matter of minutes after the Be was initially inserted into the salt. The slow increase of the effluent HF concentration after the Be was removed is believed to be the result of continued reaction of Be dissolved in the salt with HF added by ongoing gas injection. Corrosion tests were also performed with and without REDOX control for samples of the advanced ferritic steel JLF-1. The dissolution rates of Fe and Cr were suppressed by dipping Be into Flibe. However, their rates were increased when the Be rod was withdrawn from Flibe. Exposures of up to 500 hours in the non-flowing molten salt indicate a corrosion rate of 0.1μm/hr, with a Cr-rich oxide layer forming at the sample interface. Corrosion is effectively halted during periods of REDOX control using Be.

(d) Deuterium/tritium behavior

Deuterium permeation experiments were conducted in a cylindrically symmetric, dual probe permeation pot setup. Several deuterium permeation experiments were made with the system at temperatures of 600 and 650C and with a deuterium pressure of around 9.0×10^4 Pa. TMAP-4 simulation calculations were used to evaluate the overall deuterium permeation rates in the Flibe/Ni/D2 system. These analyses showed that diffusion in Flibe was rate-determining for our experimental conditions. Diffusivity of T_2 in Flibe which redox condition is sufficiently controlled was determined. The activation energy of T_2 in the redox-controlled Flibe was smaller than that of D_2 in the non-redoxcontrolled Flibe.

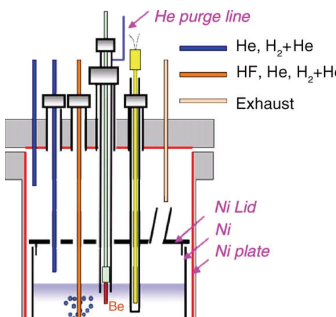


Fig. 1 Reactor for measuring redox

Task 1-1-B：FLibe Termofluid Flow Simulation

Category: JUPITER-II
Task: 1-1-B
Name: T. Kunugi / M. A. Abdou
Affiliation: Kyoto U. / UCLA

A molten salt coolant, Flibe, has attracted attention because high temperature stability and low magneto-hydro-dynamics (MHD) pressure drop are special concerns. However, there are some issues making Flibe-based blanket design challenging. The main issues include low thermal conductivity of Flibe, high kinematic viscosity and to need an additional neutron multiplier because of the limitation of the tritium breeding capability of Flibe, and the requirement of the structural material with temperature range over 650C. The high viscosity and low thermal conductivity put Flibe in the class of high Prandtl number fluids. In order to obtain sufficiently large heat transfer using high Prandtl number fluid coolant, high turbulence is required under a high magnetic field. Thus, it is important to investigate the effect of magnetic fields on the flow and heat transfer characteristics of the high Prandtl number fluids.

A pipe flow experimental facility called “FLiHy” (FLibe Hydrodynamics) was constructed at UCLA as shown in Fig. 1. The experimental facility consisted of a pipe flow loop with a transparent visualization section by using a Particle Image Velocimetry (PIV) system. Pure water and 30% aqueous solution of potassium hydroxide (KOH hereafter) were used as a working fluid for Non-MHD flow and MHD flow, respectively. The experimental approaches include flow and heat transfer measurements using a Flibe simulant fluid along with a direct numerical simulation (DNS).

The flow facility utilizing water and low electrically conducting fluid as a Flibe simulant was constructed, and turbulent flow field measurements using PIV and heat transfer measurements were carried out without magnetic field using water as a working fluid to establish the experimental techniques. The performance of this FLiHy facility for the non-MHD flows in pipe was verified with high accuracy compared with the existing experimental results and the DNS data.

As for MHD flow experiments, a magnet used for the current experiments produces maximum 2.0 Tesla magnetic fields in a narrow gap of the iron core at 3000 A of applied electric current. The pipe flow test section was placed in the gap which was 1.4 m in the streamwise direction, 25 cm in height, and 15 cm in width. The B field has uniform distribution within 5% variation for 1.0 m in the streamwise direction. The mean velocity measurements were performed for five different Hartmann numbers: Ha = 0, 5, 10, 15 and 20 (based on pipe radius). The mean velocity profiles show that it becomes flatter as the Hartmann number increases in the core region of the flow, and that the near-wall velocity gradient increases with increasing of the Hartmann number: this shows the typical characteristics of the Hartmann flow. The streamwise-velocity fluctuation distribution in the radial direction for Re=5300 showed that the intensity of the velocity fluctuation decreases with increasing of the Hartmann number. Thus, the application of the magnetic filed leads the turbulent flow to the laminar flow: this phenomenon usually calls a “Laminarization due to the Lorentz force.”

As for the heat transfer experiments, a part of the test section of FLiHy loop was heated uniformly by heating tape under the constant magnetic field up to 2.0 Tesla. Forty T-type thermocouples with a diameter of 0.75 mm were fixed with high thermal conductivity grease (15 W/mK) in the holes of 1mm diameter at five axial stations and eight angles from the horizontal magnetic field. The depths of holes and the tube wall thickness were 4 mm and 5 mm respectively, i.e., the length from the inner tube surface to measuring point was 1mm. Temperature of KOH was monitored at both the inlet and the outlet of test section using thermocouples. The bulk mixing temperature of arbitrary cross section was estimated by the linear interpolation from the inlet and the outlet temperature. The radial temperature distribution of the fluid flow in the pipe was measured by means of thermocouples tower (TC tower) which was consisted of the Inconel sheathed K-type thermocouples with a diameter of 0.13mm arranged from the inner wall surface to the centre of the pipe. The 63% response time of this thermocouple was 2 ms. The angle of TC tower and magnetic field was set to 0 degree and 90 degrees. The Reynolds number based on bulk velocity and pipe diameter was set to 5000 and 20000 for Ha=0, 5, 10 and 15, and Pr=6 and 10. A non-dimensional mean temperature distribution from the wall in case of Re=9000 indicated that the temperature inside the pipe increases in case of MHD flows, i.e., this is another evidence of the laminarization of turbulent flow under the magnetic fields. Influence of the transverse magnetic field on the heat transfer is also to suppress.

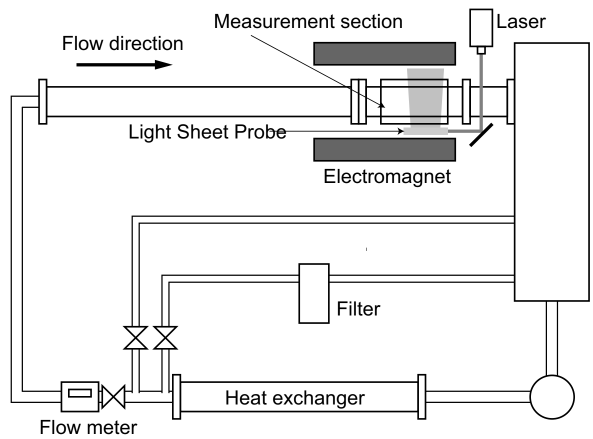


Fig. 1 Schematic drawing of FLiHy facility

Task 1-2 : Lithium Cooled with V Alloy Structure

Category: JUPITER-II
Task: 1-2
Name: T. Muroga / R.J. Kurtz
Affiliation: NIFS / PNNL

(a) Task 1-2A : MHD coating for V/Li systems

The objective of this task is to develop coatings to reduce the pressure drop associated with the magneto-hydrodynamic (MHD) effect that were compatible with Li at ~700°C. A strategy was laid out to evaluate bulk ceramics in static Li compatibility tests followed by development of coatings and evaluations in static Li and in flowing Li with a temperature gradient. Also carried out in this task were preliminary evaluation of irradiation effects of the coating and fundamental investigation on the interface structure and strength and mass-transfer in V-alloy substrate/coating/Li system.

Based on the static immersion tests of candidate bulk ceramics, the mass losses shown after 1000h exposures in Li reflect the degree of dissolution. The dissolution of CaO was observed. Calculations showed that the equilibrium solubility of Ca in Li increased dramatically with temperature, which was consistent with the high dissolution rates observed experimentally. Thus, the task focused efforts on Y_2O_3 and Er_2O_3. Feasibility of the coating with Y_2O_3 and Er_2O_3 on V-4Cr-4Ti was demonstrated by EB-PVD, Arc Source Plasma Deposition and RF sputtering. Especially, Er_2O_3 fabricated with Arc Source Plasma Deposition showed good corrosion resistance. By deposition on a substrate at higher temperature, high crystalline Er_2O_3 coating was produced, which were shown to be stable in Li to 1000hr at 700°C. Coating development focused on Y_2O_3 and Er_2O_3 and then on these coatings with a vanadium overlayer. While mass loss is one measure of performance, the principal figure of merit is resistivity. Therefore, the resistivity of bulk materials and coatings also was measured. For the coatings, an in-situ test was developed to measure the resistivity of the coating in contact with Li. These tests, along with static Li exposures, revealed that a single-layer oxide coating was not performing well and that multi-layer coatings as shown in Fig. 1 showed superior performance.

(b) Task 1-2B : Vanadium Alloy Capsule Irradiation

In this task, irradiations of vanadium alloys and MHD coating candidates in Li-filled capsules were carried out in HFIR for the purpose of studying the irradiation performance of structural components of V/Li blankets. The experimental objectives are to a) investigate the effect of trace elements C, O, and N and minor alloying elements Y, Al, Si on the properties of vanadium alloys irradiated at 425 and 600°C, b) study general aspects of deformation, fracture, and irradiation creep at irradiation temperatures of 425 and 600°C, c) examine the irradiation performance of weld joints of vanadium alloys mostly at 425°C, d) explore the fundamental effects of neutron irradiation on bulk ceramics relevant to MHD insulator coatings associated with Subtask 1-2-A, and e) perform a limited investigation of helium effects on mechanical properties of vanadium alloys using B-doping simulation techniques. Also carried out were out-of pile thermal and environmental control tests.

To examine the environmental effect on irradiation creep, pressurized creep tubes were enclosed in Li-filled capsules and irradiated in HFIR to 3.7 dpa at 425 and 600C. The results were compared to similar specimens enclosed in Na-filled capsules irradiated in JOYO. It was found that the creep strain rate exhibited a linear relationship with the effective stress up to 150MPa at 425C as shown in Fig. 2. At 600C the creep strain was much larger than that at 425C. The activation energy of irradiation creep was estimated to be 46kJ/mol·K. No significant difference in irradiation creep behavior between liquid sodium and liquid lithium environments was observed.

To understand the effect of stress state on the propensity for localized deformation in vanadium alloys, compression specimens, fabricated from Heat 832665 and NIFS-1 heats of V-4Cr-4Ti, have been tested before and after irradiation in the High Flux Isotope Reactor at 425°C and 600°C to ~3.7 dpa. Irradiation at 425C to ~3.7 dpa more than doubles the compressive yield strength of both alloys at test temperatures of 25°C and 425°C. The increase in yield strength is due to production of unshearable defect clusters and precipitates.

The determination of ~1300ºC as the solvus temperature for Ti(CON) precipitates in V-4Cr-4Ti resulted in the establishment of a thermal-mechanical treatment (TMT) that redistributes the Ti solute atoms and O, N, and C interstitial atoms from an inhomogeneous distribution of a low number density of coarse globular-shaped Ti(CON) precipitates to a more homogeneous distribution of a high number density of nano-size plate-shaped Ti(CON) precipitates. The modified TMT that produces the high number density of plate-shaped Ti(CON) precipitates and cold-work induced dislocations also improves the high temperature strength properties of V-4Cr-4Ti.

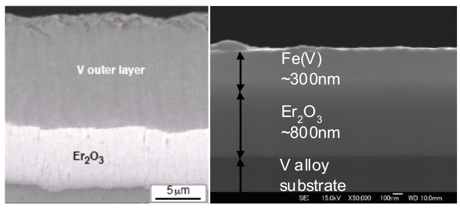


Fig. 1 Double layer of Er_2O_3/V and Er_2O_3/Fe on V alloy

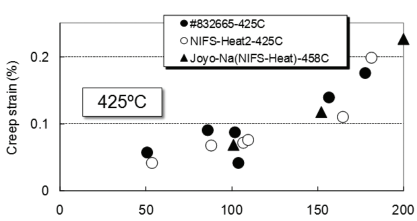


Fig. 2 Creep strain vs. applied stress for US832665 and NIFS-Heat 2 in HFIR Li capsule and Joyo Na-capsule

Task 2：High-Temperature Gas-Cooled Blanket

Category: JUPITER-II
Task: 2
Name: A. Hasegawa / R. H. Jones
Affiliation: Tohoku U. / PNNL

Materials design and fabrication, fundamental properties evaluation, and micromechanical constitutive modeling of materials behavior were studied in Subtask 2-1. In aid of other subtasks, design, fabrication, and supply of adequate SiC/SiC composites were also performed in Subtask 2-1. Thermo mechanics, compatibility and heat transfer performance of the model gas blanket systems, comprising SiC/SiC structure and ceramic breeder pebbles were studied in Subtask 2-2. Based on the material development and the thermo-mechanical analysis, radiation behavior of the advanced SiC/SiC composites and elements of solid breeding blanket systems in high temperature environment were studies in Subtask 2-3.

(a) Subtask 2-1: SiC/SiC Fundamentals and Material Processing

Extensive R&D efforts for development and characterization of advanced SiC/SiC composites for fusion have been successfully carried out in Task 2-1. The FCVI process using high purity SiC fibers was optimized and density, mechanical properties and uniformity were improved significantly. Figure 1 shows multilayer fiber/matrix interphase of reduced C and SiC and fracture surface of the composites. Complicated fracture at the fiber/matrix interphase increased ultimate tensile strength. Advanced small specimen test technologies and procedures for mechanical properties of SiC/SiC were developed. Joining and hermetic sealing using of NITE SiC/SiC and CVI / NITE hybrid process has been explored. The robust joining technique using NITE joint was successfully developed and evaluated. The optimized composite samples were produced and supplied to irradiation experiments. Refractory coating technique for SiC and SiC/SiC composites was also developed by infrared transient liquid phase processing. The tungsten armored silicon carbide samples proved uniform, strong, and capable of withstanding thermal fatigue testing. Guidance was provided for selection of appropriate materials for the pebble-bed thermo-mechanics experiments.

Anisotropy of SiC/SiC composites was characterized by transthickness tensile test, diametral compression test and shear test using double-notched specimens in addition to basic tensile test. The diametral compression experiment for SiC/SiC composites was newly developed and size effect was also evaluated. Progress has been achieved in the areas of fracture toughness evaluation and interfacial shear properties characterization for advanced SiC/SiC composites, and chemical compatibility of SiC in dual-cooled blankets. The fracture behavior of advanced SiC fiber composites with chemically vapor-infiltrated (CVI) and nano-infiltration and transient eutectic-phase (NITE) SiC matrices were successfully evaluated by bend testing of single edge notched beam (SENB) specimens. Based on that, J-integral analysis of SENB fracture was selected as a standard test method for post-irradiation examination of 18J specimens.

(b) Subtask 2-2: SiC System Thermomechanics

The task 2-2 has broadened the understanding of pebble bed material system thermomechanics and its impact on the use of SiC/SiC structure in a helium-cooled ceramic breeder blanket concept. The interface conductance was found not to be a fixed value but varies according to pebble bed thermomechanical state and design associated mechanical boundary conditions. The thermal stress induced by the differential thermal expansion between the SiC structural clad and the ceramic breeder pebble bed may crack the pebbles and cause the clad to be separated away from the pebble bed. This can form a gap at the interface and increase the breeder temperature even more. This makes a design that based on the ARIES-I type concept with He coolant pass through coolant channel, more challenging. The design based on the DREAM concept, with He coolant pass in between pebble bed, reduces the above concern, where heat generated inside the breeder bed is removed by the forced convection (rather than conduction as in the ARIES-I case.) However, a cost-effective tritium extraction technology from high mass helium flow rate is needed to make this concept attractive.

(b) Subtask 2-3: SiC Capsule Irradiation

In order to demonstrate feasibility of high efficiency gas cooling blanket system using advanced SiC/SiC composites based on new material development strategy and irradiation resistance of the material system was examined. Evaluation of radiation resistance of SiC and advanced SiC/SiC developed and fabricated JUPITER-II program were performed using HFIR irradiation (rabbit capsule and HFIR-18J RB* capsule irradiation). Additional irradiation data of the advanced SiC/SiC and SiC was also collected by alternative irradiation facilitates such as JMTR, JOYO and charged particle irradiation facilities. Radiation resistance of advanced SiC/SiC composite was demonstrated. Guideline of radiation resistance of SiC/SiC composites was confirmed. Engineering data of advanced SiC/SiC composites at high irradiation temperature was collected. The data shows feasibility of the high temperature gas cooling system with SiC/SiC composites.

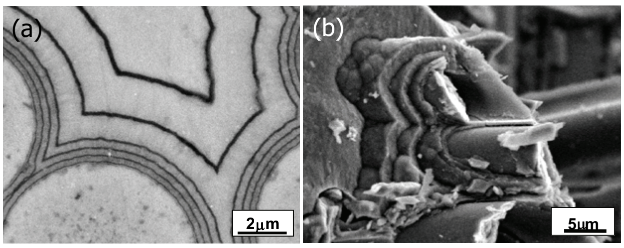


Fig. 1 A SEM image of (a) multilayer (C/SiC) fiber/matrix interphase and (b) fracture surface of the composites

Task 3：Blanket System Modeling

Category: JUPITER-II
Task: 3
Name: A. Sagara / N. Ghoniem
Affiliation: NIFS / UCLA

(a) Subtask 3-1: Design-based Integration Modeling

The main purpose of this task is to develop integrated engineering models of blanket systems based on fusion reactor designs. The constraints imposed by one area of research must be considered in solving problems in another area. Integration has been accomplished in the areas of tritium transport and permeation, thermofluids, materials, and neutronics. For this purpose, it is essential to optimize the blanket system not as a single component but as an integrated system device under the boundary conditions of burning core plasmas and out-vessel environments. Therefore, collaboration works with connecting each task are basically quite important.

Fukada *et al.* have revealed that, for the FFHR blanket system, tritium permeation windows in a realistic-scale are usable for tritium disengager systems. It is found that the diffusion process of tritium in Flibe or the surface process at the boundary is the critical rate limiting process to be investigated. From the safety point of view, they have proposed that a small amount of Flibe or He gas flow in the double tube can act as an effective permeation barriers to reduce the tritium leakage rate below 10 Ci/day.

Sagara *et al.* have newly proposed the STB (Spectral-shifter and Tritium breeder Blanket) for replacement-free blankets in the reactor life of 30 years in FFHR. For this STB, they have evaluated the first wall condition for FFHR, and have proposed enhancement of Flibe cooling capability on one-side heating over 1MW/m^2.

Hashizume *et al.* have investigated flow structures in sphere-packed pipes to enhance heat-transfer efficiency in the TNT (Tohoku-NIFS Thermofluid) loop experiments using HTS (Heat Transfer Salt, Tm= 142°C). Same performance as turbulent flow has been obtained at one order lower flow rate. This is a big advantage for reducing MHD effects and the pumping power.

Tanaka *et al.* have started a new challenge to construct an interface code between the Monte-Carlo neutron transport code MCNP-4C and a complicated blanket design such as in helical systems in order to enable us to frequently modify blanket designs and quickly check neutronics performance. The examples are shown in Fig. 1. Using this easy-feedback code system, both of the Flibe cooled reduced-activation ferritic steel (RAFS) and Li/V-alloy blanket systems have been optimized in the feasibility of tritium breeding ratio higher than 1.0 and nuclear shielding in the FFHR2m helical design.

(b) Subtask 3-2: Materials Modeling

The goal of this task at the beginning of the JUPITER-II project was to establish the methodology of "Multiscale Modeling of Mechanical Deformation (M3D)" for contributions to the research and development of fusion materials, which may cover a broad range of fundamental issues, including primary radiation damage formation, extended defect formation and evolution, dislocation-defect interaction, dislocation dynamics, developing constitutive relationships for irradiated materials, and predictions of engineering properties of materials needed for component design. For this purpose, wide variety of evaluation techniques should be used, because a solid material has essentially a hierarchical structure from atoms to continuum bodies, and a radiation damage process is essentially a multi-time, -length and -energy scale phenomenon.

Morishita *et al.* have investigated the nucleation and growth process of helium bubbles in Fe. They employed molecular dynamics and molecular statics calculation techniques as well as continuum theory to determine the formation energy of helium bubbles. Furthermore, they introduced these results as input parameters in kinetic Monte-Carlo simulations, thus enabling us to study the nucleation kinetics of helium bubbles as a function of temperature and point defect concentrations in an Fe matrix. This work was performed in collaboration with LLNL, PNNL, UC Berkeley and UCLA.

Abe *et al.* performed molecular dynamics calculations to investigate dynamical interactions between an SFT and a dislocation, and they estimated the effects of the interaction on radiation-induced hardening. Also, they investigated the migration behavior of a crowdion bundle using a molecular dynamics technique. They compared the calculation results with in situ TEM observations. This work was performed in collaboration with ORNL.

Fundamental understanding of metal/ceramics bonding will provide useful guideline to develop a robust coating technique. Satou *et al.* performed ab-initio calculations to investigate bonding states between vanadium and coated CaO. This work was done in collaboration with UCLA and CSUN.

Sharafat et al. investigated the transport of helium in irradiated materials driven by spatially dependent fields, such as temperature and stress gradients. To this end modeling of helium transport through finite geometries thus requires a spatially dependent helium transport model. A spatially resolved rate-theory based helium bubble evolution code was developed at UCLA, called HEROS (Helium Bubble Evolution and ResOlution Code).

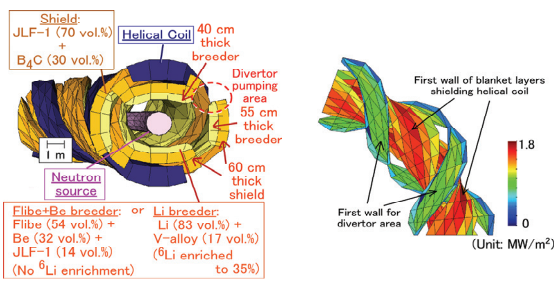


Fig. 1 Example of 3-D geometry data with MCNP (~3,000 cells) and helical neutron wall loading

5.4.2 TITAN

About 70 scientists in 20 Universities from Japan and about 50 scientists in 10 institutes from the US, including students, joined TITAN project. Participants are listed in the following table.

Table 5-6 List of participants to TITAN project

Task	Subtask	Japanese Participants	US Participants
Task 1 Transport phenomena	1-1 Tritium and mass transfer in first wall	Y. Ueda（Osaka U.）, K. Tokunaga, T. Ohtsuka (Kyushu U.), N. Ohno, S. Kajita (Nagoya U.), M. Miyamoto (Shimane U.), M. Nagata, Y.Kikuchi (Hyogo Pref. U.)	R.P.Doerner, D. Nishijima, M. Baldwin (UCSD), P. Sharpe, M. Shimada (INL)
	1-2 Tritium behavior in blanket systems	T. Terai (U. Tokyo), S. Fukada, K. Katayama, Y. Edao (Kyushu U.), S. Konishi, Y. Yamamoto, T. Kamei, K. Noborio (Kyoto U.)	P. Sharpe, P. Calderoni, M. Shimada (INL), D.-K. Sze (UCSD)
	1-3 Flow control and thermofluid modeling	T. Kunugi, Z. Kawara, Y. Ueki (Kyoto U.), T. Yokomine, S. Fukada (Kyushu U.), S. Satake, K. Yuki (Tokyo U. Science), H. Hashizume, S. Ebara (Tohoku U.), M. Kondo (NIFS)	N. Morley, K. Messadek, S. Smolentsev, A. Ying, M. Dagher, J. Takeuchi, M.Abdou (UCLA), R. Munipalli (Hypercomp), C. Wong (GA), P. Calderoni (INL), D.-K. Sze (UCSD)
Task 2 Irradiation synergism	2-1 Irradiation-tritium synergism	Y. Hatano, M. Hara, S. Akamaru, K. Zhang, A. Nozaki (Toyama U.), Y. Oya, M. Kobayashi (Shizuoka U.), T. Oda (U. Tokyo), K. Satoh (Kyoto U.), H. Kurishita, K. Nagai, K. Toyama (Tohoku U.)	M. Sokolov, Y. Katoh (ORNL), P. Calderoni(INL), R. Stoller (ORNL), T. Yamamoto (UCSB), P. Sharpe, M. Shimada, S.Shultz(INL), R. Kolasinski (SNL)
	2-2 Joining and coating integrity	A. Kimura, R. Kasada, K.Yabuuchi (Kyoto U.), S. Ukai, S. Ohnuki, N. Hashimoto (Hokkaido U.), A. Hasegawa, H. Kurishita (Tohoku U.), H. Watanabe (Kyushu U.), T. Nagasaka (NIFS)	Roger Stoller、Michel Sokolov、Yutai Katoh(ORNL)、Takuya Yamamoto(UCSB)、Rick Kurtz(PNNL)
	2-3 Dynamic deformation	A. Hasegawa, T. Shikama, S. Nogami, H. Katsui (Tohoku U.), T. Hinoki, S. Kondoh (Kyoto U.), T. Shibayama (Hokkaido U.), Y.B. Choi (Hiroshima U.)	Y.Katoh, L.L.Snead, E.Byun, K.Ozawa, R.Stoller（ORNL), C.Henager, R.Kurtz (PNNL), S.Sharafat, N.Morley (UCLA)
Common Task System integration modeling	MFE/IFE system integration modeling	A. Sagara (NIFS), T. Norimatsu (Osaka U.), H. Hashizume (Tohoku U.), K. Morishita, S. Konishi, T. Kunugi, A. Kimura (Kyoto U.), T. Yokominem S. Fukada (Kyushu U.),, T. Terai (U. Tokyo)	R.Nygren(SNL), R.Causey, P.Sharpe (INL), D. Sze, R.Raffray(UCSD), M.Abdou, N.Morley, S.Smolentsev, A.Ying, K.Messadek, N.Ghoniem, S.Sharafat(UCLA)

Task 1-1 : Tritium and mass transfer in first walls

Category : TITAN
Task : 1-1
Name: Yoshio Ueda, R. Doerner
Affiliation: Osaka University, University of California, San Diego

1. Background and Purpose

It is of great importance to understand tritium behavior in fusion reactors in terms of safety and fuel economics. In fusion reactors, edge plasma environment is very complicated. Several ion species such as fuel ions (D, T), fusion reactant (He), wall materials (Be, W, C for ITER 1st set of divertor), and edge cooling gas (Ne, N, Ar). In addition, neutron irradiation would affect material degradation due to radiation damage and transmutation. These effects, especially synergistic one, are still under intensive investigation and are not known very well. In addition, first walls of blankets will be coated with armor materials (probably tungsten), but it is not well known how this armor layer affect tritium retention and diffusion. In Task 1-1 of TITAN, the purpose is to clarify tritium and mass transfer in the first walls of blankets by using tritium plasma, Be and He seeded plasma, and pulsed laser system.

2. Research plan

In Task 1-1, the following subjects are studied.

(1) To investigate tritium retention and diffusion behavior in tungsten and tungsten coated reduced activation materials (F82H, Vanadium alloy)

(2) To investigate production processes of material mixing layers and D retention by Be/He/D mixed plasma irradiation to tungsten under high temperature (>1100 K) and low temperature (~600 K) conditions.

(3) To investigate erosion of Be/W mixed materials under simultaneous irradiation of high density plasma and pulsed laser.

3. Experimental facilities

Tritium Plasma Experiment (TPE) in INL : High density tritium plasma simulator TPE is used to expose specimens with T/D mixed plasma (T/D = 0.1~0.5%). Then specimens are cut in a dry system and 2D tritium distribution is measured by Imaging Plate (IP).

Plasma Interactive Surface Component Experimental Station (PISCES) in UCSD : Be/He/D mixed high density plasma is exposed to tungsten. Then D retention mesurement by thermal desorption spectroscopy (TDS) and observation of microstructure (He bubbles, etc.) by transmission electron microscope (TEM) are made. Ablation of Be/W mixed layer by pulsed laser irradiation are made.

4. Principal achievement in first half of TITAN

Results from TPE

(1) A new method to study tritium distribution in materials exposed to T plasmas with a dry cutting and IP technique.

(2) Tritium distribution in tungsten, F82H (Ferritic/martensitic low activation steel), and tungsten coated F82H (VPS coating) exposed to TPE T/D plasmas were measured by these methods. For tungsten samples, tritium distribution is well described by simple diffusion of T and D, while for F82H T distribution was not simply understood by a diffusion equation with a single diffusion coefficient and a plasma ion source term. More experimental data are necessary to draw some conclusions. For tungsten coated F82H, it was clearly shown that the W coating layer greatly reduced T diffusion into the F82H substrate material.

Results from PISCES

(1) D/He (He:20%) mixed plasma exposure to pure tungsten was made at 573 K. By He addition, D retention was decreased by two orders of magnitude and blistering seen for pure D exposure was suppressed. According to TEM observation, thickness of He nano bubble layers was 20-30 nm, see Fig. 1, this layer could have some functions to reduce D influx and increase D release, leading to significant reduction of D retention.

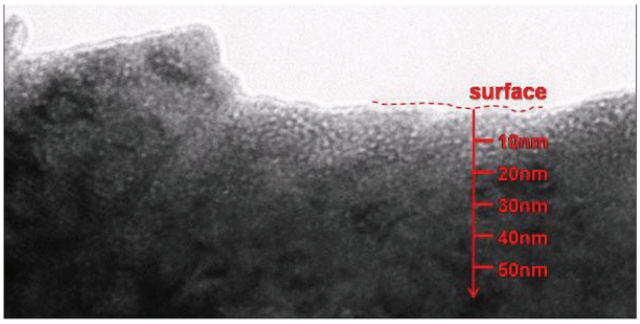


Fig. 1 Cross sectional view of He nano bubble layer exposed to D/He mixed plasma at 573 K.

(2) Pure He plasma exposure to various W (SCR, stress relieved, W-Re alloy, fine grained W) at ~1100 K always showed nano-structure (often called “fuzz”).

(3) Simultaneous plasma and pulsed laser irradiations to solid Be and Be coated W were performed. Structure of ablation plume formed by Be atoms (clusters) and BeD molecules was observed.

Domestic activity

(1) Be/W mixed layer formation processes are simulated by the EDDY code.

(2) Effects of pulse plasma irradiation to tungsten pre-exposed to D/He at 573 K and 1100 K were examined.

5. Future directions

Task 1-1 activity came to halt after first half of 6 years period of TITAN because of budget reduction. But collaboration with UCSD and INL will continue based on TITAN achievements. In addition, domestic research activity will be activated more by the impact of TITAN collaboration.

Task 1-2: Tritium behavior in blanket systems

Category : TITAN
Task : 1-2
Name: T. Terai, S. Konishi, S. Fukada, P. Sharpe, P. Calderoni
Affiliation: Tokyo University, Kyoto University, Kyushu University, Idaho National Laboratory

Background and purpose

In a fusion energy system tritium is generated by neutron capture in the blanket's breeder material, extracted and re-circulated as fuel in the plasma. When the breeder is designed to operate in the liquid phase, the interaction of tritium with the lithium bearing material is one of the most important physical processes in determining the feasibility and the attractiveness of the system because it is fundamentally linked with all aspects of plant operation, from fueling (tritium breeding ratio, tritium availability, etc) to power extraction (heat transfer capability, heat cycle efficiency, etc) to safety (tritium inventory, tritium release, etc). Since the blanket operates in steady-state conditions, the accurate determination of the tritium solubility, defined as the function linking the concentration of dissolved tritium with its corresponding partial pressure at equilibrium over the liquid surface, is a fundamental design data need for all systems (magnetic or inertial confinement, hybrid systems, etc) based on liquid breeders. The other main transport properties, the diffusion constant and the mass transport coefficient at liquid and structures interfaces, play a major role in the selection and optimization of the tritium extraction and coolant purification system (in dual function blankets the two systems are acting on different fluids).

Another aspect related to tritium transport in blanket systems considered in this task is the evaluation of tritium permeation barriers, which may play a fundamental role in maintaining the tritium emission to the environment within the regulatory limits in a fusion energy system. Although the fabrication of such materials is not included in the Task scope, samples may become available from recent developments both in Japan and the US and could be tested with tritium within TITAN activities.

Test plan

1. Measure hydrogen isotopes solubility in lead-lithium eutectic at blanket conditions
2. Tritium permeation in structural materials and permeation barriers at very low concentrations
3. Investigate tritium extraction from lead-lithium eutectic at blanket conditions
4. Modeling and system design for tritium extraction from fusion blankets

Facilities

Several experiments including a dedicated tritium glove box at the Safety and Tritium Applied Research facility, Idaho National Laboratory.

Main achievements

The initial focus of the experiments was the measurement of hydrogen solubility in LLE in a static configuration. The figure below summarizes the results first obtained with hydrogen at input pressure above the liquid surface ranging from 10 Pa to 100 kPa and LLE temperature ranging between 300 C and 650 C. The dotted lines are the exponential fits proposed by F. Reiter and A. Aiello and used here to summarize the extremes of the wide range of results reported in the literature. However, the initial technical approach was based on a set of implicit assumptions which have been undermined by the first 3 years experimental results, resulting in a more complex matrix of parametric evaluation of materials, test procedures and system configurations required to accurately define the solubility. As a result system optimization for tritium testing is still ongoing.

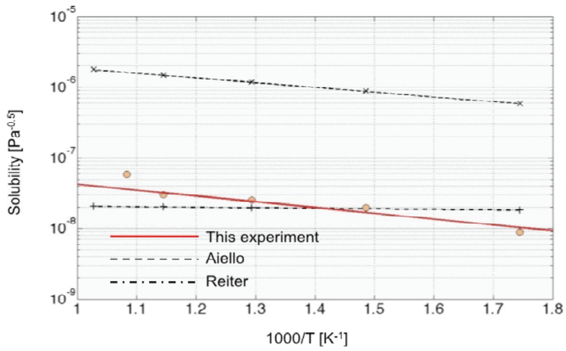


Fig. 1 Temperature dependence of hydrogen solubility in LLE (initial results)

Pre-conceptual design analysis of a forced convection experiment to investigate tritium extraction from lead-lithium eutectic based on the vacuum permeator concept have also been carried out. They resulted in the definition of the main components based on a single leg loop, although further design development and construction is not currently foreseen.

Future directions

Tritium solubility tests will start in FY10 in parallel with continued evaluation with hydrogen in a second bench-top experimental system that will later be modified to investigate other transport properties (diffusivity, mass transport coefficient). Test of tritium permeation barriers is foreseen in the last 2 years of the collaboration.

Task1-3: Flow control and thermofluid modeling

Category : TITAN
Task : 1-3
Name: Tomoaki Kunugi, Takehiko Yokomine, Neil Morley, Karim Messadek
Affiliation: Kyoto University, Kyushu University, University of California Los Angeles (UCLA)

A liquid metal (LM) flow in a fusion blanket interacts with a plasma-confining magnetic field, and eventually a flow structures is strongly affected by a MHD (magneto-hydrodynamics) effect. Especially, LM flows under the strong magnetic field including the flow instabilities and the flow distribution in a coolant channel such as a manifold may determine the heat removal, the hot spots, the corrosion and the tritium transport. Therefore, the understanding of MHD themofluid behavior and the flow control are the key issues for fusion blanket research and development. This task has been studying characteristics of the thermofluid under the strong magnetic field and modeling the MHD phenomena. This task conducts some MHD experiments using the MTOR (Magneto-Thermofluid Omnibus Research) facility at UCLA, which is able to make a uniform magnetic field of maximum 2T in a rectangular gap of 15 cm in width and 1m in length.

<u>LM flow distribution tests under strong magnetic field</u>

Flow distribution of liquid metal in the coolant manifold was studied, which consists of three parallel channels under strong magnetic field with the electrically insulating walls. The working fluid was mercury, and the electrical potential probes were used to measure the flow rates in each channel. As results, a uniform distribution was achieved in the case of the ratio of a magnetic force (Ha) and an inertia force (Re): $N = Ha^2/Re > 90$ (Fig. 1) [1].

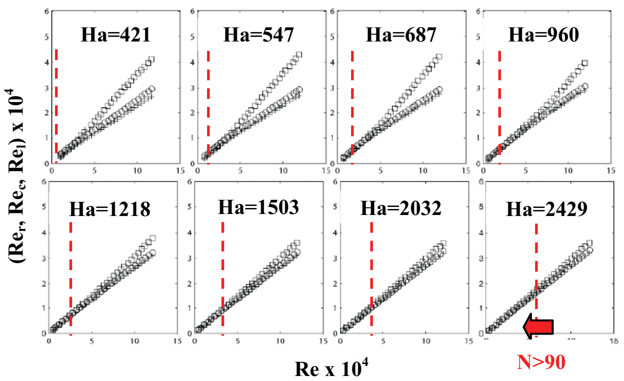


Fig. 1. The LM flow distribution under B-field

<u>Development of PbLi flow diagnostic and interfacial effects</u>

A lead-lithium eutectic alloy (PbLi) is chosen as a working fluid in this task because the PbLi is one of the candidates of LM coolants for fusion blanket designs. In order to grasp the PbLi flow field, we have been developing a High-Temperature Ultrasonic Doppler Velocimetry (HT-UDV). To do this, PbLi acoustic properties necessary for the HT-UDV [2] was obtained and a tracer particle for PbLi flow was investigated. Interfacial phenomenon related to the PbLi wettability may affect the MHD flows. This task has made the quantitative evaluations of the interfacial effects by measuring the contact angles of a PbLi droplet on a silicon carbide (SiC) surface, and also measuring an electrical contact resistivity at a SiC-PbLi interface.

<u>MHD modeling and numerical simulation</u>

In order to establish the MHD flow control manners, some MHD models and numerical simulations have been conducting and the MHD turbulent effects on the heat transfer has been studying. A mixed convection which consists of both a forced convection driven by pump and a natural convection due to the buoyancy under the strong magnetic field is one of the key issues for the blanket designs. This task has developed the turbulent model for a MHD quasi two-dimensional (MHD-Q2D) flow, and also numerically simulated the MHD-Q2D flows based on this model, so that the detailed understandings on the complex thermofluid where strong magnetic field and the buoyancy force interact (Fig. 2) have been obtained [3].

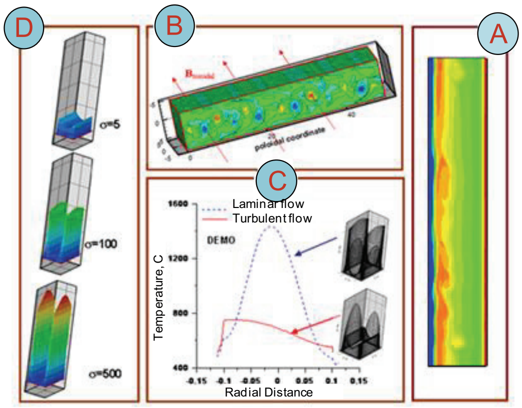


Fig. 2. A: MHD buoyancy flow B: MHD Q2D flow
C: MHD turbulent effect on temp. profile
D: M-shaped velocity profile

This task focuses on PbLi flows under strong magnetic field in later half of TITAN project. At present a PbLi loop at UCLA is being constructed, and the non-MHD/MHD flow measurements with the HT-UDV system installed on the PbLi loop will be conducted. Moreover in the latter half of TITAN project, this task plans to carry out an experimental study on the main techniques mitigating the MHD pressure drop, e.g. a flow channel insert (FCI) and an electrically insulation coating techniques.

The goal of this task is that MHD thermofluid models based on both experiments and numerical simulation are established for designing the fusion LM blanket.

1) Messadek, K. *et al.*, Magnetohydrodynamics, 45 (2009) 233-238.
2) Ueki, Y. *et al.*, Fusion Sci. & Tech., 56 (2009) 846-850
3) Smolentsev. S. *et al.*, Fusion Eng. & Des., 83 (2008), 771-783

Task 2-1 : Irradiation-tritium synergism

Category : TITAN
Task : 2-1
Name: Yuji Hatano, Yasuhisa Oya, Mikhail Sokolov, Yutai Katoh, Pattrick Calderoni
Affiliation: University of Toyama, Shizuoka University, Oak Ridge National Laboratory (ORNL), Idaho National Laboratory (INL)

Understanding of tritium behavior (diffusion, trapping, desorption, etc.) in neutron-irradiated materials is indispensable for evaluation of tritium balance in fusion reactors. Tungsten (W) is currently recognized as candidate of plasma facing material because of its low tritium solubility. Recent ion irradiation experiments, however, show that the radiation defects in W such as vacancies and voids act as strong trapping sites against hydrogen isotopes. Hence, the tritium retention in W may significantly increase with neutron irradiation. The objective of this work is to understand the effects of neutron irradiation on tritium behavior in W. Disk-type samples of pure W are irradiated in HFIR, ORNL and retention and desorption of hydrogen isotopes including tritium are examined in STAR facility, INL. Nickel is also examined as reference material. Accomplishments in the first three years are described here.

(1) Determination of Irradiation Matrix

From the viewpoints of neutron-induced activation, small samples are preferable. On the other hand, accuracy of retention and desorption measurements could be poor if samples are too small. In order to optimize the sample size, radioactivity after neutron irradiation was evaluated by FISPACT-2001 code in NIFS, and the accuracy of measurements was assessed with expected hydrogen isotope retention. Finally, the sample size was determined to be ϕ 6 mm x 0.2 mm. Small samples (ϕ 3 mm x 0.2 mm) were also prepared for microstructure examination.

Conditions of neutron irradiation were determined by taking account of expected wall temperature and neutron dose in fusion reactors, development of microstructure and project schedule. Irradiation temperature was decided to be 50 °C (quick start of irradiation due to simple capsule design), 300 °C (close to wall temperature of existing fusion machines and ITER), and 650 °C (close to expected wall temperature in DEMO). In W, only interstitial atoms migrate at 50 and 300 °C, while vacancy diffusion and void growth take place at 650 °C. Similar difference in microstructure is obtained for Ni by the irradiation at 50 and 300 °C. The duration of irradiation was determined to be ca. 1 day, 1 month and 1 year (W only). Tungsten receives irradiation dose of 0.025, 0.3 and 2.4 dpa (displacement per atom), and that for Ni is 0.1 and 1.2 dpa.

Irradiation at 50 and 300 °C for ca. 1 day and 1 month has been completed. The extent of activation after ca. 1 day irradiation at 50 °C agreed well with the above-mentioned evaluation.

(2) Measurement of Thermal Desorption Spectrum of Deuterium from Low-Dose Neutron-Irradiated W

The W sample irradiated at 50 °C for 0.025 dpa was shipped INL and exposed to deuterium plasma by linear plasma machine TPE. The samples used in the present study are significantly small and thin in comparison with the standard size for TPE (1 inch diameter and ca. 1mm thickness). Hence, a new sample holder specially designed for the small samples with thermocouple mounted on precise linear motion feedthrough was fabricated. The surfaces of neutron-irradiated W samples were covered by black contaminant, although the samples were kept in sealed Mo envelopes during irradiation. One of W samples was exposed to deuterium plasma by TPE at ca. 200 °C and flux of 5.0×10^{21} D $m^{-2}s^{-1}$ for 2.0 h (fluence 3.6×10^{25} D m^{-2}). After exposure to deuterium plasma, the black contaminant completely disappeared from the exposed surface, indicating this black matter is the layer of W oxides. The cause of oxide formation was considered to be a leak in Mo envelopes resulting in reaction between samples and coolant water. Although the contaminant remained on side and backside, preliminary thermal desorption spectrum was measured as shown in Fig. 1. Characteristic points of spectrum from neutron-irradiated samples are: (1) burst-like desorption observed in the low temperature region (＜100 °C), and (2) continuation of desorption in the temperature range above 500 °C. The burst-like desorption was ascribed to deuterium release from oxide layers on the side and backside. The desorption in the high temperature region was attributed to the trapping effects by defects created by neutron irradiation. It should be emphasized that such clear effects of neutron irradiation was observed at irradiation dose as low as 0.025 dpa. The measurement will be repeated after removal of oxide layers from all surfaces. Measurements of deuterium depth profiles with nuclear reaction analysis are currently under preparation. Behavior of hydrogen isotopes including tritium in high dose samples will also be examined in the near future.

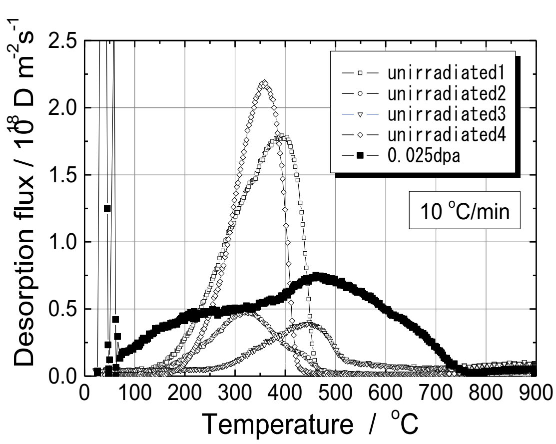


Fig. 1. Preliminary data on deuterium desorption from W sample irradiated by neutron at 50 °C for 0.025 dpa. Spectra from unirradiated tungsten samples are also shown.

Task 2-2 : Joining and coating integrity

Category: TITAN
Task : 2-2
Name: Akihiko Kimura[1], Naoyuki Hashimoto[2], Takuya Yamamoto[3], Michel Sokolov[4],
Affiliation:[1]Kyoto University, [2]Hokkaido University, [3]UCSB, [4]ORNL,

There are many issues to be solved for practical construction of DEMO blanket, although the basic blanket fabrication technologies for ITER test blanket module made of reduced activation ferritic steels have been well progressing so far. Among the technologies, joining/coating technology is inevitable for assembling blanket in which the weld line is expected to be 500 m per single body of blanket module. Therefore, it is considered that the lifetime of the blanket will be controlled by performance of weld bond.

The objective of this sub-task is to develop the joining and coating technology of advanced structural materials for DEMO blanket and to evaluate the performance of the joint and coating under irradiation.

The materials used were nano-sized oxide dispersion strengthened (ODS) steels, vanadium alloys and SiC composites. Since the ODS steels can be simultaneously used with reduced activation ferritic steels (RAFS) without any significant design modifications, ODSS/RAFS joint as well as ODSS/ODSS joint fabrication technology development were targeted. The maximum usage temperature of the ODSS is considered to be 150°C higher than RAFS, which can contribute to elevate thermal efficiency of the reactor. However, melting during welding changes the morphology of the dispersion of nano-oxide particles and degrades material performance, the other joining method than welding is necessary for ODSS. In this sub-task, friction staring welding (FSW) and solid state diffusion bonding (SSDB) method was applied to the ODSS (16Cr-4Al-2W-0.35Y_2O_3), and the joints were irradiated in HFIR to be evaluated their performance under irradiation.

FSW was performed for an ODS steel with high Cr concentration at a rotating speed of 800 rpm with a line-scanning speed of 50 mm/min. The FSW treatment resulted in a growth of the grains, and consequently, a remarkable reduction of the strength at RT. However, the reduction of strength at elevated temperatures was so small that the FSW is adequate for the application of ODSS to practical blanket fabrication..

SSDB was carried out at 1200°C at 25MPa for 1 ht with and without insert material. Since the melting temperature of the insert material was lower than 1200°C, insert material is melted and the method is often called as liquid state diffusion bonding (LSDB). Tensile strength of both the SSDB and LSDB was not degraded by the bonding treatment. The elongation of LSDB was reduced to about a half of the material. However, the elongation of SSDB was not reduced at all, indicating the joining method is very suitable to ODS steels.

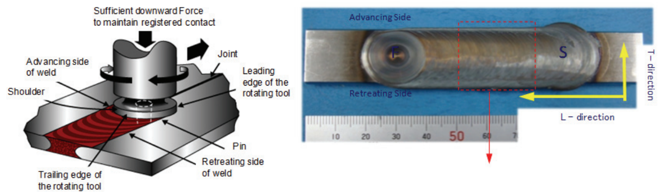


Fig.1 : Schematic diagram of FSW method and a FSW treated ODS steel.

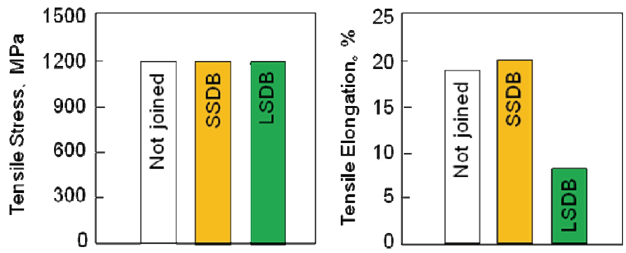


Fig.2 : Tensile stress and elongation of the ODS steel with and without joining.

W-coating technology is inevitable for fabrication of diverter and first wall towards realization of fusion energy. The most difficulty of W in application is due to brittleness of W that was not plastically deformed at RT. Plasma facing material, which suffer a cyclic high heat loading, has been required to be refractory material and resistant to high thermal fatigue. Furthermore, the sustaining structure of diverter and first wall should contact to the coating tightly.

In this work, SSDB of W-ODSS was done at 1240°C with and without insert material (Fe-3B-5Si). The strength of joint between W/ODSS was evaluated by means of torsion tests, and a rather high value of 300 MPa was attained for the SSDB joint. A vacuum plasma splay (VPS) method was also attempted for W-coating on ODSS. It was confirmed that the fabricated W-coat on ODSS withstood a cyclic heat load at 4.8 MW/m^2 to 16 cycles.

As a summary, the following accomplishments were obtained in this sub-task:
1) ODSS/ODSS joint technique was developed.
2) The joint strength of 300 MPa was obtained for LSDB joint of W/ODSS.
3) Non-damaged W-coat was fabricated on ODSS in terms of cyclic heat loading test at 4.8 MW/m^2 to 16 cycles.

Task 2-3 : Dynamic deformation

Category : TITAN
Task : 2-3
Name: Akira Hasegawa (1), Tatsuya Hinoki(2), Yutai Katoh(3)
Affiliation:(1) Tohoku University, (2) Kyoto University, (3) Oak Ridge National Laboratories

1. Background and objectives

Irradiation creep is an important irradiation effect phenomenon for materials for radiation services, because it is a major contributor to potential dimensional instability of materials under irradiation at such temperatures that thermal creep is not strongly anticipated. For silicon carbide (SiC)-based nuclear components, the irradiation creep may be important, in particular when a significant temperature gradient exists and the secondary stresses developed by differential swelling can be severe. Flow channel insert in liquid metal blankets of fusion energy systems is an example of such applications.

Studies on neutron irradiation creep of SiC have so far been extremely limited and insufficient. The experimental method of estimating the creep parameters based on the stress relaxation in elastically bent strip samples developed by Price[1] was later adopted to examine the thermal creep behavior of refractory ceramic fibers and was named bend stress relaxation (BSR) method. In a recent work, Katoh et al. applied it for studying the irradiation creep of high purity, stoichiometric CVD SiC, demonstrating that the BSR technique is effective to determine the irradiation creep parameters [2,3].

Based on the previous demonstration of the experimental technique and the recognized importance of the irradiation creep, a more detailed study on the BSR irradiation creep of SiC ceramics and composites was planned as the Phase-I program of Task 2-3 on dynamic deformation of fusion materials in the TITAN Collaboration program. The objective of the Phase-I study is to gain understanding of the transient creep and stress relaxation behavior of SiC ceramics, model composites, and composite constituents during neutron irradiation. More specifically, the study aims at determining the dose, temperature, and stress dependent BSR behavior of those materials and the correlation between the point defect swelling and the transient creep deformation.

2. Experimental

The standard "SiC Bend Bar" type capsule housing configuration were employed. Inside the standard sleeve, which holds two ceramic bend bar samples in the standard configuration, a rectangular casing is accommodated. Four BSR assembly units are accommodated in each coffin. Each BSR assembly is of size approximately 48 mm x 5.1 mm x 1 mm. The BSR assembly units are stacked together with CVD SiC liners/separator plates at the top, bottom, and between the units.

Materials to be studied and specimen loading to each rabbit are CVD processed SiC, polycrystalline (R& H and Coorstek: beta SiC) and single crystal (Cree : 6H SiC) and NITE processed SiC matrix. The dimensions of the BSR creep specimens are 40 mm (l) x 1 mm (w) x varied thickness. The thickness was varied to allow determination of the effect of stress magnitude. Typical initial flexural stresses for the specimen thicknesses 0.05, 0.1, and 0.15 mm are ~100, ~200, and ~300 MPa, respectively. The neutron irradiation experiments were performed using hydraulic and fixed rabbit facilities of the High Flux Isotope Reactor (ORNL). Target irradiation temperatures and fluence in the Phase-I were 300, 500, 800, and 1200ºC in the irradiation level from 0.01 to 1dpa[2].

3. Results

Figure 1 shows the relationship between the stress relaxation ratio and the initial flexural stress of R&H SiC after various irradiation conditions [5]. The result show that the BSR ratios are about the same at 300C and 500C in spite of swelling difference and it does not have initial stress dependence. Detail analysis of the irradiation behavior compared with unirradiated data[4] and micro structural development is on going. The phase-I result indicated that the BSR method in a conventional pre-straining configuration may be used to determine the steady state creep compliance.

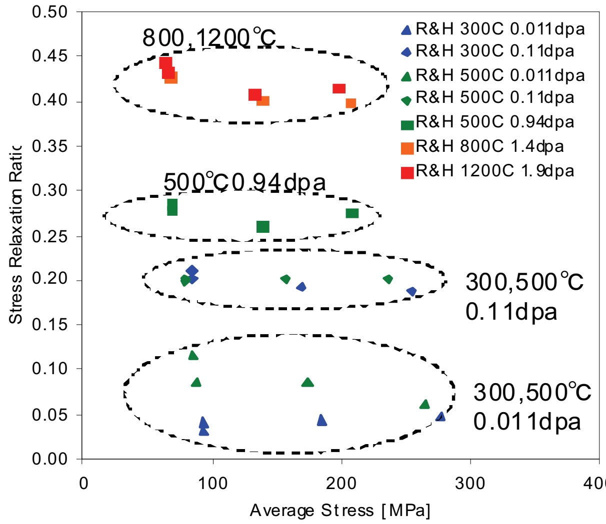


Fig.1 Stress Relaxation Behavior of CVD-SiC after HFIR Irradiation

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[2]Y. Katoh, Y.B.Choi, T. Hinoki, Fusion Materials Semi-Annual Prog. Reports, DOE/ER-0313/45 (2008) 140-145
[3]Y. Katoh, T. Hinoki, K. Ozawa, Y.Choi, A. Hasegawa, L. L. Snead, Properties of Advanced SiC Fiber Composites Irradiated at High Temperatures: Results from US/Japan HFIR-18J Experiment, J. Nuclear Materials (submitted)
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[5]Y.Katoh, T.Hinoki, A.Hasegawa et al. to be submitted.

Common Task : MFE/IFE system integration modeling

Category : TITAN
Task : Common Task
Name: Akio Sagara, Hidetoshi Hashizume, Takayoshi Norimatsu, Richard Nygren
Affiliation: NIFS, Tohoku Univ., Osaka Univ., Sandia National Laboratory (SNL)

1. Purpose

Aiming at the formation of the fusion engineering basis which is necessary for the development of the MFE and IFE reactors, it is designated as purpose that the integrated engineering model of reactor system is constructed with executing the tritium and thermofuid system designs under the boundary conditions of burning core plasmas and out-vessel environments. Those activities cooperate with science and engineering experiment researches on estimating and controlling the time and spatial behaviors of tritium and energy flow formed in nuclear reactions. The uniqueness of this task is (1) to perform modeling of the integrated engineering system for design optimization (2) by crossly connecting each task in this project (3) with improving consistency of elemental device researches and (4) making feed back from each task.

2. Task plan

The former half of this task consists of
(1) Identification of key issues and key parameters,
(2) Identification of baseline designs and operating conditions in such as FFHR, ARIES, KOYO,
(3) Execution of analysis of key issues on tritium and heat systems.
The later half consists of
(1) Integration of results from TITAN tasks into design process,
(2) Integration of blanket modeling,
(3) Providing researchers with information needs.

3. Achievements

(1) Experimental models in each task were reviewed and listed up major parameters for model integration with selecting models and physics to be included. This was collected in the form of a spreadsheet that lists 25 items to be checked (Table 1).
(2) To identify modeling targets, a seminar series in Journal of Atomic Energy Society of Japan was arranged mainly by this task members, and published for the total 12 issues with the main title of "The Fusion Reactor Wall is Getting Hot ! -- A Challenge towards the Future for Numerical Modeling", covering MFE and IFE reactor designs, edge plasma, PWI, materials damage, neutronics, tritium breeding, heat removal [1]. This article included results of discussion in the past TITAN workshops.
(3) The first review was performed for the recent stellarator/heliotron designs of FFHR, HSR, ARIES-CS [2]. Design optimization and engineering feasibility are highlighted including maintainability, fabricability with prospect towards DEMO. Development of long-life blanket and unscheduled blanket replacement are common engineering key issues.
(4) Evaluation of tritium permeation loss rate was performed on the Flibe blanket and LiPb blanket systems, and it was found that rate limiting processes depending on tritium concentration profiles are key issues in modeling [3].

4. Prospect and expected results

By combining model components, which are expected to be improved in each task on microscopic behaviors of tritium and heat transfer in blanket systems, both of developing an integrated system model and establishing its methodology are expected regarding macroscopic behaviors between each element in the recycling loop for blanket systems. At the same time, by making feedback of key issues to each task, it is expected to enhance task activities on developing tritium and thermofluid system with high consistency between each task.

The integrated system model with high consistency is used for optimization of mass and heat transfer system in MFE and IFE reactor designs. Furthermore, creation of breakthrough on reactor designs and proposal of new research issues are expected. As a result, the formation of the fusion engineering basis is expected to be pushed forward.

Table 1 The list of key 25 items to be checked for reactor system integration modeling.

item	task	parameters	model	physics	assessment	coupling / remakrs	Coupling
PFCS							
erosion	1.1	N,Te,Ti,lSOL,G (edge), impurity	REDEP HEIGHTS	•sheath •sputtering	Input: plasma edge, angular-		
BLANKET							
nuclear response functions from		material, plasma source, geometry,	MCNP, TRIM ANISN			coupling for activation	all material property
LM thermfluid		Geometry, material properties,	HiMAG	3D potential	good for complex geometries and 3D	also applicable to	
TRIT RECOVERY							
extraction			ASPEN, Wilms/Merrill				
MATERIALS		dose, dose rate, material, particle	codes: molecular	binary collisions,			thermomechanics, tritium

1) A. Sagara, T. Norimatsu, S. Sharafat, et al., J. of Atomic Energy Society of Japan, 50(6)(2008) to 51(7)(2009).
2) A. Sagara, Y. Igitkhanov, F. Najmabadi, Fusion Eng. Des., in press.
3) S. Fukada, Y. Edao, A. Sagara, Fusion Eng. Des., in press.

CHAPTER 6 DIII–D

6.1 Objectives

Collaborative activities on the DIII-D program were extended to establish the scientific basis for the optimization of the tokamak for fusion energy, using a non-circular cross-section plasma with high triangularity, double-null divertor configuration, and various current drive system. These activities were aimed towards understanding the physics of steady and high performance plasmas and determining methods of steady-state operation over the last decade.

6.2 Activities

The Japan Atomic Energy Research Institute (JAERI), from October 2005 Japan Atomic Energy Agency (JAEA), extended an agreement with the U.S. DOE to collaborate on the DIII-D tokamak at General Atomics (GA) in San Diego. This Agreement has provided close collaborative work on the research programs at JAERI (later JAEA) and GA for 30 years. In the last 10 years, JAEA has sent at least a total of 100 person-weeks of physicists and engineers to GA.

Joint research activities were carried out through participation in the DIII-D program and exchange of information. Progress has been made in several areas including advanced tokamak physics, divertor properties, confinement improvement such as H-mode, high beta physics and control, electron cyclotron heating and current drive, diagnostics development, and tokamak stability theory. These collaborations with DIII-D also complemented the research programs on JT-60U.

This experience built enduring mutual respect and friendships between JAEA and GA scientists and engineers. This collaboration has indeed strongly progressed in the last 10 years, leading to significant scientific achievements as well as contributing to Japan's JT-60 program and improving the world fusion program.

6.3 Administration

The Steering Committee Meeting is held at General Atomics, San Diego every year throughout the period of collaboration between the U.S.DOE and JAERI/JAEA in order to coordinate the collaborative work program. The committee comprises representatives of JAEA, DOE and GA. The steering Committee discussed the accomplishments of the collaboration and the potential benefits of the collaboration for advancing plasma physics in general, and for the ITER program specially. The committee reviewed and recommended approval of the proposed exchanges from JAEA to DIII-D in each fiscal year. The meeting was sometimes organized in conjunction with the "DOE-JAERI Technical Planning of Tokamak Experiments" meeting and the DIII-D advisory committee meeting. It emphasized technical discussions and closer collaborations.

6.4 Accomplishments and Highlights

The main subjects of collaboration in the last 10 years have emphasized progresses towards higher-beta, a higher confinement and steady-state plasmas. During 2001-07, joint research has supported both the DIII-D and JAEA program efforts in furthering Advanced Tokamak (AT) research, in particular the study of edge localized mode （ELM ） stability, the development of particle control, the suppressions of Neoclassical Tearing Mode (NTM) and Resistive Wall Mode instabilities (RWM), vessel activation studies, edge stability physics and edge current density measurements, transport barrier studies, ITER Hybrid scenarios, and ECH technology, NBI and advanced control technology.

On the occasion of the successful completion of JT-60 experiments in 2008, after 23 years of operations, the DIII-D team commends the JT-60 team on their many superb accomplishments in advanced tokamak physics research fully exploiting the JT-60 device and pointing the way towards an attractive future fusion energy source.

During 2008-09, joint research has continuously supported by both the DIII-D and JAEA program, that is effort toward progress in Advanced Tokamak (AT), in particular the study of rotation effects on RWM, QH-mode plasmas, edge stability physics, momentum transport studies, advanced control studies and efforts of Test Blanket Module (TBM) ripple. These activities are of direct benefit to the DIII-D and JT-60SA programs and have supported resolution of ITER physics issues.

One of the outstanding achievements in recent years has been the discovery that a low toroidal rotation of 0.3% of the Alfvȇn velocity has an effect on the suppression of RWMs. This rotation value is much smaller than previous predictions by theory and from experiments of magnetic braking through the application of asymmetric magnetic fields, the so-called error fields. These results obtained through collaborative work on JT-60U and DIII-D have had a large impact on the design of the advanced tokamak reactor where the RWM might be stabilized and controlled by the rotation.

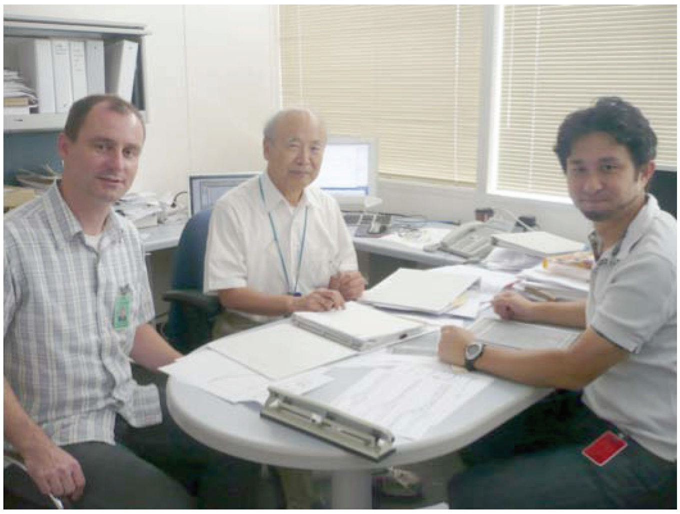

Table discussion for RWM physics. (2010, General Atomics)

Particle and heat transport is another important area of research under this collaborative framework. Investigations of the transport barrier with a pedestal structure near the plasma edge are important subjects. Several small ELM or ELM–free regimes such as grassy ELM, QH-mode and type II

ELMs with good confinement properties have been obtained on DIII-D, JFT-2M, JT-60U and other tokamaks. All these regimes show considerable reduction of the instantaneous ELM heat load on the divertor target plates when compared to regimes with conventional type I ELMs. These small or ELM-free regimes can be categorized in an operational space with non-dimensional pedestal parameters and with specific requirements in plasma shape/configuration.

Discharges that simulate advanced operating scenario with large bootstrap current, high beta and high confinement have been jointly investigated in addition to hybrid scenarios with moderately high beta, higher performance and partly inductive current drive. Advanced tokamak plasma with high beta, wall-stabilized discharges with fully non-inductive current drive that project to steady-state operation in ITER have been sustained for more than a current relaxation time.

A number of pioneering results have been achieved through the collaborative work between the DIII-D and JT-60U devices, in particular investigations on NTM physics with electron cyclotron current drive (ECCD), as a result of the DIII-D high-power EC system, high resolution diagnostics and advanced real-time NTM control capabilities. In collaboration with DIII-D and JT-60 and other tokamaks, the marginal island width for NTM has been investigated, which is important in estimating the required EC power and establishing a working scenario for NTM stabilization. It was found that the marginal island is about twice the ion banana width. In addition, requirements for real-time NTM stabilization in ITER have been investigated. This research has led to the application of ECCD at the mode rational surface before the NTM onset for preemptive stabilization of the NTMs. This capability has been effectively demonstrated on both JT-60 and DIII-D in high-β regimes. More recently, NTM stabilization by modulated ECCD has been demonstrated as a result of the close research collaborative efforts between DIII-D and JT-60.

Stabilization of Neoclassical Tearing Modes by Electron Cyclotron Current Drive

Category : Doublet III
Year-Number : 2001-DO-4, 2003-DO-6, 2004-DO-3
Name: A. Isayama, R.J. La Haye*, R. Prater*
Affiliation: Japan Atomic Energy Research Institute, *General Atomics

Neoclassical tearing mode (NTM) is an magnetohydrodynamic (MHD) instability which appears in high-β plasmas with positive magnetic shear (β is the ratio of the plasma pressure to the magnetic pressure). Since the NTMs degrade the plasma confinement through the formation of magnetic islands, stabilization of the NTMs is required to sustain a high-β plasma. Localized current drive at the mode rational surface using electron cyclotron (EC) waves, electron cyclotron current drive (ECCD), is considered to be the most promising method for NTM stabilization due to the capability of high magnitude of current drive density and high accuracy of current drive location.

Both JT-60U and DIII-D devices have the capability of detailed investigation on NTM physics because they equip (a) high-power heating system to obtain a high-beta plasma, (b) high-power EC wave system to actively stabilize NTMs, (c) high temporal and spatial resolution diagnostics to measure and control NTMs and (d) advanced plasma control system for real-time NTM stabilization. A number of leading results have been reported from the both devices. For example, most recently, NTM stabilization by modulated ECCD was demonstrated [1, 2]. Against the backdrop of these results, close research collaboration has been continued between JT-60U and DIII-D.

It is known that NTM islands have the property of spontaneous shrinkage at small island width due to several stabilization effects, and such shrinkage has also been observed experimentally. Investigation on the island width at which the spontaneous shrinkage begins, which is referred to as the marginal island width, is important in estimating the required EC wave power and establishing the scenario for NTM stabilization. In collaboration with ASDEX-U (Max-Planck-Institut für Plasmaphysik, Germany), DIII-D and JT-60U, the marginal island width for an $m/n = 3/2$ NTM was investigated. Here, m and n are the poloidal and toroidal mode numbers, respectively. It was found that the marginal island is about twice the ion banana width (Fig. 1) [3]. In addition, based on the results and experiences in ASDEX-U, DIII-D and JT-60U, requirement for real-time NTM stabilization in ITER was also investigated [4].

Stabilization of NTMs by ECCD is usually achieved by injecting EC waves inside the NTM islands. As a new strategy, ECCD at the mode rational surface before the NTM onset, what we call preemptive stabilization, was developed and the effectiveness was successfully demonstrated in JT-60U [5, 6]. Preemptive stabilization in a higher-β regime was demonstrated in DIII-D with participation of JT-60 staffs. Experiments using a newly developed real-time control system were successfully conducted, where equilibrium reconstruction with current density measurement and identification of the mode location were performed in real time [7]. Typical example is shown in Fig. 2. In the discharge, the beta value was raised to the no-wall ideal MHD limit by suppressing the onset of an $m/n = 2/1$ NTM. Soon after the switch-off of the ECCD, an $m/n = 2/1$ NTM appeared. This result shows the effectiveness of the preemptive ECCD.

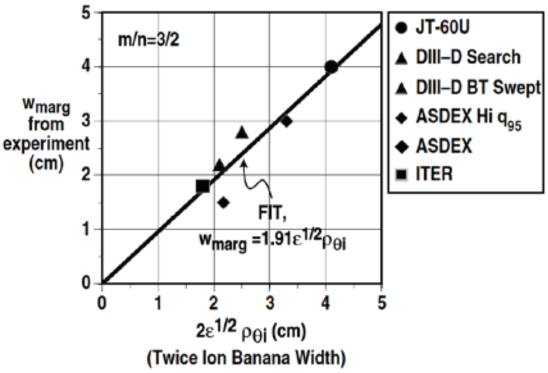

Fig. 1. Marginal island widths in ASDEX-U, DIII-D and JT-60U versus twice the ion banana width. Expected marginal island width in ITER is also shown. [from Ref. 3]

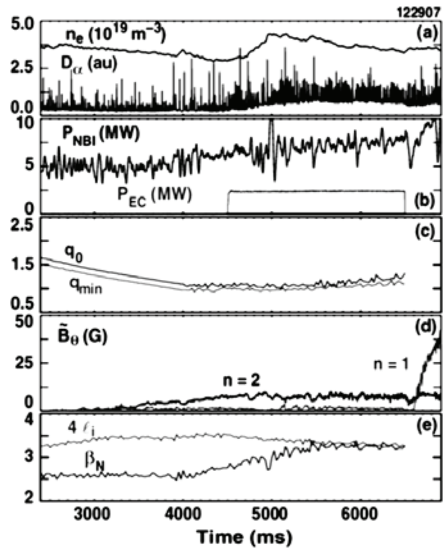

Fig. 2. Evolution of plasma behavior of a preemptive ECCD discharge in DIII-D. (a) line-averaged density and D_α emission, (b) EC wave power and time-averaged neutral beam power, (c) central and minimum value of safety factor, (d) amplitudes of $n = 2$ and $n = 1$ tearing modes and (e) normalized beta and four times the internal inductance (an estimate of the beta limit for the ideal $n = 1$ kink mode in the absence of a conducting wall). [from Ref. 7]

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High-brightness and low-divergence lithium neutral beam for a Zeeman polarimetry on JT-60U

Category : Doublet III
Year-Number : 2005-DO-9,
Name: A. Kojima, K. Kamiya, T. Fujita, H. Kubo, H. Iguchi*.
Affiliation: Japan Atomic Energy Agency, *National Institute for Fusion Science.

Lithium beam probes (LiBP) are powerful diagnostic for pedestal studies since the electron density and the pitch angle of the magnetic field line in edge plasmas can be measured from the beam emission signal and its polarization angle. In order to measure the edge plasmas with high-spatial and high-temporal resolutions, high-performance neutral lithium beams are required. In the previous works on DIII-D, direct measurements of the edge current density was carried out by use of 30 keV, >10mA lithium beams [1]. Recently, JT-60U planned to install the LiBP for the measurement of the edge electron density and current density. For the LiBP on JT-60U, the optimum beam energy was lower than that for DIII-D because of lower pedestal density. However, the large beam current was also required to obtain a high S/N ratio. Such beams are strongly affected by the space charge effects and easy to spread. Therefore, a high-brightness and low-divergence neutral lithium beam source with low energy of 10 keV has been developed on JT-60U.

In order to obtain a large current over 10 mA, a thermionic ion source heated by an electron beam has been developed. The diameter of the ion emitter is 50 mm which is made from porous tungsten with porosity of 30 %. The porous tungsten disk is mounted on the molybdenum holder as shown in Fig. 1. The acceleration voltage of 1.5 kV for the electron beam is applied between the disk and a tungsten filament behind the disk. The surface temperature of the disk reaches to 1500 ^{o}C with the typical heating power of 1.3 kW. The extracted ion current can exceed 10 mA in this case. The maximum power of the electron beam heating is 5 kW which is enough to make β eucryptite ($Li_2O \cdot Al_2O_3 \cdot 2SiO_2$) soaked in the disk.

The beam optics has been designed after detailed numerical simulation taking the space charge effects into account because a low divergence angle of the neutral lithium beam is required in terms of the narrow spectrum of the beam emission and the high transmission of the long beam line of 6.5 m. Although the beam energy of 10 keV is relatively low, an extraction electrode installed in front of the ion source can produce a large current beam over 10 mA.

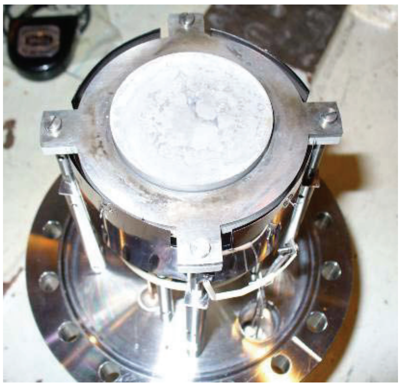
Fig. 1. The electron beam heated ion source with a 50 mm porous tungsten disk and a molybdenum holder.

The newly-developed ion gun has been operated on a test stand which simulates the diagnostic geometry on JT-60U. The ion beam current of 10mA at a beam energy of 10 keV is successfully extracted from the ion source and focused by Einzel lens. The FWHM (Full Width at Half Maximum) radius of the ion beam at the neutralizer is about 9 mm. A sodium vapor neutralizer neutralizes the collimated ion beam fully at the temperature of 300 ^{o}C. The neutral beam profiles have been measured at two locations of the beam line at 2.3 m (beam monitor position) and 6.5 m (plasma region) from the neutralizer. The HWHM radius of the neutral beam of 26mm and the equivalent beam current of 3 mA with the beam divergence angle of 0.2 degree which is the half-angle divergence have been obtained. Those parameters satisfy the requirements of the Zeeman polarimetry. Furthermore, a long pulse extraction with a current of 10 mA and duration of 50 seconds has been attained [2].

After developing the detectors, the LiBP has been installed on JT-60U. The LiBP has 20 viewing chords in the edge region r/a = 0.8 ~ 1.0 with a spatial resolution of 1 cm. Etalon and band-pass filters are applied to separate the polarized spectrum of the beam emission. In order to tune the etalon filters, a new technique in which the Doppler shifted spectrum is varied by sweeping the beam energy has been developed and has demonstrated the availability [3].

The electron density profiles in the edge region have been measured by using the LiBP with a temporal resolution up to 0.5 ms. In addition, an ELM cycle in cases of type I and grassy ELMs have been observed [4]. The collapse of density pedestal of grassy ELMs is smaller (<20%) and the radial extent is narrower (~ 5 cm) than those of type I ELMs (~30%, >15cm). The measurement of the edge current density has been also achieved by using the LiBP [3]. Time evolution of the edge current density profiles have been determined for the current ramp up/down in the OH plasmas. Moreover, the edge current density profile having the local peak of 0.15–0.25 MA/m^2 at r/a ~ 0.9 has been identified in the H-mode plasma. The local peak might be caused by the strong pressure gradient in the edge pedestal region.

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Numerical Method for the Stability Analysis of Ideal MHD Modes with a Wide Range of Toroidal Mode Numbers in Tokamaks

Category : Doublet III
Year-Number : 2004-DO-2, 2005-DO-2,
Name: N. Aiba, S. Tokuda, M. S. Chu[1], P. B. Snyder[1]
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In tokamaks, an ideal magnetohydrodynamic (MHD) instability attracts attention as one of key issues for a high performance operation. This is because a low-*n* MHD mode often restricts a plasma performance (beta limit), and intermediate / high-*n* MHD modes sometimes determine an edge pedestal performance, where *n* is a toroidal mode number. To identify the stability of these MHD modes, we have invented the effective numerical method for the stability analysis of ideal MHD modes with the physical model based on the two-dimensional Newcomb equation in combination with the conventional compression-less ideal MHD model. The MARG2D code has been developed based on this numerical method, and realizes to analyze the stability of ideal MHD modes with a wide range of toroidal mode number *n* [1,2]. In this collaboration, we execute the benchmarking test of this MARG2D code with the DCON code [3] for a low-*n* mode stability analysis, and that with the ELITE code [4,5] for an intermediate / high-*n* mode analysis.

Figure (a) shows the dependence of the β_N limit on the wall position d/a. These dependences identified with MARG2D and DCON are almost identical to each other. Unfortunately, since the DCON code used in this benchmarking (ver. 3.2) cannot output the marginally stable eigenfunction, we cannot compare the radial structure of the eigenfunction. However, in a up-down symmetric equilibrium, the benchmarking tests between MARG2D and the ERATOJ code [6] have been executed in Ref. [2], and the radial structures of the marginally stable eigenfunctions have been identified as almost same as each other.

Figure (b) shows the toroidal mode number *n* dependence of the growth rate γ normalized with the toroidal Alfv´en frequency on the magnetic axis ω_A. The agreement between MARG2D and ELITE is quite good, and as shown in Ref. [7], the radial structures of the most unstable eigenfunction obtained with MARG2D and ELITE are almost identical to each other. The results of these benchmarking tests show the validity of the MARG2D code for the stability analysis of not only low-*n* but also intermediate / high-*n* MHD modes [7].

With this code, we investigated the MHD stability property in JT-60SA, the complemented device for ITER focusing on effect of the plasma shape. These stability analyses show that the highly shaped plasma designed for achieving high performance discharges in JT-60SA is suitable for stabilizing not only low toroidal mode number MHD modes, which restrict the β_N limit of discharges, but also intermediate to high toroidal mode number MHD modes, which relate to the edge pedestal performance and ELM phenomena. For not only the experimental analysis of existing devices but also the design of ITER and JT-60SA, MARG2D realizes the stability analysis of the various kinds of ideal MHD modes that restrict the beta limit and the pedestal performance.

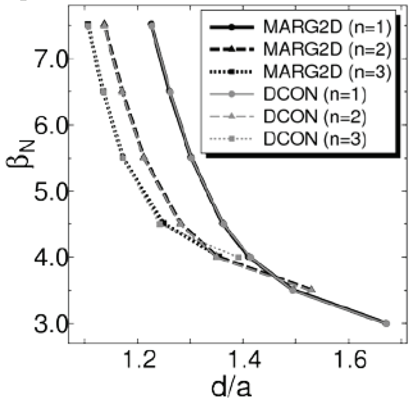

Fig. 1: Dependence of the β_N limit on the wall position *d/a*. Each dependence of the β_N limit restricted by the *n* = 1, 2, 3 MHD modes stability estimated with MARG2D is almost identical to that calculated with DCON.

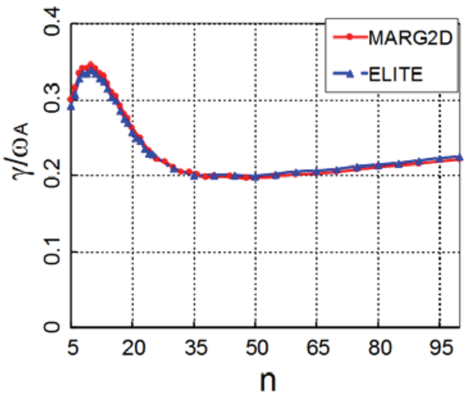

Fig. 2: Dependence of γ / ω_A on n calculated with MARG2D (solid line) and ELITE (broken line). The agreement between both codes is quite good.

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Rotation effect on RWM stabilization

Category : Doublet III
Year-Number : 2003-DO-5, 2004-DO-6, 2006-DO-2
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To realize an economical fusion reactor, stabilization of the low-*n* kink-ballooning mode is necessary: An economical fusion reactor, in its steady state, relies largely on the spontaneously flowing bootstrap current for its plasma current that produces the confining magnetic field, because this can reduce the externally driven current. But such plasma has generally a hollow current profile and is susceptible to the low-*n* kink-ballooning mode, which can limit the achievable beta. The growth rate of the external kink-ballooning mode can be reduced with a close-fitting conducting wall, and the resulting mode, the so-called resistive-wall mode (RWM), has a growth time corresponding to the time constant of the relaxation of the wall current [1]. There are two different procedures for stabilizing RWM. The first is the feedback control stabilization using externally applied nonaxisymmetric magnetic fields with coils in order to compensate for the diffusion of flux [2]. The second is stabilization of RWM by toroidal plasma rotation. Bondeson and Ward showed that RWM could be fully stabilized with resistive walls when the plasma rotation is sufficiently large [3]. Both theories and experiments imply that the critical rotation velocity is around 1% - 2% of the Alfvėn velocity. This estimated critical rotation is comparable to a predicted toroidal rotation of 2% of the Alfvėn velocity at plasma center and much larger than 0.3% of that in the peripheral region including the q = integer surface for the ITER advanced scenario. The most significant problem in the previous experiment is that investigation of the critical rotation is performed with magnetic braking by adding an asymmetric magnetic field, the so-called error field. It has been pointed out that the error field plays a very important role in the destabilization of RWM and should be substantially reduced near the no-wall limit. Since RWM stability itself is affected by the error field, which is the origin of magnetic braking, we should not use magnetic braking in the investigation of critical rotation.

A very low rotation threshold was obtained in the JT-60U in an investigation of the critical rotation for stabilizing RWM by controlling the toroidal plasma rotation with changing the combination of tangential neutral beams (NBs) without magnetic braking [4-6]. The observed critical rotation is V_t~20 km/s and corresponds to 0.3% of the Alfvėn velocity at the $q = 2$ surface, much smaller than the previous prediction with magnetic braking (Fig. 1). This low critical rotation does not increase as increases toward the ideal wall limit. Also an ITER relevant low rotation (~0.4% of the Alfvėn velocity) stabilization of RWM is demonstrated for 50 times the skin time of the first wall. These results indicate that for large plasmas such as in future fusion reactors with low rotation, the requirement of the additional feedback control system for stabilizing RWM is much reduced.

Around the same time, similar experiments were performed on DIII-D. High-β DIII-D experiments with the new capability of balanced neutral beam injection also show that the resistive wall mode (RWM) remains stable when the plasma rotation is lowered to a fraction of a per cent of the Alfv´en frequency by reducing the injection of angular momentum in discharges with minimized magnetic field errors [7,8]. A toroidal rotation frequency of less than 10 krad/s at the q = 2 surface corresponding to 0.3% of the inverse of the toroidal Alfve´n time is sufficient to sustain the plasma pressure above the ideal MHD no-wall stability limit (Fig. 1). The low-rotation threshold is found to be consistent with predictions by a kinetic model of RWM damping. Previous DIII-D experiments yielded a high plasma rotation threshold (of order a few per cent of the Alfv´en frequency) for RWM stabilization when resonant magnetic braking was applied to lower the plasma rotation. They propose that the previously observed rotation threshold can be explained as the entrance into a forbidden band of rotation that results from torque balance including the resonant field amplification by the stable RWM.

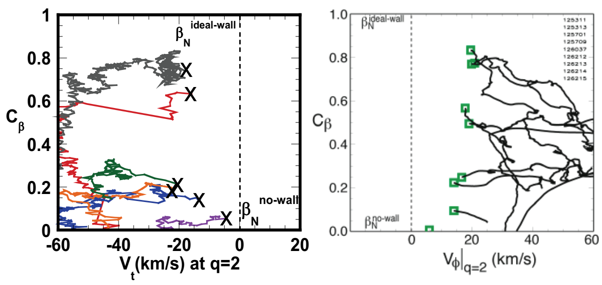

Fig. 1. Trajectories of the C_β versus toroidal rotation at q = 2 for JT-60U (left) and DIII-D (right). The crosses and squares denote the onset points of RWM on JT-60U and DIII-D, respectively [6,8].

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CHAPTER 7 HFIR

This program has contributed for thirty years to the development of fusion reactors by the scientific and engineering products about the irradiation damage on the structural materials obtained by U.S. and Japanese Scientists.

7.1 Objectives

The objective of this collaboration is to design, conduct and evaluate joint irradiation experiments in the High Flux Isotope Reactor (HFIR) of the Oak Ridge National Laboratory for the purpose of investigating the irradiation response of Japanese and U.S. structural and special purpose materials to high levels of atomic displacement and Helium content in order to establish the database on the properties and behavior of such materials and to evaluate their performance for the use in future fusion reactors.

7.2 Activities

The collaborative Program consists of the following;
(1) Planning of the collaborative program;
(2) Design and conduct of irradiation experiments in HFIR;
(3) Technology development for evaluation, post-irradiation testing;
(4) Exchange of personnel and information necessary to carry out the collaborative program; and
(5) Exchange of results arising from the collaborative program.

Five phases of the collaborative Program have been completed. These phases had begun in '83, '88, '94, '99 and 2004, respectively. Post phase V activity has been started in 2009 and is expected to continue until 2014.

Phase I of the program focused on the effects of high concentrations of transmutation produced helium coupled with displacement damage on mechanical properties and swelling behavior of the Japanese and U.S. austenitic stainless steels. Phase II was also devoted to the understanding of the irradiation effects of austenitic alloys. Spectral and isotopic tailoring techniques were developed and utilized to reproduce the ratio of the generation rates of helium and the displacement damage (He/dpa ratio) typical of the fusion reactor environment. Also, irradiation behavior of the variety of weld materials was evaluated. In Phase III of the program, examination of the irradiation response of advanced materials for DEMO reactors was initiated. Materials of the reduced activation ferritic/martensitic (RAF/M) steels, vanadium alloys, SiC/SiC composites and titanium aluminides were included. Also, in situ test techniques to evaluate thermal conductivity and electro-resistivity of ceramic materials (SiC/SiC composites, Alumina etc.) during irradiation have been developed in the collaboration, and the measurements were carried out. The objectives of the Phase IV program were (a) development of improved methods for predicting the in-service operation of first wall and blanket structure utilizing RAF/M steels and development of a high quality database on the mechanical behavior of F82H (a RAF/M steel developed by JAEA and JFE corp.), including the effects of helium generation and (b) resolution of fundamental issues of flow and fracture in BCC alloys and in particular those issues related to the simultaneous generation of displacement damage and helium in F82H and related alloys. As a major goal of Phase V program, both Japanese and U.S. sides recognized the importance to provide the critical irradiation performance data on RAF/M steels without which it will not be feasible to proceed with the design, construction and operation of the TBMs in ITER. To utilize the irradiation program to explore nano-scale microstructural strategies designed to minimize the impact of high levels of displacement damage and helium damage on mechanical behavior was determined to be another goal of Phase V program. Results of this work also provided a scientific basis of innovative and RAF/M steels for critical structural components for DEMO.

7.3 Administration

The general management of the Collaborative Program has been carried out by a Steering Committee. The Steering Committee has been composed of four members, two each are assigned by JAEA and DOE and conduct following assignments.

(1) Plan the Collaborative Program, and develop the annual work plan which shall be included the annual budget and the financial contributions of JAEA and DOE.

(2) Review the cost and the projection of expenditures.

(3) Review plans for joint paper publication.

(4) Discuss personal assignments.

(5) Recommend the annual program of work, budget and personnel assignments and other such matters to JAEA and DOE approval.

(6) Report to the Japan-U.S. Coordinating Committee on Fusion Energy through the Contact Persons on the technical progress in the current annual work and make recommendations for approval of the next annual work plan and budget and for the financial contributions of JAEA and DOE to the Collaborative Program to the next annual program of work.

7.4 Accomplishments and Highlights

One of the major outcomes from Phase I of the program is the optimization of the chemical composition and the heat mechanical treatment of the Japanese and U.S. austenitic stainless steels. The features of phase II are (i) utilization of the spectral and isotopic tailoring techniques to reproduce the ratio of the generation rates of helium and the displacement damage (He/dpa ratio) typical of the fusion reactor environment, and (ii) the evaluation of irradiation behavior of the variety of weld materials. Results from phase I and II are utilized to establish service conditions of the austenitic alloys for the first wall of ITER, although the postulated service conditions at the beginning of the Program was considerably different from that of ITER.

One of the major accomplishments during phase III is the development of the Japanese and U.S. RAF/M steels. These steels exhibited superior resistance for irradiation and is expected to have low induced activities after fusion neutron irradiation. Another important result of phase III is the evaluation of electrical and thermal properties of ceramics under irradiation using the in-situ measurement technique.

During the Phase IV program; (a) test method development to examine helium effect on microstructural and mechanical property changes, as well as small size specimen technique development to increase the number of specimens loaded in the irradiation capsule by optimizing specimen configuration; (b) development of innovative/advanced materials, such as SiC/SiC composite exhibiting superior resistance for irradiation damages; and (c) extending the knowledge about the irradiation performance of RAF/M (F82H was used as a reference alloy), including the stress level, damage level and temperature dependence of irradiation creep and the effect of heat treatment condition on post irradiation tensile properties have been also accomplished.

Improvement of small size specimens (e.g. pre-cracked bend fracture specimens) has been also carried out during Phase IV and utilized to evaluate post-irradiation fracture toughness of RAF/Ms during Phase V of the program. Irradiation response, especially reduction of fracture toughness and ductility has vital importance for the application of RAF/Ms to TBMs and in-vessel components of the DEMO. During the Phase V, mechanical properties after irradiation to 20 dpa at temperatures between 300^{o}C and 500^{o}C have been examined to expand irradiation materials database prepared in the previous phases of the program. F82H and its variants, as well as advanced U.S. ferritic/martensitic steels were used. The variants were irradiated for "tightening of heat treatment condition" and "evaluating the effect of tantalum addition". Results indicated that residual ductility and fracture toughness of RAF/Ms including shift in ductile to brittle transition temperature (DBTT) remained in the ranges appropriate for the fusion systems; DBTT (<100^{o}C) was lower enough than service temperature and considerable level of residual ductility (reduction of area >50% at 7.9 dpa) was maintained. As for the irradiation effect on these two of the critical mechanical properties, RAF/Ms (e.g. F82H and ORNL 9Cr) exhibited their feasibility for in-vessel components to a damage level of 20 dpa. Variants of F82H and ORNL 9Cr exhibited superior performances, such as lower post irradiation DBTT (lower than room temperature). This and the saturation tendency of ductility and toughness degradation with damage levels are suggesting their feasibility to higher damage levels. Result of irradiation induced microstructural change revealed the mechanism of the superior irradiation response found in the specimens for "tightening of heat treatment condition experiments". As for advanced nano-composite ferritics (NCFs) and SiC/SiC composites, high stability of nano-oxide particles during aging and irradiation has been demonstrated, as well as the outstanding irradiation resistance of high purity/near stoichiometric SiC/SiC composite. Efforts for the resolution of fundamental issues of flow and fracture of BCC alloys and for exploring nano-scale microstructural strategies designed to minimize the impact of high levels of displacement damage and helium damage made a good progress. Development of the technique to introduce helium atoms in RAF/Ms with adjustable He/dpa ratio using Ni (NiAl alloy) plating on specimen surface has been successfully demonstrated. Development of both atomistic model and macroscopic model of the irradiation effects has been also conducted. These modeling activities have been also carried out to understand fundamental issues of irradiation damages on flow and fracture of BCC alloys, as well as to obtain fundamentals for the development of structural designing methodologies of intensely irradiated components. After the period of phase V, examination of the irradiation effects on fatigue and creep properties as well as critical short term properties of ductility and fracture toughness of various joints are expected to be accomplished with precisely adjusted production ratio of helium atoms and displacement damage rates relevant to fusion neutrons (10appmHe/dpa) to establish database and macroscopic models of irradiated RAF/Ms for the development of TBMs. This and the examination to higher damage levels (>50dpa and 500appmHe) is also going to be conducted to supply the basic knowledges for DEMO application. Modeling activities are expected to play vital roles to establish design methodologies of intensely irradiated structures and the development of innovative materials including NCFs and SiC/SiC composites.

List of accomplishments during five phases; Highlights for Phase IV and V are attached

(i) Austenitic stainless steel

(i-1) Irradiation response to high damage levels (to 50 dpa) (Phase I)

(i-2) Behavior of weldment (Phase II)

(i-3)Spectral tailoring experiment to obtain appmHe/dpa ratio for fusion (Phase I and II)

(i-4) Fracture toughness of austenitic steels (Phase II)

(i-5) Irradiation assisted stress corrosion cracking (IASCC) (Phase III)

(ii) In situ testing

(ii-1)In-situ electrical and thermal conductivity measurement of ceramics (Phase III)

(iii) Reduced activation ferritic/martensitic (RAF/M) steel

(iii-1) Development of RAF/M steels (Phase II and III)

(iii-2) Fracture behavior of RAF/M steels (Toughness and ductile-to-brittle transition temperature) (Phase IV and V, Highlights No. 1, 2, 3 and 4)

(iii-3) Tightening of heat treatment condition and the evaluation of the effect of tantalum (a minor alloying element) (Phase V, Highlights No. 1, 4 and 5)

(iii-4) Irradiation creep (Phase IV, Highlights No. 1 and 7)

(iv) Test methods

(iv-1) Small size specimen technology (Phase IV and V, Highlight No. 4 and 7)

(iv-2) In situ helium implantation technique (Phase V)

(v) Modeling

(v-1) Behavior of helium atoms in steels (Phase V, Highlight No. 8)

(v-2) Constitutive equation of irradiated RAF/M steel (Phase V, Highlights Nos. 1 and 9)

(vi) Innovative/advanced materials

(vi-1) SiC/SiC composite (Phase IV and V, Highlight No. 10)

(vi-2) Nano-composite ferritics (Phase IV and V, Highlight No. 1)

Irradiation effects on deformation and fracture of reduced activation ferritic steels

Category: Fusion engineering/HFIR
Year-Number : 04-09 - No. 1

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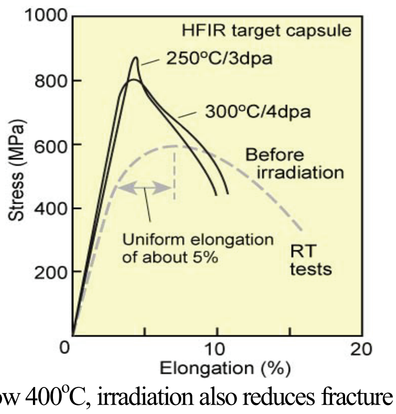
Reduced activation ferritic steels (RAFs) are candidate structural materials for in-vessel components of a DEMO. The service temperature is expected to range between 300 and 550°C while 14MeV D-T fusion neutron irradiation introduces displacement damage to 100-150 dpa and damage from transmutation produced atoms (e.g. He atoms with production rate of 10-15 appmHe/dpa) to cause reductions of elongation, fracture toughness and fatigue life, as well as dimensional changes by irradiation creep and swelling[1]. Therefore, the DOE-JAEA collaborative experimental program using HFIR has been conducted to investigate the irradiation response of RAFs. Japan's F82H was chosen as a reference heat with objective of producing an irradiation materials database, while analyzing deformation and fracture for the modeling of the irradiation effects. The results indicate that degradation by displacement damage is manageable for the doses examined [2]. Moreover, tightening/optimization of heat treatment conditions reduced radiation-induced embrittlement, suggesting the feasibility of RAFs for the DEMO[2, 3]. Analysis on deformation and fracture also provided post-irradiation constitutive equations. This and the fracture behavior are essential for developing a design methodology.

Effects of irradiation on tensile, fracture and creep properties are summarized, as well as the analysis of deformation. Methods to improve post irradiation fracture resistance are also introduced.

1) Tensile property: Below 400°C, irradiation often causes hardening and reduction of elongation (see, Fig. 1). The reduction of elongation has been recognized as an issue, however detailed analysis revealed that relatively large ductility remained even after irradiation [4]. Moreover, tightening/optimization of the heat treatment condition was found to keep post irradiation ductility even higher [3].

Fig.1 Engineering stress-strain relations of F82H before and after irradiation[2]. Irradiation reduces elongation (One of the issues).



2) Fracture toughness: Below 400°C, irradiation also reduces fracture toughness and upper shelf energy, and increases the shift in ductile to brittle transition temperature (DBTT). Fig. 2 shows DBTT-shift of several ferritic steels by irradiation. It should be noted that DBTT-shifts of RAFs are smaller than those of conventional steels. 14 MeV high energy D-T neutrons introduce He atoms at a high rate and is thought to cause additional toughness degradation. Doping of ^{58}Ni and ^{10}B introduces He atoms during irradiation of RAF in HFIR. Fractography revealed that 300-400appmHe introduced a change in the mechanism of cracking to promote failure at crystallographic boundaries, although it introduced no apparent change in DBTT-shift [4, 5]. On the other hand, reduction of the post irradiation DBTT has been successfully achieved by tightening/optimization of heat treatment condition before irradiation (see, Fig. 3) [5].

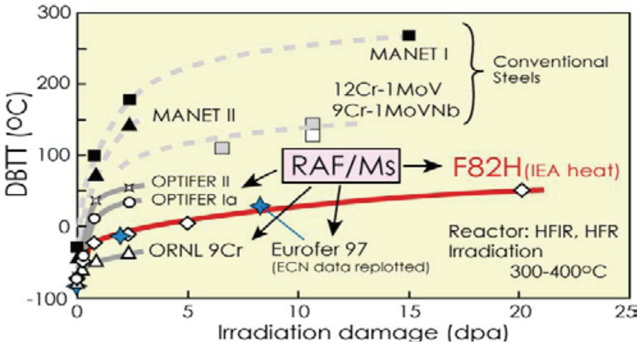
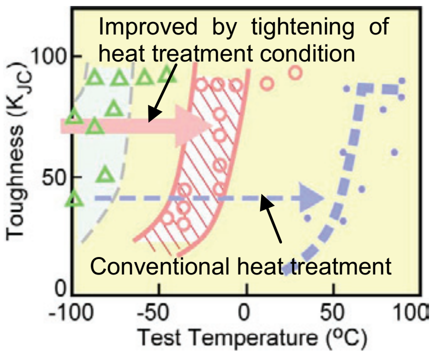


Fig.2 Damage level dependence of DBTT for F82H [2]. F82H exhibits smaller DBTT-shift than conventional steels.

Fig.3 Improvement of DBTT-shift by tightening/optimization of heat treatment [5]. Lower postirradiation DBTT was achieved.



3) Irradiation creep: Irradiation creep strain has been evaluated from diametral change of pressurized tube specimens. At 300 and 500°C, creep strains were rather small and almost proportional to hoop stress below 380 and 180 MPa, respectively [6].

4) Modeling of deformation and fracture (Macroscopic models): Analysis of the deformation of tensile specimens with macroscopic defects (e.g. holes) has been conducted to evaluate constitutive equation after irradiation [7]. The strain distribution was measured with 3D image analysis equipment and optical microscopy. Either Ludwik or Swift type constitutive equations was applied, and stress-strain relations have been successfully reproduced to fracture strain levels. This provides the fundamentals required for a design methodology for components under intense neutron irradiation [2].

5) Microstructure and alloy development: Microstructural examinations including fractography have been conducted. The results indicate the deteriorating effects of inclusions containing Ti and N, as well as that by other complex inclusions [8]. Dispersion of Ti and Y containing nano-scale oxide particles in RAF has been successfully achieved by mechanical alloying. One of the alloys, 14YWT exhibited superior strength at high temperatures [9].

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[4]R.L.Klueh et al., J. Nucl. Mater., 357 (2006) 156–168
[5]N. Okubo et al., to be published
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Fracture Toughness of HFIR Irradiated Tempered Martensitic Steels

Category : Fusion engineering/HFIR
Year-Number : 2004-09 - No.2,
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Irradiation embrittelement, as characterized by upward shifts (ΔT_o) in the cleavage fracture toughness master curve (MC), is one of the key issues that control the operation window of the 8-9Cr-1-2W normalized and tempered martensitic steels (TMS) in fusion reactor first wall applications. At irradiation temperatures less than ≈ 400°C, the ΔT_o are primarily due to irradiation hardening, $\Delta\sigma_y$. One of the keys to understand and model the mechanism is to obtain the correlation between ΔT_o and $\Delta\sigma_y$.

Large number of small pre-cracked bend bar (PCBB) specimens, with single or multiple cracks, of several TMS were irradiated from 300 to 500 °C in HFIR target capsules, JP26 and JP-27, up to≈ 22 dpa. Figure 1 summarizes the results for F82H IEA and F82H mod.3 heats. Figure 1a shows ΔT_o of the IEA heat as a function of neutron dose at four irradiation temperatures. There are clear trend showing less embrittlement at higher irradiation temperature corresponding to the irradiation hardening trend, except: 1) the 300ºC embrittlement trend shows no sign of saturation up to 20 dpa, 2) the embrittlement insists beyond the temperature of ≈ 450 ºC where the irradiation hardening turns to softening regime. The F82H mod.3 heat seems to show less embrittlement than the IEA heat at the same dose level; however this needs further confirmation.

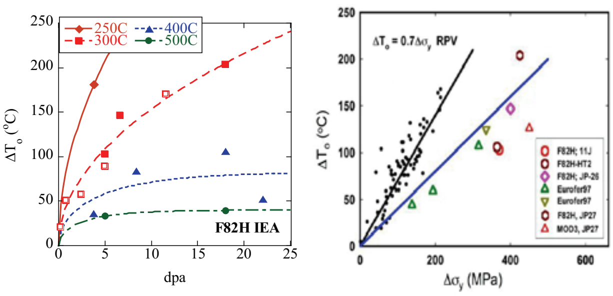

Fig. 1 a) Toughness reference temperature shift, ΔT_o, of F82H IEA heat as a function dpa at four irradiation temperatures; b) ΔT_o vs. $\Delta\sigma_y$ relation for various TMS steels obtained using PCBB specimens, compared to RPV database by Sokolov et al.[1]

Figure 1b summarizes relation between ΔT_o and $\Delta\sigma_y$ for the TMS measured using similar small specimens, compared with reactor pressure vessel (RPV) steel data collected by Sokolov [1] primarily using larger specimens. The TMS data show $\Delta T_o/\Delta\sigma_y$ ratio of≈ 0.4 significantly smaller than that for RPV steels of≈ 0.7. The major reasons for the low $\Delta T_o/\Delta\sigma_y$ ratio are believed to be due to 1) loss of strain hardening capacity in the irradiated TMS, and 2) constraint loss (CL) in the small specimens. The fracture toughness, K_{Jm}, measured using small specimens is generally higher than those obtained from larger, conventional specimens, due to both statistical stressed volume (SV) and CL size effects. Size adjustment procedure developed for RPV steel [2] has successfully been applied to a large database of F82H K_{Jm} measured on specimens of various size and geometry [3]. The size adjustment procedure has been applied to a subset of the JP-26 irradiated specimen data. The CL adjustment is based on finite element analyses (FEA) of the crack tip stress field for actual specimen geometry compared to an ideal small scale yielding condition. The SV effect is adjusted by modified $B^{-1/4}$ scaling as is incorporated in ASTM E 1921 Master Curve standard. Details are given in ref [4]. Figure 2a shows B-adjusted toughness data before (K_{JB}) and after (K_{Jr}) the CL adjustment for F82H-IEA irradiated to≈ 7 dpa at 300 ºC. The CL adjustment resulted in ΔT_o ≈ 200 ºC, ≈ 60 ºC more than the unadjusted case. The $\Delta T_o/\Delta\sigma_y$ of≈ 0.56 after adjustment is consistent with larger CT specimen data as shown in Figure 2b, while it is still smaller than the RPV data. The effect of strain-hardening loss in irradiated TMS can be accounted for using the change in flow stress, resulting in more consistent $\Delta T_o/\Delta\langle\sigma_{fl}\rangle \approx 0.68$ in good agreement with the theoretical study by Odette et al. [5] shown in Figure 2c. The CL-adjusted ΔT_o data also showed good agreement with a hardening based prediction model [6] shown in Figure 2d. This research is on going.

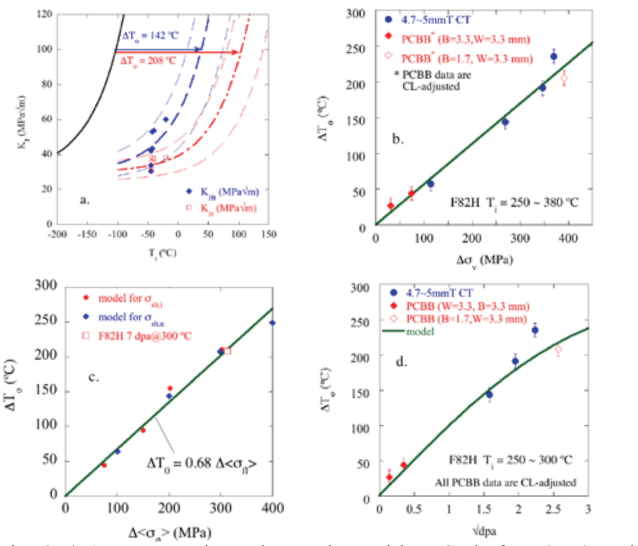

Fig. 2 a) 1T-conveted toughness data with MCs before (K_{JB}) and after (K_{Jr}) CL adjustment; b) ΔT_o vs. $\Delta\sigma_y$ relations in CL-adjusted PCBB or CT specimens of irradiated F82H-IEA; c) ΔT_o vs. $\Delta\langle\sigma_{fl}\rangle$ (flow stress change) compared with theoretical relation study[5]; d) ΔT_o in relatively high constraint specimens of F82H irradiated at ≈ 300ºC with a model prediction[6].

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Charpy impact properties of reduced-activation ferritic/martensitic steels irradiated in HFIR up to 20 dpa

Category: Fusion engineering/HFIR
Year-Number : 04-09 - No. 3
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Irradiation up to 11 dpa at temperatures below 400°C indicated that the magnitude of the shift in ductile-brittle transition temperature (DBTT) to a higher temperature depends on irradiation dose. This is important because 100°C is expected to be the lowest temperature of fusion reactor blankets [1-3]. Current interest is to determine whether or not there is a dose at which the change in DBTT saturates, and to know the degradation level of toughness at saturation. Additionally, the effect of transmutation-formed helium on the mechanical properties, especially fracture toughness, is one of the most important issues that need to be understood for expected power plant reactor application. The effects of irradiation up to 20 dpa on the Charpy impact properties of reduced-activation ferritic/martensitic steels (RAFs) were investigated.

The irradiation dose dependence of the shift in DBTT (ΔDBTT) for F82H-IEA is summarized in Fig. 1. Irradiation up to 5 dpa at 300°C shifted the DBTT up to near room temperature, and there was no obvious indication suggesting a saturation of the DBTT shift. On the other hand, the DBTT was not further increased by an increase in irradiation from 11 dpa [3] to 20 dpa at 380°C. This result indicates the ΔDBTT induced by irradiation around 380°C was saturated at 11 dpa.

The effects of prior austenite grain size on DBTT shift were investigated by comparing F82H-IEA (ASTM grain size 3.3) to F82H-HT2 (ASTM grain size 6.5). The fine grain structure in F82H-HT2 was obtained by renormalizing F82H-IEA using a lower austenitization temperature (920°C). The results show that the DBTT of both unirradiated and irradiated HT2 are slightly (~20°C) lower than for F82H-IEA, and the finer-grain F82H-HT2 has a higher USE than F82H-IEA. (see Fig. 2). From these results, it is concluded that F82H-HT2 benefited from the fine grain size after irradiation compared to F82H-IEA steel.

The correlation between ΔDBTT and yield stress increase ($\Delta\sigma_y$) is shown in Fig. 3 for F82H-IEA, F82H-HT2, F82H+2Ni, 9Cr-2WVTa and JLF-1. The three F82H variants follow the same trend. Ni-doped specimens are also on the same trend. From these data, the large ΔDBTT of Ni-doped F82H could be explained as the effect of radiation hardening, just as the other steels. The values for 9Cr-2WVTa and JLF-1 are slightly lower than the main trend. The reason for this difference between F82H and the two 9Cr steels was not clarified in this study, and will be investigated further in the future.

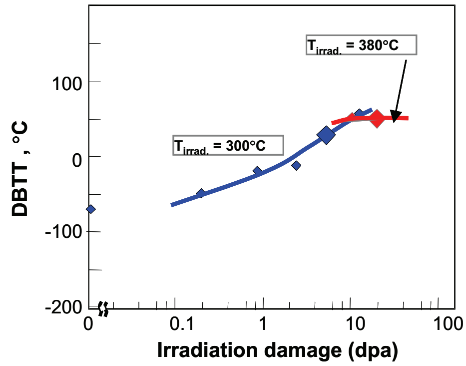

Fig. 1. Irradiation damage dependence of the DBTT of F82H-IEA irradiated at 300°C and 380°C. Data points indicated by small squares were reported elsewhere [3].

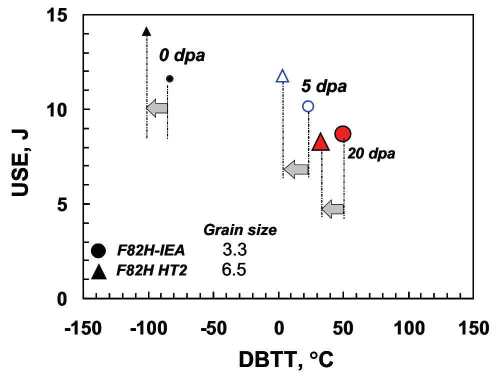

Fig. 2. Effect of prior austenite grain size on Charpy impact properties.

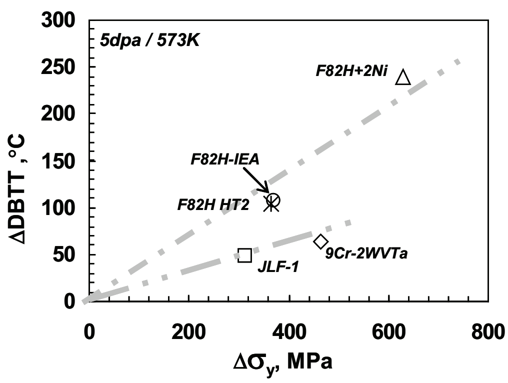

Fig. 3. Relation between DBTT shift and yield stress increase.

1. K. Shiba, M. Suzuki and A. Hishinuma, J. Nucl. Mater. 233-237 (1996) 309
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Heat Treatment Effect on Fracture Toughness of F82H Irradiated at HFIR

Category: Fusion engineering/HFIR
Year-Number : 04-09 - No. 4
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JAEA, *ORNL.

The reduced activation ferritic/martensitic (RAF/M) steel F82H is recognized to be a leading candidate material for in-vessel components in a future fusion DEMO reactor, as well as that for ITER test blanket modules (TBM) in Japan [1]. Examination of the neutron irradiation response of RAF/M steels has been carried out mainly in DOE-JAEA collaborative experiments using the High Flux Isotope Reactor at Oak Ridge National Laboratory. F82H is the reference heat for the collaborative experiments. The results of recently completed post-irradiation examination demonstrated a significant improvement in the irradiation-induced degradation of fracture toughness after optimizing and tightening the heat treatment condition. The degradation of fracture toughness was evaluated by the shift of ductile to brittle transition temperature (DBTT-shift). The optimization and tightening of tempering condition are also revealed to be effective for maintaining post-irradiation ductility. DBTT-shift and reduction of ductility by irradiation have been recognized to be critical issues for RAF/M steels; therefore, the beneficial effect of the optimization of tempering condition may be extended to the service conditions of RAF/M steels.

After irradiation, the DBTT is known to be dominated by hardness or flow stress level. Some of the tensile results of irradiated weld joint specimens indicated that the post-irradiation flow stress level might be reduced by modification of tempering conditions [2]. Based on this knowledge, ion and neutron irradiation experiments have been carried out to examine the dependence of post-irradiation hardness and ductility on tempering conditions using hardness and tensile specimens, respectively [3]. The specimens were tempered between 700 and 800°C for 0.5 to 10 hrs before irradiation. Results showed that longer tempering times are beneficial for reducing the post-irradiation hardness. Miniaturized bend bar specimens (half size of 1/3-CVN specimen) with a fatigue pre-crack were tempered at a higher temperature and/or for a longer time. The specimens were irradiated to 20 dpa and tested at several temperatures. Figure 1 shows the results. Data points for IEA-F82H show the result for a reference tempering condition of 750 °C for 1h. Data for a longer tempering time (700°C for 10 hrs), noted as a "Mod1 Series" clearly exhibit lower DBTT after irradiation. The DBTTs are about 0 and 50°C for Mod1 and IEA, respectively. The DBTT reduced by about 50°C. Although the 20 dpa damage level is much less than the target of 100 dpa for DEMO, the tendency for the DBTT-shift to saturate with increasing damage level suggests that the large improvement of irradiation performance of DBTT would be maintained at higher damage levels.

Results of irradiation experiments on mechanical properties at temperatures from 250 to 500°C at damage levels up to 20 dpa indicated that the irradiation effects were in a manageable range. Improvements of post-irradiation toughness and ductility by optimization and tightening of tempering condition are quite beneficial to expand the service condition of RAF/M and seem to deliver more flexibility for DEMO design. The methodology of improving post-irradiation toughness and ductility is also expected to be applicable for other RAF/M steels.

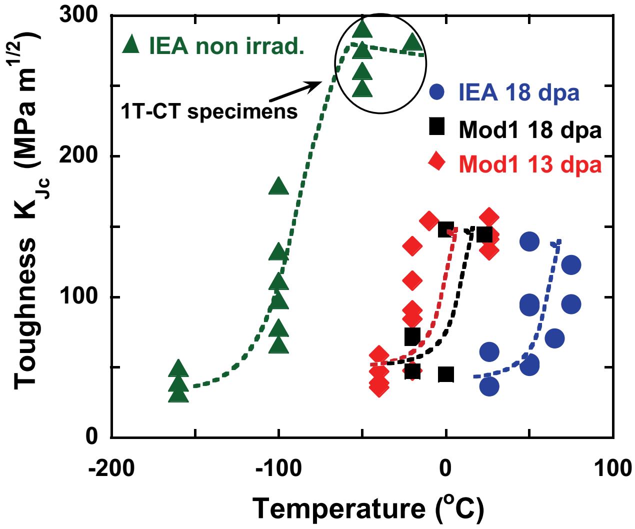

Fig. 1. Temperature dependence of fracture toughness of F82H specimens irradiated to 18 dpa Results indicate substantial reduction of the effect of radiation on fracture toughness due to optimization/tightening of tempering conditions. Miniaturized bend bar specimens were used. Data shown in the circle were measured from large size (1T-CT:1 inch thickness) specimens.

[1] A. Hishinuma, A. Kohyama, R. L. Klueh, et al., J. Nucl. Mater. 258-263(1998)193.
[2] K. Shiba, R.L. Klueh, Y. Miwa, N. Igawa and J.P. Robertson, DOE/ER-0313/28(2000)131.
[3] M. Ando, H. Tanigawa, E. Wakai, and R.E. Stoller, J. Nucl. Mater. 386-388(2009)315.

Microstructure and hardness variation in a TIG weldment of irradiated F82H

Category: Fusion engineering/HFIR
Year-Number : 04-09 - No. 5
H. Tanigawa, M. Ando, T. Sawai, K. Shiba, .R.L.Klueh*, R.E.Stoller*, N. Hashimoto**
JAEA, *ORNL, **Hokkaido Univ.

To validate the potential of reduced-activation ferritic/martensitic steel (RAFM) as a structural material for fusion power plants, the methodology for joining the steel to form welds with adequate toughness before and after irradiation must be developed. An irradiated tungsten inert-gas (TIG) weld (weld metal, base metal and heat-affected zone (HAZ)) of the IEA-modified F82H (F82H-IEA) was investigated. Post-irradiation tensile tests and a hardness trace across the irradiated weld joint was conducted to investigate the mechanical property changes of the TIG weld and to identify the location of the weld that was involved with this low hardening.

Post-irradiation tensile tests of F82H-IEA TIG weldment specimens were conducted. The results indicated that the weld metal exhibited nearly the same irradiation hardening as the base metal, but the HAZ showed far less hardening than the base metal (Fig. 1).

The microstructure of the TIG weldment is shown in Fig. 2. The microstructure consisted of 3 regions; i.e., weld metal, HAZ, and base metal. The HAZ can be further divided into 3 regions with obviously different microstructures, and those regions are denoted with circled numbers in Fig. 2. Here we call the boundary line between region 1 and region 2 the transformation line, since the $\alpha-\gamma$ transformation occurred during welding within the region inside these lines. It should be noted that the microstructure of the weld metal was rather fine except for the last pass region, and the HAZ was wider than that of a single-pass weldment, since a multi-pass TIG weld was used.

The microhardness profiles across the weld joint are shown in Fig. 3. Figure 3 (a) shows that minimum hardness was obtained for both unirradiated and irradiated specimens in the "over-tempered region," the region next to the transformation line in region 1. On the other hand, both the minimum ΔHv and the minimum hardening ratio were obtained in the "over-tempered region" (region 1) and "fine-grain region" (region 2) located next to the transformation line in region 2.

The tensile results suggest that a TIG weld joint of F82H exhibited low irradiation hardening in a tensile test, compared to the base metal, and microhardness tests and microstructure observation revealed that the over-tempered zone in the HAZ exhibited similar good performance, i.e., low irradiation hardening. Hashimoto et.al. performed transmission electron microscopy to analyze the microstructure of these regions in the irradiated weldments [2]. No visible dislocation loops were observed in the over-tempered region and the fine-grained region. Small dislocation loops were the main microstructural features in F82H irradiated up to 5 dpa at 573K. This result indicates that more active point defect absorption and re-combination took place in those regions, and they show smaller irradiation hardening as a result.

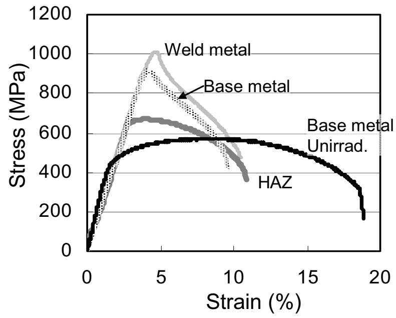

Fig. 1. Tensile results of irradiated weldments and unirradiated base metal [1].

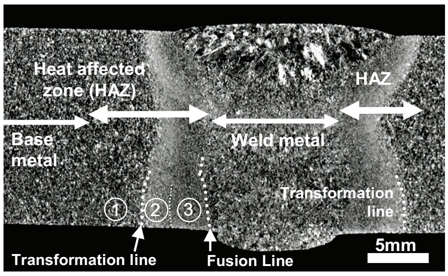

Fig. 2. Microstructure of TIG weldment and the definitions of the different regions.

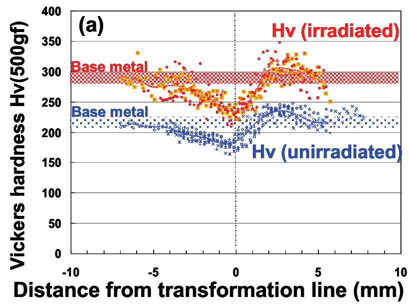

Fig. 3. The profile of hardness over irradiated and unirradiated weldments

1. K. Shiba, R.L. Klueh, Y. Miwa, N. Igawa, and J.P. Robertson, Fusion materials semiannual progress report, DOE/ER-0313/28 (2000) 131
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Irradiation effects on precipitation in reduced activation ferritic steels

Category: Fusion engineering/HFIR
Year-Number : 04-09 - No. 6
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Reduced-activation ferritic/martensitic steels (RAFs), such as F82H-IEA and its variants, ORNL9Cr-2WVTa, JLF-1 and 2%Ni-doped F82H, show a variety of changes in ductile-brittle transition temperature (DBTT) and yield stress after irradiation at 573K up to 5 dpa [1]. These differences could not be interpreted as an effect of irradiation hardening caused by dislocation loop formation.

The effects of irradiation on precipitation of RAFs were investigated to determine how these effects might affect the mechanical properties. The precipitation behavior of the irradiated steels was examined by weight analysis, X-ray diffraction analysis and chemical analysis on extraction residue.

The mass of extracted residue before and after irradiation is shown in Fig. 1. Here the mass of residue obtained with the coarse filter (column denoted 'Large') is interpreted as the value corresponding to the mass of large precipitates, and the difference of mass obtained with the fine filter and the coarse filter (column denoted 'Small') is interpreted as that of the small precipitates. These results indicate that during irradiation (1) the mass of larger precipitates increased in F82H-IEA, JLF-1, ORNL9Cr and F82H+2Ni, (2) small mass change occurred in F82H HT2, (3) small precipitates disappeared in JLF-1, and (4) the amount of small precipitates doubled in F82H+2Ni.

The chemical composition of extracted residue was analyzed and the results show that (1) the precipitates consisted mainly of Cr, Fe, V and W, (2) Cr increased after irradiation of each RAF except for JLF-1, and (3) W decreased after irradiation. It should be noted that (1) about half of the Ta was included in precipitates before irradiation but dissolved after irradiation in JLF-1 and ORNL9Cr, and (2) the amount of Ni in precipitates from F82H+2Ni doubled after irradiation.

The XRD analysis of extracted residue (Fig. 2) revealed that the majority of precipitates are $M_{23}C_6$ type (denoted with diamond mark) for all unirradiated and irradiated steels. Three distinctive peaks (denoted with triangle) are observed on unirradiated JLF-1 and ORNL9Cr, and those peaks are not detected on irradiated specimens. There is no exact match pattern for those peaks, but the best match is for the TaC. This supposition is quite reasonable as a high number density of Ta- and V-rich precipitates is observed in these steels[2], and this agrees with the change of V and Ta mass in precipitates. The reason for these peak offsets from TaC could be that MX is a combination of V- and Ta-rich carbides, nitrides, and carbonitrides (M: Ta, V, Ti; X: C, N). The other feature obtained from Fig. 2 is the decrease of the $M_{23}C_6$ peaks of F82H-2Ni after irradiation. It also should be noted that the spectra of all irradiated specimens tended to have broad and shallow peaks with the median about 42 degrees.

These analyses suggest that irradiation caused (1) an increase of the amount of precipitates (mainly $M_{23}C_6$), (2) an increase of Cr and decrease of W contained in precipitates, and (3) the disappearance of MX (TaC) in ORNL9Cr and JLF-1.

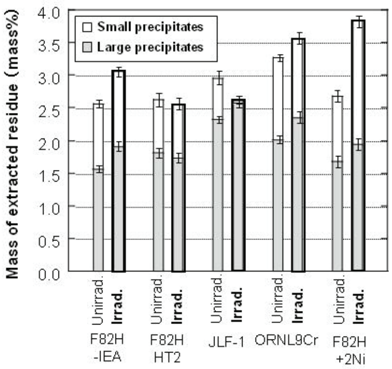

Fig. 1. Mass of residue of unirradiated and irradiated RAFs extracted with coarse filter (Large) and fine filter (Large + Small).

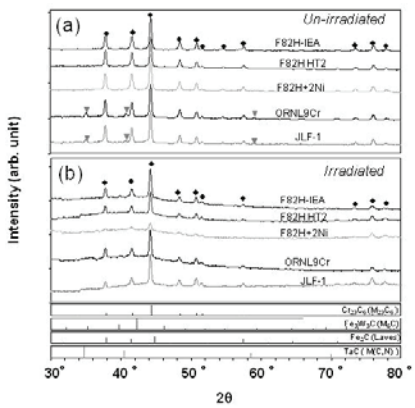

Fig. 2. XRD peaks of extracted residue from unirradiated and irradiated RAFs. Peaks marked with diamonds correspond to the peaks from M23C6, and those marked with triangles correspond to peaks from MX (TaC).

1. H. Tanigawa, M. A. Sokolov, K. Shiba and R. L. Klueh: Fusion Sci. Tech. 44 (2003) 206
2. H. Tanigawa, H. Sakasegawa, S. J. Zinkle, R. L. Klueh and A. Kohyama: Fusion Materials Semiannual Progress Report, (U.S. Dept. of Energy, Office of Fusion Energy Science) DOE/ER-0313/35 (2003) pp. 30–32.

Creep behavior of RAFM irradiated at 300 and 500°C up to 5 dpa

Category: Fusion engineering/HFIR
Year-Number：99-04 - No. 7
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H. Tanigawa, K. Shiba, S. Jitsukawa,
Y. Kohno**, A. Kohyama**
JAEA, *ORNL, ** Muroran Institute of Technology

Reduced activation ferritic/martensitic steels (RAFM) are the most promising candidates for blanket structural materials for fusion reactors. Irradiation creep has been recognized as one of the most important properties for which engineering data is needed for blanket structural design. Several researchers have reported on irradiation creep and void swelling behavior of austenitic stainless steels (Type 316 and PCA) and ferritic steels (HT9 and 9Cr-1Mo) irradiated above 400°C[1-6]. In addition, some results of irradiation creep experiments on RAFM above 390°C have been reported by the Japan/US collaboration program for fusion materials [7]. For fusion reactors, it is anticipated that irradiation creep of RAFM at lower temperatures could be also significant, and this would have a large impact on the life expectancy of a water-cooled blanket system. However, irradiation creep behavior of RAFM at temperatures below 400°C has not yet been reported.

In the HFIR Phase IV program, pressurized creep tube specimens were irradiated up to 5 dpa at 300 and 500°C and measured in ORNL Hot Laboratory.

The materials were the RAFM steels (F82H prepared by JAERI and JLF-1 prepared by MEXT). The tube specimens had dimensions of 4.57mm outside diameter and 22.4mm length with a 0.2mm wall thickness as shown in Fig. 1. End caps were electron beam welded to the tube segments, and the specimens were pressurized with high purity helium (99.999% He) to obtain the desired hoop stresses at the irradiation temperatures. The hoop stresses ranged from 0 to 400 MPa at the irradiation temperature. The diameter of these tubes was measured at the PNNL before irradiation. Irradiation was performed in HFIR up to 5 dpa. The tubes were measured with a non-contacting laser micrometer system.

Fig. 2 shows the relationship between the total diametral strain and the hoop stress in RAFM irradiated at 300 and 500°C. RAFM steels exhibit similar irradiation creep behavior at 300°C up to 5 dpa. The irradiation creep in these steels irradiated at 300°C is almost linearly dependent on the hoop stress level below 380MPa. Above 380MPa, creep strain tends to increase strongly with increasing stress. For 500°C irradiation, the irradiation creep of F82H is linearly dependent on the hoop stress level below 180MPa. At higher stress levels, the creep strain increased strongly in these steels because thermal creep had also occurred during irradiation.

A small piece was cut from the center of each irradiated tube after diametral measurement. Microstructural examination with FIBed samples and replica films was carried out using TEM. For the 300°C irradiation, the microstructure with hoop stress level of 250 MPa was similar to that in an unpressurized (zero stress) tube. Precipitates were observed along both lath and prior γ-boundaries. Results of extraction replicas indicated that finer spherical precipitates were observed at the highest hoop stress level. For 500°C irradiation, large precipitates (>200nm) were observed along the grain boundary at a hoop stress level 200MPa.

These results provide irradiation creep data for a materials database for blanket structural design in fusion reactors.

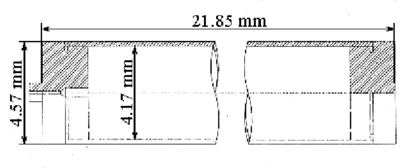

Fig. 1 Geometry of creep tube specimen

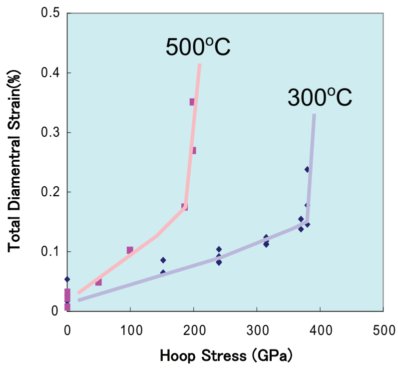

Fig. 2 Hoop stress dependence of irradiation creep at 300 and 500°C.

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Plastic property and fracture condition of structural steels after irradiation

Category: Fusion engineering/HFIR
Year-Number：04-09 - No. 8
K.Suzuki, T.Taguchi, N.Okubo and S.Jitsukawa, JAEA

At temperatures lower than 700K, irradiation often cause a severe hardening to introduce a large change in stress-strain relation [1]. The present authors, however, have indicated that the plastic property before and after irradiation may be expressed by a simple equation of $\sigma = A(\varepsilon_0 + \varepsilon_p)^n$ (1) where ε_0, ε_p, A and n are an equivalent plastic strain by irradiation hardening, plastic strain, strength coefficient and work hardening exponent, respectively; A and n are the constants without regard to the hardening level by irradiation. Similar discussion has been also made in several researches [2-6]. The present authors also indicated the relatively large margin to ductile fracture was remained even after irradiation to some tens of dpas. In case the equation (1) is applicable for the plastic property of irradiated alloys, ductile fracture condition under tensile forces may be estimated by e.g. Hill's or Ghosh's criteria [7, 8]. In other words, irradiation hardened steel which has been recognized as a quasi-brittle material is still ductile enough depending on the deformation mode. In the present paper, plastic properties of irradiated steels are introduced. Features of structural design criteria for intensely irradiated steel component are also introduced.

A reduced activation ferritic steel F82H (0.1C-7.8Cr-2W-0.04Ta-Fe bal.) in normalized and tempered condition was used. Tensile specimens of the steels were irradiated to 5 to 30 dpa at temperatures between 250 to 400C in HFIR (some of the specimens were irradiated in JMTR). Size of the gage region is 7.6mm long-1.5mm wide-0.76mm-thickness. Specimens were also obtained from cold worked plates. All the mechanical tests on irradiated specimens were performed at room temperature in JMTR hot cell. The images of gage region during deformation were recorded continuously.

Irradiation hardening caused to reduce tensile elongation (especially, uniform elongation often reduced to zero) and to occur plastic instability, as seen in the engineering stress-strain relation in the literature [1]. The area at minimum cross section of the specimen during the tensile test was evaluated from the image of the necked region. From the area during testing and the engineering stress-strain relation, an approximate true stress-true strain (Ts-s) curve has been obtained (strain is in logarithmic strain). Results for the specimens irradiated to 0, 5 and 20 dpa are shown in Fig. 1 (a). The curves for 5 and 20 dpa irradiated specimens were shifted along strain axis to overlap the Ts-s curve for the unirrdiated specimen (see also Fig. 2(b)). The figure clearly shows that the curves overlap well with each other, indicating that the equation (1) is applicable for the Ts-s relation before and after irradiation without regard to irradiation damage levels. The values of e0 applied for the curves of the specimens irradiated to 5 and 20 dpa were of 0.33 and 0.7, respectively. Even after irradiation to 20 dpa, residual ductility was about 30% of that before irradiation. Indeed, as seen in Fig.2, effect of structural discontinuity (circular hole at the center of the strip) was observed to be relaxed during deformation before cracking had occurred [2]; general yield occurred before the load attained maximum suggesting considerable level of margin remained even for the specimen with discontinuity after irradiation and this was followed by neck development (images of the deformed specimens were also reported [2]). Moreover, bend testing on simulated irradiation hardened specimen by cold working exhibited no apparent plastic instability. As indicated above, the margin to fracture can be determined as a function of deformation mode either by calculation or experiment. This is also true for austenitics [4]. Structural design criteria assuring the structural integrity of intensely irradiated steel component delivering more freedom to designing comparing with current methodology has began to be developed based on the analysis of plastic and ductile fracture condition behavior after irradiation[2].

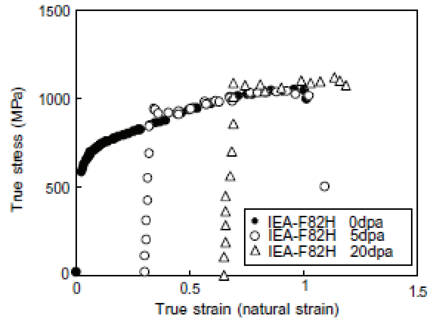

Fig. 1 (a) True stress-strain relations after 0, 5 and 20 dpa irradiation

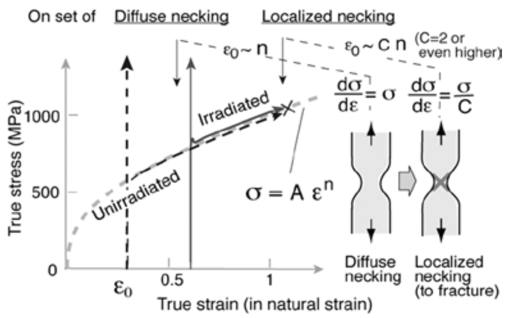

Fig.1 (b) Illustration of the relation between True stress-strain relations of unirradiated and irradiation hardened specimens.

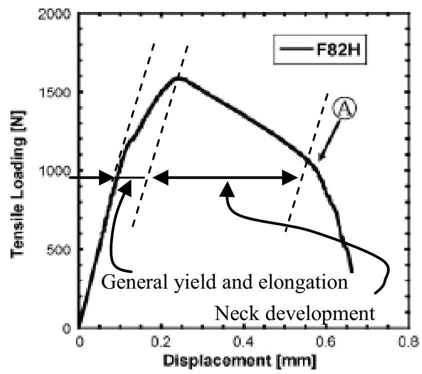

Fig. 2 Load-displacement curve of the irradiated plate tensile specimen with a hole (a discontinuity) at the center [2]

[1]S.Jitsukawa et al., Nuclear Fusion 49 (2009) 115006
[2]K.Suzuki, Nucl. Eng. Design 240(2010)1290
[3]T.Taguchi, et al., J. Nucl. Mater., 335(2004)457,
[4]S.Jitsukawa, et. al., J. Nucl. Mater. 271&272(1999)162
[5]R.J.DiMelfi et al., J. Nucl. Mater., 252 (1998) 171
[6]T.S.Byun, K.Farrel, Acta Mater. 52(2004)1597
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[8]A.K.Ghosh, in: D.P.Koinstein, N.M. Wang (Eds.), Mechanics of sheet metal forming, Plenum, 1987, p.287

High Fluence Radiation Effects on Advanced SiC/SiC Composites

Category : Fusion Engineering / HFIR(No. 9)
Year Number: 99-09 – No. 9
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Silicon carbide (SiC) has been studied for fission fuel applications for several decades, and for the past two decades as the base material for SiC fiber-reinforced SiC-matrix (SiC/SiC) composites, a potential high-temperature, low-activation structural material for fusion energy. The primary focus of study has been the development of a radiation stable material, given the poor as-irradiated performance of early materials. Over the past decade significant progress has been made towards this goal with the development of what is now considered a nuclear grade SiC/SiC composite composed of high purity, near-stoichiometric, and dense fibers and matrix. However, these composite materials have not been demonstrated to retain such fundamental properties as strength and dimensional stability under the high-dose irradiation typical of power reactor blankets. In the DOE/JAEA fusion materials collaboration, the high-dose stability of the current nuclear grade SiC/SiC composite was examined.

The material examined was chemically vapor-infiltrated (CVI) SiC matrix, Hi-Nicalon™ Type-S (HNLS) SiC fiber-reinforced composite with multilayer pyrocarbon/SiC interphase. Rectangular flexure beams measuring 50.2 x 6.35 x 2.63 (mm) were irradiated in HFIR to ~41 dpa at 800ºC. Post-irradiation mechanical properties are briefly discussed in the present report, whereas the more detailed report is found elsewhere.[1]

The results of the post-irradiation examination are summarized in Table 1. The composite material retained its unirradiated ultimate and the proportional limit stresses after irradiation. Moreover, no significant increase in data scatter was observed for either property. Slight increases in both the ultimate and proportional limit stresses may have been the case, but this increase is not statistically significant. Examples of the recorded load – crosshead displacement curves are presented in Fig. 1, showing no noticeable difference between the unirradiated and irradiated conditions. From these observations and accepted composite theory it can be reasonably concluded that no significant effect of irradiation on either the fracture energy of the matrix material, CVI SiC or the statistical strength properties of the reinforcing fibers.

The fracture surfaces of the broken samples were examined, and high magnification images of both the composite fracture surfaces and the fiber fracture surfaces were compared for regions under tensile stress during testing. The composite fracture surfaces were characterized by generally very short yet finite fiber pull-out length and debond/slide at the interface of the fiber and the interphase whether or not the material has been irradiated. Both the unirradiated and irradiated fiber surfaces appear to be typical of those observed for intact Hi-Nicalon™ Type-S fibers, presenting river-like patterns originating from indefinite mirrors around the fracture origins either on the surface or at the fiber interior. No significant different in the fracture surfaces, irradiated and unirradiated, was observed.

The swelling and the through-thickness thermal conductivity, shown in Table 1, indicated the absence of progressive property evolution beyond a few dpa, proving true saturation in key properties[2]. The electrical resistivity measurement revealed a transition from the unirradiated nearly temperature-independent conduction of pyrocarbon interphase into a reduced, moderately temperature-dependent conduction[1]. The effect of irradiation on the composite electrical resistivity appeared to be relatively minor. Overall, outstanding irradiation resistance of the nuclear grade SiC/SiC composite to neutron irradiation to a dose exceeding 40 dpa at temperature of 800ºC was demonstrated.

Table 1. Summary of unirradiated and irradiated properties.

	2D-HNLS/	ML/CVI-SiC
Irradiation Temperature [ºC]		800
Fast Fluence [dpa]	Unirr.	40.7
Mass Density [g/cm^3]	~2.4	~2.4
Swelling [%]	n/a	0.68 (0.01)
RT Thermal Conductivity [W/m-K]	~9.8	~2.7
Young's Modulus [GPa]	212 (10)	210 (8)
Number of Flexural Tests	8	7
Proportional Limit Stress [MPa]	317 (27)	330 (20)
Ultimate Stress [MPa]	444 (34)	461 (48)

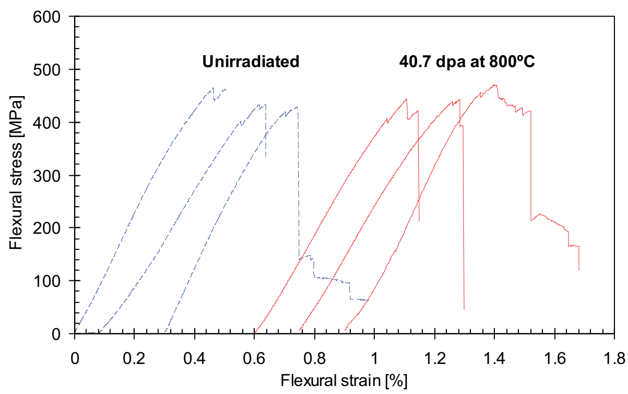

Fig. 1. Examples of four-point flexural load – crosshead displacement curves for unirradiated and irradiated Hi-Nicalon™ Type S, CVI SiC matrix composites. Charts are offset for visibility purpose.

[1] Y. Katoh, T. Nozawa, L.L. Snead, K. Ozawa, H. Tanigawa, J. Nucl. Mater., (submitted).
[2] Y. Katoh, L.L. Snead, T. Nozawa, S. Kondo, J.T. Busby, J. Nucl. Mater., (2010).

Modeling the Influence of Helium on Iron-based Alloys

Category : Fusion Engineering / HFIR
Year-Number : 2004-09 - No. 10
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In fusion applications, helium created by transmutation plays an important role in the response of reduced-activation ferritic/martensitic (RAFM) steels to neutron radiation damage. We have performed extensive atomistic simulations using the ORNL 3-body Fe–He interatomic potential [1] combined with three interatomic potentials for the iron matrix. Interstitial helium is very mobile and coalesces together to form clusters; the growth and mobility of these clusters has been investigated. When an interstitial He cluster reaches sufficient size, it punches out an Fe interstitial, creating an immobile helium–vacancy cluster. If more helium atoms join it, more Fe interstitials can be created; the He–V defect is a nascent bubble. These mechanisms have been investigated together in simulations that examine the nucleation of He defects. Mobile interstitial He clusters and helium bubbles from 1 to 6 nm in diameter were also simulated separately.

Helium-vacancy cluster growth and coalescence were studied in molecular dynamics simulations to investigate the nucleation of helium bubbles from interstitial helium atoms using the Ackland iron and ORNL He–Fe potentials. He interstitial cluster growth, coalescence and Frenkel pair creation were almost negligible at 200K but prevalent at all higher temperatures. The temperature affected not just the rate but also the nature of the defect creation process. The higher the temperature, the faster He atoms and clusters diffuse, which makes coalescence occur faster. This is balanced by higher temperatures leading to small clusters being broken up, delaying the creation of larger, stable clusters. The result is that that the cluster size distribution is temperature dependant; higher temperatures lead to fewer but larger clusters. Higher temperatures also increase the number of Frenkel pairs likely to be emitted from a larger He–V cluster.

Diffusion rates for clusters of 1 to 6 interstitial helium atoms were calculated for several combinations of potentials. Various combination of Fe and HE-Fe potentials were compared. In general, larger clusters were found to diffuse slower, however there were significant differences between the potentials. He-2 clusters tended to have a similar or lower energy barrier than single interstitial helium atoms but still diffuse slower due to a lower pre-exponential factor. The ORNL and Wilson potentials show significantly higher barriers for He-3 and larger. The J–N potential shows barriers of about 0.06eV for clusters of 1 to 4 interstitials, with the pre-exponential factor decreasing with increasing cluster size. He-5 was found to have a (usually substantially) lower migration barrier than He-4 with all combinations of potentials used. A possible explanation is that the tetrahedral arrangement of He-4 is much more stable due to its high symmetry that matches the symmetry of the Fe matrix. He-5 configurations are far less symmetrical and, in some potentials, allow for rapid 1D diffusion.

In the investigation of helium bubbles, it was found that the helium atoms stand off a small distance from the surface iron atoms, leaving a between the He and Fe matrix atoms on the surface of the bubble [2]. The gap was large enough that the He atoms rarely come close enough to an iron atom to invoke the 3-body component of the ORNL Fe–He potential (range 2.2Å), so their interactions are effectively described by the pair part of the potential. The helium density oscillates enough to suggest a shell structure to the arrangement of atoms, but not enough to suggest solid helium. This agrees with predictions that the helium in the bubble would not be solid. In a void, the surface matrix atoms relax inwards slightly, reducing the volume of the void. At higher temperatures, they move in more due to the thermal expansion of the iron. Adding helium to the void pushes the atoms outwards, increasing the volume again. The more helium added, the further the bubble expands. There is a point where the forces balance and the bubble is neither expanded nor contracted; the surface atoms are at the same place as they would be in a perfect lattice. We use this point as our condition for equilibrium. The equilibrium He/V ratio is temperature and size dependant. In general, the equilibrium He/V ratio is lower for higher temperatures and larger bubbles.

Figure 1 shows the dilation of a 2 nm diameter bubble as a function of He/V ratio for different temperatures. The equilibrium ratio for each temperature can be determined by where it crosses the horizontal zero line. At 2 nm, the curves for the different temperatures are close together and the equilibrium He/V ratios lie in the range 0.4–0.55; for larger bubbles, the curves spread out more (not shown).

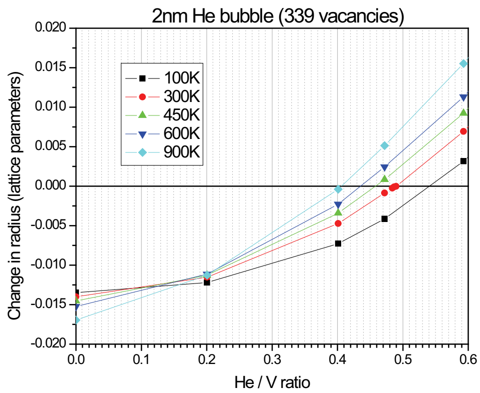

Fig. 1. Dilation of 2 nm bubbles as a function of He/V ratio at different temperatures.

[1] R. E. Stoller, S. I. Golubov, P. J. Kamenski, T. Seletskaia, and Yu. N. Osetsky, Phil. Mag. 90 (2010) 923.
[2] D. M. Stewart, Yu. N. Osetsky, R. E. Stoller, S. I. Golubov, T. Seletskaia, and P. J. Kamenski, Phil. Mag. 90 (2010) 935.

CHAPTER 8 Fusion Archives Activity

8.1 Objectives

History is said to be "an unending dialogue between the present and the past" (Edward H. Carr). Even in the field of natural sciences, we should pay attention to history for looking at the present state and the future. In particular, to learn lessons from the history of fusion is important for making future plans of fusion research. Fusion archives play the role of providing "evidence" in studying this history. Moreover, big sciences like fusion research should fulfill their obligation of social accountability. A formal organization in NIFS was established for fusion archives. Archives in the US, in general, have been very advanced, which are expected to promote archives of fusion researches. Moreover, fusion archives should cover not only the fusion research activities of each country, but also the US-Japan collaborations, which occupy an important part of the fusion activities in both countries.

8.2 Administration

A US-Japan workshop on fusion archives was planned and held in 2005 on the basis of activities in both countries. Key persons were Prof. Mohamed Abdou in UCLA and Prof. Keisuke Matsuoka in NIFS, respectively. At UCLA, there is active study of archives and Prof. Abdou, a fusion scientist, has very much appreciated the importance of archives. At NIFS, Prof. Matsuoka had been nominated as the director of the NIFS Fusion Science Archives (NIFS-FSA).

8.3 Summary of Activities

Fusion archives in universities in Japan originated in the move of Institute of Plasma Physics (IPP), Nagoya University, to become part of the new National Institute for Fusion Science (NIFS) in Toki. A vast amount of documents belonging to Prof. Kodi Husimi, the first director of IPP, was transported from Nagoya to Toki in 1997, and their arrangement and registration was started on a volunteer basis by retired professors of IPP and NIFS. In 1999, collaborative research at NIFS on the fusion archives was initiated under the leadership of Prof. Sigeko Nisio of Nihon University. A short time later, the Graduate University for Advanced Studies (Sokendai), which consists of several inter-university research institutes such as NIFS, High Energy Accelerator Research Organization (KEK), Institute of Molecular Science (IMS), and National Astronomical Observatory of Japan (NAOJ), began to focus on archives in natural sciences, especially in big sciences. Prof. Sharon Traweek at UCLA played a role in starting the archives activity of Sokendai.

Workshop at UCLA. From left, T. Tamano, A. Popescu, F. Chen, and Y. Tomita.

On the basis of achievements at NIFS and the approach by Prof. Hirotaka Sugawara of Sokendai, the

NIFS Fusion Science Archives was established on January 1, 2005.

The NIFS Fusion Science Archives collaborates with universities where fusion research has been done and with Sokendai. At PPPL, Ms. Adriana Popescu, the librarian, has worked to organize and resister historical documents.

A US-Japan workshop on fusion archives was proposed in the same year that the NIFS Fusion Science Archives was established. The workshop was held in the US in December 2005. The workshop consisted of two parts: the first part was a workshop held at UCLA on December 12 and 13, and the second part consisted of interviews with Dr. Kenneth M. Young and Dr. Shoichi Yoshikawa on December 15 at PPPL. The speakers and their topics at the workshop in UCLA were as follows.

"Welcome"	M. Abdou (UCLA)
"Address (representing Japan)"	K. Matsuoka (NIFS)
"Establishment of Fusion Science Archives and its activities"	K. Matsuoka
"The Big Picture: Why Archives"	S. Traweek (UCLA)
"History and Archives of Inter-University Research Institute: Related to Digital Contents in NIFS and Sokendai"	N. Abe (Sokendai)
"A History of progress in magnetic fusion energy research"	T. K. Fowler (UC Berkeley)
"Archiving of nuclear fusion research in NIFS"	C. Namba (NIFS)
"Archival study from chronological aspects"	K. Kimura (NIFS)
"Role of Inter-University Institute in early days of nuclear fusion research in Japan"	H. Obayashi (NIFS)
- Visit and Discussion at Center for Information as Evidence, UCLA –	
"The early days of Project Matterhorn"	F. F. Chen (UCLA)
"Short history of Heliotron research and archiving activities in Kyoto University"	T. Mizuuchi (Kyoto Univ.)
"Preservation and access of fusion research archives"	A. Popescu (PPPL)
"International 4 year archive collaboration among physical scientists and social scientists"	S. Traweek
"Complementary study of fusion science archives by means of oral history"	J. Fujita (NIFS)
"Oral history projects with American research scientists"	M. Meldrum (UCLA)
"Suggestions for Fusion Archives"	T. Tamano (GA)

The topics from Japan included an overview of NIFS Fusion Science Archives activities, a history of Heliotron machines, and digital archives necessary for cross-retrieval, chronological studies, and oral history. The US presentations covered the importance of archives and the early days of US fusion research activities.

Both interviews at PPPL were conducted in English, following prepared questions. In Dr.

Young's interview, the topics were his research career before joining PPPL, the conversion of the C Stellarator to the ST tokamak, diagnostics in TFTR, and comments on ITER. In the interview with Dr. Yoshikawa, his involvement in Japan was the major topic due to his large impact on fusion research in Japan. Transcriptions of both interviews have been completed.

The work on oral histories of prominent scientists has been continued. An interview with Dr. Tihiro Ohkawa was carried out in Japanese at his home in November 2009 with detailed questions (this interview was supported by other funding). Topics in this interview covered his start of fusion research, multi-pole experiments at GA, and his involvement in Japan research, since he had had a significant influence on Japan, similar to Dr.Yoshikawa.

At PPPL on December 15. From left (front) C. Namba, N. Abe, T. Mizuuchi, K. Kimura, (rear) M. Okabayashi, K. Matsuoka, Y. Tomita, J. Fujita, H. Obayashi.

Interview with Dr. S. Yoshikawa on December 15, 2005.

Interview with Dr. Ken M. Young on Deember.15, 2005.

Interview with Dr. T. Ohkawa on Noember 18-19 2009. From left, K. Kimura, K. Matsuoka, T. Ohkawa, T. Amemiya (Nihon Univ.). Photo by C. Namba.

Since this workshop, the NIFS Fusion Science Archives has focused its efforts mainly on digital archives via collaborations with inter-university research institutes of Sokendai, especially the National Institute of Japanese Literature (NIJL), KEK, and IMS, aiming to construct cross-retrieval capability among database at these institutes, based on Encoded Archival Description (EAD). At NIFS, the EAD system has been completed, as shown below, and the number of documents under cross-retrieval is increasing day by day.

Subsequent visits (supported with other funding) to related institutes in the US—namely, CDL (California Digital Library), OAC (Online Archive of California), LBL Archives, SLAC and Stanford Univ. Archives, UCLA (Information Studies Dept., University Archives, Digital Library Program, Japanese Studies, East Asian Library, Oral History Research Center, Center for Society and Genetics), NARA (National Archives and Records Administration) and LOC (Library of Congress) provided much useful information about archives.　Although the US is one of the most advanced countries on archives and a well-regarded cross-retrieval system has been established at some organizations, e.g., LOC, there has been no construction of systematic archives on fusion science.　The ultimate goal of the US-Japan fusion science archives collaboration is to construct a system for cross-retrieval of historical documents between Japan and US on the basis of EAD. Further effort is needed to promote Fusion Science Archives, in anticipation of the construction of fusion archives in US.

Cross-retrieval of "plasma" as an example.　Database of materials provided by Prof. Yoshi-Hiko Ichikawa and late Professors Tadashi Sekiguchi and Satio Hayakawa are retrieved on the screen of a computer.　Materials are arranged in the hierarchical structure that is characteristic of EAD.　Database of NIFS FSA, KEK, IMS are registered in the server of NIJL (National Institute of Japanese Literature) that have constructed the cross-retrieval system of a vast amount of database among institutes and libraries of humanities.

CHAPTER 9　Safety Monitoring Activities

9.1 Background and Objectives

In early 1992, there was an unfortunate event of concern in the US when a visiting Japanese researcher was overcome by leaking nitrogen coolant gas. After this near-miss event, discussions were held between Japan and US about conducting safety walkthroughs of fusion research facilities and experiments in each country. As a result, the Japan-US Safety Monitoring Joint Working Group (JWG) was established to work on understanding and addressing the various issues regarding safety in inter-institutional collaborations, to examine these issues, to develop methods of resolving them, and to make a set of recommendations directed to the governmental and operational institutions of both parties. The activities of the JWG at fusion laboratories provide for an excellent exchange of information and perspective resulting in increased attention toward personnel safety with specific attention to visiting collaborators at the national institutes and universities of both countries.

The purpose of the site visits by the JWG is to evaluate the programmatic aspects of environmental, safety and health (ES&H) programs at fusion research facilities informally by touring laboratory areas and meeting with researchers and safety professionals. Based on these interactions, the JWG members have been able to share information and provide suggestions in an effort to reduce the likelihood of bodily injury and/or property damage. The JWG encourages that good approaches and practices developed at a certain institution be utilized to improve ES&H programs at other institutions, and to provide guidance for necessary safety orientation programs for foreign collaborators.

JWG site visits since FuY1995 (FuY coincides with Japanese fiscal year, and FuY corresponds to April 1995 to March 1996) are summarized in Appendix B.2. Activities during the last 10 years are summarized in the next sub-section. The JWG toured US laboratories and Japanese laboratories alternately every two years during this period. Detailed reports of the JWG site visits are available at http://www.pppl.gov/esh.cfm.

9.2 Summary of JWG Activities

9th JWG (J to US: March 18-22, 2002)

The Japanese delegation was particularly impressed by the commitment to safety by the laboratory management. At most institutions, the EHS/ESH manager reports directly to the director of the laboratory. Integrated Safety Management (ISM) is practiced at all institutions visited. DOE provides the basic guidelines of ISM, but its implementation is tailored to suit specific needs of each institution. Each institution has a comprehensive training program, which has been useful in raising awareness of hazards and reducing the number of accidents/incidents. At many institutions EHS/ESH related information is readily available.

In Japan, the JCO accident in Tokai has prompted reexamination of the safety program, and many changes have been made, but there is a need to update English versions of the Safety Manuals. This tour included visits to smaller, university-scale labs to learn how their safety programs are implemented. It was useful to hear about recent accidents/near-misses and what kinds of counter measures were implemented.

10th JWG (US to J: February 16-25, 2004)

The US delegation was impressed with nearly all the labs' progress and attention to the items identified in the 1999 safety tour. During each site visit, an overview of the activities in the lab and the overall safety program that was active in the lab were provided, followed by a tour of the labs and associated facilities. After the tour of each lab, findings were shared with the Management and Staff in a closeout meeting, providing immediate feedback to the staff regarding issues that were identified. Many times during our tour, issues that were identified in the labs were immediately corrected by tour participants or by individuals working in the lab. This action shows a proactive attitude towards safety and is greatly appreciated.

Gas bottles need to be secured when in use. A gas bottle on a cart with a regulator installed is not considered secured. Electrical cords need to be of the industrial grade type which includes two layers of insulation and not just one. The use of "ground pin bypass units" should be reviewed in each lab and eliminated wherever possible. When a piece of equipment is manufactured with a ground pin it should always be used for safety reasons.

It was anticipated that new safety rules will come into effect in April 2004 when the national universities will be given increased safety regulations by the Ministry of Health, Labor, and Welfare. This new overview agency may help in providing guidance to the universities and can be looked at as a positive step toward a safer laboratory environment.

Most of the facilities visited were either maintaining a high level of safety or had shown improvement in safety. Some professors stated that this improvement was created by two reasons, namely, our visits that gave them some guidance and the new rulemaking for university safety that soon takes effect. Only in one experiment did it appear that safety had decreased and immediate attention should be placed on the serious safety items that were identified. The universities have cost constraints, so focusing on means to increase safety without incurring high costs is needed. Using daily safety checklists before experiment operation, appointing a key person of the experiment day to track safety issues, once-a-month cleanup days, and using pictogram warning signs are all low cost means to achieve safety.

11th JWG (J to US: February 22-27, 2006)

This was the first time that representatives of inertial confinement fusion (Dr. Norimatsu) and fusion technology (Dr. Kohyama) participated in this activity. The Japanese delegation noted substantial improvements in safety records since the last visit. At most institutions, ES&H policies are based on the concept of Integrated Safety Management (ISM). DOE provides the basic guidelines of ISM, but its implementation is tailored to suit the specific needs of each institution. Each institution has a comprehensive training program which has been useful in raising the awareness of hazards and reducing the number of accidents/incidents. At many institutions, information related to ES&H is readily available electronically. The overall evaluation of the 2006 site visits by the JWG is highly satisfactory, especially from the viewpoint of mutual understanding of differences in safety culture between the two countries. At institutes with many visiting scientists or workers from outside, it is extremely important for everyone to have enough knowledge of safety.

12th JWG (US to J: March 10-21, 2008)

Overall impressions of the labs and universities were very good. A major change since the previous U.S. visit in February 2004 is that the major universities are now subject to Japan national rules for occupational and industrial safety. Some of the professors stated that compliance with some of the national laws and rules was expensive, but overall we noted the facilities were cleaner, less cluttered, and tools were better organized. There was better attention to gas cylinder safety, more safety signs were in use, and more attention to general industrial safety than in past visits. As always, the facilities with larger annual operating budgets tend to have more safety provisions. It is a well known, but not quantified, safety principle that well-run, safe facilities are cleaner, more productive, and more efficient than facilities that do not practice safety.

There were many port covers and flanged openings at all of the facilities we visited, but few were designated or labeled as confined spaces, and several facilities did not have a formal program for personnel entry into these spaces. Confined spaces may be encountered in virtually any occupation; therefore, their recognition is the first step in preventing fatalities. Since deaths in confined spaces often occur because the atmosphere is oxygen-deficient, toxic or combustible, confined spaces that contain or have the potential to contain a serious atmospheric hazard should be classified as Permit-required confined spaces and should be tested prior to entry and continually monitored. The information source for the U.S. Occupational Safety and Health Administration (OSHA) regulations with regard to confined spaces was provided.

Information in regard to the U.S. fall protection programs was also provided. In the US, all fall protection products fit into four functional categories: 1. Fall Arrest, 2. Positioning, 3. Suspension, 4. Retrieval. A fall arrest system is required if any risk exists that a worker may fall from an elevated position. As a general rule, the fall arrest system should be used anytime a working height of six feet or more is reached. A full-body harness with a shock-absorbing lanyard or a retractable lifeline is the only product recommended. A full-body harness distributes the forces throughout the body, and the shock-absorbing lanyard decreases the total fall arresting forces. A positioning system holds the worker in place while keeping his/her hands free to work. Whenever the worker leans back, the system is activated. However, the personal positioning system is not specifically designed for fall arrest purposes. A suspension system lowers and supports the worker while allowing a hands-free work environment, and is widely used in window washing and painting industries. Retrieval Preplanning for retrieval in the event of a fall should be taken into consideration when developing a proactive fall management program.

The US visitors also noted that there have been several new machines built and operated since the 2004 visit. These new machines indicate not only a healthy research program but also the need to continue performing these safety walkthrough tours.

13th JWG (J to US: Feb. 22-25, 2010)

Three members (Professor Nishimura of NIFS, Associate Professor Seki of NIFS, and Dr. Sukegawa of JAEA) of the Japanese delegation participated for the first time in the Japan-US Safety Monitoring Joint Working Group. The Japanese delegation was greatly impressed by high attention to the ES&H and established safety organization. At most institutions, ES&H policies are based on the concept of Integrated Safety Management (ISM). DOE provides the basic guidelines of ISM, but its implementation is performed by discretion of each institution. Each institution has a comprehensive training program which has been useful in deepening the awareness of hazards and reducing the number of accidents/incidents. At many institutions ES&H related information is readily available electronically, and it is possible to make an application for training program online. In some institutions, a personal attendance history of a necessary training program is managed online, and suitable measures such as prohibition of entrance are taken automatically for a person who does not take necessary lectures. The overall evaluation of the 2009 site visits by the JWG is highly satisfactory. In particular, understanding of differences in safety culture between the two countries and between the different states in USA is worthy of note. At institutes with many visiting scientists or workers from outside, it is extremely important for everyone to have enough knowledge of safety. Therefore, Japanese visitors were able to recognize the importance of safety education based on a difference in safety standards in various countries.

Publications

R. L. Savercool and L. C. Cadwallader, “Activities of the U.S.-Japan Safety Monitor Joint Working Group,” *Fusion Science and Technology*, **47** (2005) 974-978.

L. C. Cadwallader, “Compressed Gas Safety for Experimental Fusion Facilities,” *Fusion Science and Technology*, **47** (2005) 989-994.

K. R. Rule, L. C. Cadwallader, T. Norimatsu, Y. Takase, M. Sato, O. Kaneko, and R. Savercool, “Elements of Successful and Safe Fusion Experiment Operations,” *Proceedings of the 23rd Symposium on Fusion Engineering*, June 1-5, 2009, San Diego, CA, IEEE (2009).

Appendices

Appendix A
List of Published Papers

Appendix B
Statistics and Related Documents

Appendix A

List of Published Papers

CHAPTER 2 FTPC

2.4.1 Superconducting Magnets

1. Journal Paper

No	Year	Authors	Title of Paper	Journal	Vol. (Year) Page (Start) -Page(End) or Identification No.	Year-Category-No.
1	2002	N. Yanagi, J. Morikawa, T. Mito, Y. Ogawa, S. Hamaguchi, H. Chikaraishi, M. Iwakuma, T. Uede, I. Itoh, S. Nose, and S. Fukui	Engineering Research and Development of Magnetically Levitated High-Temperature Superconducting Coil System for Mini-RT Project	IEEE Trans. Appl. Supercond	12 (2002) 948-951	2001-FT1-2
2	2003	Y. Ogawa, J. Morikawa, T. Mito, N. Yanagi, M. Iwakuma, H. Nihei, K. Ohkuni, D. Hori, S. Yamakoshi, I. Itoh, S. Nose, and T. Uede	Construction and Operation of an Internal Coil Device with a High Temperature Superconductor	IEEE Trans. Appl. Supercond	13 (2003) 643-644	2001-FT1-2
3	2003	T. Mito, N. Yanagi, Y. Hishinuma, Y. Ogawa, J. Morikawa, K. Ohkuni, M. Iwakuma, T. Uede, S. Nose, I. Itoh and S. Fukui	Engineering Design of the Mini-RT Device	IEEE Trans. Appl. Supercond	13 (2003) 1500-1503	2001-FT1-2
4	2003	N. Yanagi, T. Mito, Y. Hishinuma, Y. Ogawa, J. Morokawa, K. Ohkuni, M. Iwakuma, T. Uede, S. Nose, and I. Itoh	Excitation Test Results of the HTS Floating Coil for the Mini-RT Project	IEEE Trans. Appl. Supercond	13 (2003) 1504-1507	2001-FT1-2
5	2004	N. Yanagi, T. Mito, J. Morikawa, Y. Ogawa, K. Ohkuni, D. Hori, S. Yamakoshi, M. Iwakuma, T. Uede, I. Itoh, M. Fukagawa, and S. Fukui	Experiments of the HTS Floating Coil System in the Mini-RT Project	IEEE Trans. Appl. Supercond	14 (2004) 1539-1542	2001-FT1-2
6	2004	T. Hemmi, K. Takahata, T. Mito, A. Iwamoto, H. Tamura, and N. Yanagi	Experimental Apparatus for Measuring the Characteristics of HTS Coils under Controllable Magnetic Field, Orientation and Temparature	IEEE Trans. Appl. Supercond	14 (2004) 1806-1809	2001-FT1-2
7	2005	N. Yanagi, T. Mito, T. Hemmi, K. Seo, J. Morikawa, Y. Ogawa, and M. Iwakuma	Effective Resistance of the HTS Floating Coil of the Mini-RT Project	IEEE Trans. Appl. Supercond	15 (2005) 1399-1402	2004-FT1-2
8	2005	T. Hemmi, N. Yanagi, K. Seo, R.Maekawa, K. Takahata, and T. Mito	Experimental Evaluation of Loss Generation in HTS Coils Under Various Conditions	IEEE Trans. Appl. Supercond	15 (2005) 1711-1714	2004-FT1-2
9	2006	Y. Ogawa, J. Morikawa, T. Mito, N. Yanagi, and M. Iwakuma	Application of high-temperature superconducting coil for internal ring devices	Fusion Engineering and Design	81 (2006) 2361-2369	2005-FT1-1
10	2006	T. Mito, A. Sagara, S. Imagawa, S. Yamada, K. Takahata, N. Yanagi, H. Chikaraishi, R. Maekawa, A. Iwamoto, S. Hamaguchi, M. Sato, N. Noda, K. Yamauchi, A. Komori, and O. Motojima	Applied superconductivity and cryogenic research activities in NIFS	Fusion Engineering and Design	81 (2006) 2389-2400	2005-FT1-1
11	2006	T. Hemmi, N. Yanagi, G. Bansal, K. Seo, K. Takahata, and T. Mito	Electromagnetic behavior of HTS coils in persistent current operations	Fusion Engineering and Design	81 (2006) 2463-2466	2005-FT1-1

2.4.2 Structural Materials

1. Journal Paper

No	Year	Authors	Title of Paper	Journal	Vol. (Year) Page (Start) -Page(End) or Identification No.	Year-Category-No.
1	2001	K. Morishita, T. Diaz de la Rubia and A. Kimura	Mobility of Self-interstitial Atom Clusters in Vanadium, Tantalum and Copper	Nuclear Instruments and Methods in Physical Research B	180 (2001) 66-71	2001 MM-32
2	2002	A. Kimura, R. Kasada, K. Morishita, R. Sugano, A. Hasegawa, K. Abe, T. Yamamoto, H. Matsui, N. Yoshida, B.D. Wirth and T.D. de la Rubia	High Resistance to Helium Embrittlement in Reduced Activation Martensitic Steels	J. Nucl. Mater	307-311 (2002) 521-526	2002 MM-27 MM-28

3	2002	S. Jitsukawa, M. Tamura, B. van der Schaaf, R.L. Kleuh, A. Alamo, C. Petersen, M. Schirra, P Spaetig, G.R. Odette, A.A. Tavassoli, K. Shiba, A. Kohyama and A. Kimura	Development of an Extensive Database of Mechanical and Physical Properties for Reduced-Activation Martensitic Steel F82H	J. Nucl. Mater	307-311 (2002) 179-186	2002 MM-27 MM-28
4	2002	R.L. Klueh, D.S. Gelles, S. Jitsukawa, A. Kimura, G.R. Odette, B. van der Schaaf and M. Victoria	Ferritic/Martensitic Steels – Overview of Recent Results	J. Nucl. Mater	307-311 (2002) 455-465	2002 MM-27 MM-28
5	2004	D. C. Dube, P.D. Ramesh, J. Cheng, M.T. Lanagan, D. Agrawal and R. Roy	Experimental evidence of redistribution of fields during processing in a high-power microwave cavity	Appl. Phys. Lett.	85 (16) (2004) 3632-3624	2004-FT2-1
6	2004	S. Jitsukawa, A. Kimura, A. Kohyama, R.L. Klueh, A.A. Tavassoli, B. van der Schaaf, G.R. Odette, J.W. Rensman, M. Victoria and C. Petersen	Recent Results of the Reduced Activation Ferritic/Martensitic Steel Development	J. Nucl. Mater	329-333 (2004) 39-46	2004 FT2-2
7	2005	S.A. Maloy, M.R. James, T.J. Romero, M.B. Toloczko, R.J. Kurtz and A. Kimura	Tensile properties of the NLF reduced activation ferritic/martensitic steels after irradiation in a fast reactor spectrum to a maximum dose of 67 dpa	J. Nucl. Mater.	341 (2005) 141-147	2004 FT2-2
8	2007	Kotaro ISHIZAKI, Kazuhiro NAGATA	Selectivity of Microwave Energy Consumption in the Reduction of Fe3O4 with Carbon Black in Mixed Powder	ISIJ.	47 (2007) 811-816	2004-FT2-1, 2005-FT2-1, 2006-FT2-1, 2007-FT2-1
9	2008	V.D. Buchelnikov, D. V. Louzguine-Luzgin, G.Q. Xie, S. Li, N. Yoshikawa, M.Sato	Heating of metallic powders by microwaves: Experiment and theory	J. Appl. Phys.	104 (2008) 113505	2004-FT2-1,2-3, 2005-FT2-1,2-3, 2006-FT2-1,2-2, 2007-FT2-1,2-2
10	2008	A.P. Anzulevich, I.V. Bychkov, and A.Inoue	Numerical study of microwave heating of micrometer size metal particles	ISIJ (Iron and Steel Institute of Japan)	48 (2008) 681-684	2004-FT2-1, 2005-FT2-1, 2006-FT2-1, 2007-FT2-1
11	2008	H.Tanigawa, T.Hirose, K.Shiba, R.Kasada, E.Wakai, H.Serizawa, Y.Kawahito, S.Jitsukawa, A.Kimura, Y.Kohno, A.Kohyama, S.Katayama, H.Mori, K.Nishimoto, R.L.Klueh, M.A.Sokolov, R.E.Stoller, S.J.Zinkle	Technical issues of reduced activation ferritic/martensitic steels for fabrication of ITER test blanket modules	Fusion Engineering and Design	83（2008）1471-1476	2008 MM- 19
12	2009	M. Tanaka, H. Kono, and K. Maruyama	Selective heating mechanism of magnetic metal oxides by a microwave magnetic field	Phys. Rev. B	79 (2009) 10442	2004-FT2-1,2-3, 2005-FT2-1,2-3, 2006-FT2-1,2-2, 2007-FT2-1,2-2
13	2009	M.Ignatenko, M.Tanaka, and M.Sato	Handling Technology of Mega-Watt Millimeter-Waves For Optimized Heating of Fusion Plasmas	Jpn.J.Appl.Phys.	48 (2009) 067001	2004-FT2-1,2-3, 2005-FT2-1,2-3, 2006-FT2-1,2-2, 2007-FT2-1,2-2
14	2009	A. Matsubara, S. Takayama, S. Okajima and M. Sato	Evolution of the near-UV emission spectrum associated with the reduction process in the microwave iron making	J. Microwave Power Electromagnetic Energy	42 (2008) 4	2004-FT2-1,2-3, 2005-FT2-1,2-3, 2006-FT2-1,2-2, 2007-FT2-1,2-2

2. Conference Paper

No	Year	Authors	Title of Paper	Conference Name	Month Date, Year, Place, Country	Year-Category-No.
1	2001	K. Morishita, R. Sugano, B.D. Wirth, H. Iwakiri, T. Diaz de la Rubia, N. Yoshida and A. Kimura	Atomistic Simulation Study of Helium Behavior in Iron and Helium Desorption Experiments	Proc. of the CARET Symposium on Advanced Research of Energy Technology	March 18-16,2001, Sapporo, Japan	2001-MM-32
2	2004	M. Sato, S.Takayama	Microwave Sintering Technology in Japan	4th International Congress on Microwave and Rf Applications	Nov.7-11, Texas Austin	2004-FT2-1,
3	2008	M. Sato, K. Nagata, A. Matsubara, S.Takayama	Greener Steel Making Process by Microwave Irradiation with Discharges	ICPOS2008	June 15-19 (2008) Karlsruhe, Germany	2004-FT2-1, 2005-FT2-1, 2006-FT2-1, 2007-FT2-1
4	2009	M. Sato, N. Nishi, M. Tanaka, A.Matsubara, S Takayama, H. Fukushima, M. Ignatenko, Rustum Roy, Dinesh Agrawal, J. Fukusima	Formation of Nano-Domains by Microscopic Thermal Non-Equilibrium Generated in GHz High Frequency Microwave Field	Ist Global Cong MW Energy Applications, August 2008, Japan	Aug.7-10,2008, Otsu, Japan	2004-FT2-1,2-3, 2005-FT2-1,2-3, 2006-FT2-1,2-2, 2007-FT2-1,2-2

5	2009	M.Sato	Microwave Excited Non-equilibrium Reaction Field that Brings Revolution to Key Industries of 21 Century・IEICE MWE2009・2009	IEICE MWE2009	Nov. 16-18, 2009, Yokohama, Japan	2004-FT2-1, 2005-FT2-1, 2006-FT2-1, 2007-FT2-1
6	2009	M.Tanaka, H.Kono, K.Maruyama, and M.Ignatenko	Classical and Quantum Mechanical Theories of Microwave Heating of Magnetic Materials	12th AMPERE International Conference 2009	Sep 16-21, Karlsruhe, Germany (AMPERE Europe,The 2009 Best Paper Award)	2004-FT2-1,2-3, 2005-FT2-1,2-3, 2006-FT2-1,2-2, 2007-FT2-1,2-2
7	2009	K.Nagata, K. Ishizaki, M.Kanazawa, T. Hayashi, M.Sato, A.Matsubara, S.Takayama, O.Motojima, D.Agrawal, R. Roy	A Concept of Microwave Furnace for Steel Making in Industry Scale	12th AMPERE International Conference 2009	Sep 16-21, Karlsruhe, Germany	2004-FT2-1, 2005-FT2-1, 2006-FT2-1, 2007-FT2-1

2.4.3 Plasma Heating Related Technologies

1. Journal Paper

No	Year	Authors	Title of Paper	Journal	Vol. (Year) Page (Start) -Page(End) or Identification No.	Year-Category-No.
1	2001	M. A. Shapiro, T. S. Chu, D. R. Denison, M. Sato, T. Shimozuma, R. J. Temkin	Design of correcting mirrors for a gyrotron used at Large Helical Device	Fusion Engineering and Design	53 (2001) 537–544	2005-FT3-5 2003-FT3-7 2000-FT3-3
2	2002	N. Takeuchi, R. Kumazawa, K. Saito, T. Watari, T. Seki, et al.	The radio frequency charactertistics of the combline antenna	Journal of Plasma Fusion Research SERIES	5 (2002) 314-317	2002-FT3-2
3	2004	N. Takeuchi, T. Seki, Y. Torii, K. Saito, T. Watari, et al.	Variation of N// and its effect on fast wave electron heating on LHD	Journal of Plasma Fusion Research SERIES	6 (2004) 642-646	2003-FT3-3
4	2004	Y. Takase, C.P. Moeller, T. Seki, N. Takeuchi, T. Watari, et al.	Development of a fishbone travelling wave antenna for LHD	Nuclear Fusion	44 (2004) 296-302	2003-FT3-3
5	2005	N. Takeuchi, T. Seki, K. Saito, T. Watari, R. Kumazawa, et al.	Studies of the electrical properties of the LHD combline antenna	Fusion Science and Technology	48 (2005) 1267-1284	2003-FT3-3
6	2005	T. Shimozuma, H. Idei, M. A. Shapiro, R. J. Temkin, S. Ito, T. Notake, S. Kubo, Y. Yoshimura, S. Kobayashi, Y. Mizuno, Y. Takita, K. Ohkubo	Alignment Method of ECH Transmission Lines Based on the Moment and Phase Retrieval Method Using IR Images	J. Plasma Fusion Res.	81 (2005) 191 - 196	2005-FT3-5 2003-FT3-7 2000-FT3-3
7	2009	T. Shimozuma, S. Kubo, Y. Yoshimura H. Igami, H. Takahashi, Y. Takita, S. Kobayashi, S. Ito, Y. Mizuno, H. Idei, T. Notake, M. A. Shapir, R. J. Temkin, F. Felici. T. Goodman, O. Sauter, R. Minami, T. Kariya, T. Imai and T. Mutoh	Handling Technology of Mega-Watt Millimeter-Waves For Optimized Heating of Fusion Plasmas	Journal of Microwave Power & Electromagnetic Energy	43 (2009) 60-70	2007-FT3-6 2008-FT3-1 2009-FT3-3
8	2010	T. Shimozuma, H. Idei, M. A. Shapiro, R. J. Temkin, S. Kubo, H. Igami, Y. Yoshimura, H. Takahashi, S. Ito, S. Kobayashi, Y. Mizuno, Y. Takita and T. Mutoh	Mode-Content Analysis and Field Reconstruction of Propagating Waves in CorrugatedWaveguides of an ECH System	Plasma and Fusion Research	5 (2010) S1029-1-5	2007-FT3-6 2008-FT3-1 2009-FT3-3

2. Conference Paper

No	Year	Authors	Title of Paper	Conference Name	Month Date, Year, Place, Country	Year-Category-No.
1	2001	N. Takeuchi, K. Saito, R. Kumazawa, T. Watari, et al.	The Radio Frequency Characteristics of the Combline antenna	The 12th International Toki Conference	Dec. 11-14, 2001, Toki, Japan	2002-FT3-2
2	2003	N. Takeuchi, T. Seki, Y. Torii, K. Saito, et al.	Ray tracing calculation for the fast wave electron heating on LHD	The 13th International Toki Conference	Dec. 9-12, 2003, Toki, Japan	2003-FT3-3
3	2003	T. Shimozuma, H. Idei, M. A. Shapiro, T. Notake, S. Ito, S. Kubo, R. J. Temkin and K. Ohkubo	Alignment Method of Transmission Lines Based on the Moment and Phase Retrieval Method Using IR images	EU-US-JA RF heating technology workshop 2003	Sept. 25-26, Tokai, Ibaragi, Japan	2000-FT3-3 2005-FT3-5
4	2004	T. Shimozuma, H. Idei, M. A. Shapiro, R. J. Temkin, S. Ito, T. Notake, S. Kubo, Y. Yoshimura, S. Kobayashi, Y. Mizuno, Y. Takita and K. Ohkubo	Alignment Method of Transmission Lines Based on the Moment and Phase Retrieval Method Using IR images	15th Nucler Fusion Energy Conference	June 17-18,2004, Sendai, Japan	2003-FT3-7 2000-FT3-3

5	2005	T. Shimozuma, S. Kubo, Y. Yoshimura, H. Igami, H. Idei, T. Notake, S. Ito, S. Kobayashi, Y. Mizuno, Y. Takita, M. A. Shapiro, R. J. Temkin, K. Ohkubo and T. Mutoh	Improvement of ECH System for High Performance Experiments in LHD	EU-US-JA RF heating technology workshop 2005	Jun. 15-18, 2005, Santa Cruz, California, USA	2005-FT3-5
6	2007	T. Oosako, et al.	Combline Antenna for Lower Hybrid Current Start-up Experiments in Tokyo Spherical Tokamak-2	Korea-Japan workshop on heating technology of Fusion plasmas	Oct.16-17, 2007, Jeju, Korea	2005-FT3-2 2006-FT3-2
7	2007	T. Shimozuma, H. Idei, M.Shapiro, R.J.Temkin, S. Kubo, Y. Yoshimura, H. Igami, T. Notake, S. Ito, S. Kobayashi. Y. Mizuno, Y. Takita, T. Mutoh	Efficiency improvement in long-distance transmission of high-power millimeter waves by propagating mode analysis in corrugated waveguides	24th annual meeting of the Japan Soc. of Plasma Physics and Nuclear Fusion Research	Nov. 27-30, 2007, Himeji, JAPAN	2007-FT3-6 2009-FT3-3
8	2008	T. Shimozuma, H. Idei, M. A. Shapiro, R. J. Temkin, S. Kubo, H. Igami, Y. Yoshimura, H. Takahashi, S. Ito, S. Kobayashi, Y. Mizuno, Y. Takita and T. Mutoh	Propagating Mode Contents in the Corrugated Waveguides of ECH System for Precise Alignment	18th International Toki Conference (ITC18)	Dec. 9 - 12, 2008, Toki, Japan	2007-FT3-6 2008-FT3-1 2009-FT3-3
9	2008	T. Shimozuma, H. Idei, M. A. Shapiro, R. J. Temkin, S. Kubo, Y. Yoshimura, H. Igami, H. Takahashi, S. Ito, S. Kobayashi, Y. Mizuno, Y. Takita and T. Mutoh	In-situ mode analysis of high power millimeter-waves propagating in the corrugated waveguide	25th annual meeting of the Japan Soc. of Plasma Physics and Nuclear Fusion Research	Dec. 2-5, 2008, Utsunomiya, Japan	2007-FT3-6 2008-FT3-1 2009-FT3-3
10	2008	T. Shimozuma, H. Idei, M. A. Shapiro, R. J. Temkin, S. Kubo, Y. Yoshimura, H. Igami, H. Takahashi, T. Notake, S. Ito, S. Kobayashi, Y. Mizuno, Y. Takita and T. Mutoh	Propagating Mode Analysis and Field Reconstruction in the Corrugated Waveguides of a High Power Electron Cyclotron Heating System	IRMMW-THz 2008	Sept. 15-19, 2008, Pasadena, California USA	2007-FT3-6 2008-FT3-1 2009-FT3-3
11	2008	T. Shimozuma, S. Kubo, Y. Yoshimura, H. Igami, H. Takahashi, Y. Takita, S. Kobayashi, S. Ito, Y. Mizuno, H. Idei, T. Notake, M. A. Shapiro, R. J. Temkin, F. Felici, T. Goodman, O. Sauter, and T. Mutoh	Recent Studies toward Improvement of Total ECH Efficiency in LHD	US-EU-JPN RF Heating Technology Workshop 2008	Sept. 10-12, 2008, San Diego, California, USA	2009-FT3-3
12	2008	T. Shimozuma, S. Kubo, Y. Yoshimura, H. Igami, H. Takahashi, Y. Takita, S. Kobayashi, S. Ito, Y. Mizuno, H. Idei, T. Notake, M. A. Shapiro, R. J. Temkin, F. Felici, T. Goodman, O. Sauter, R. Minami, T. Kariya, T. Imai and T. Mutoh	HANDLING TECHNOLOGY OF MEGA-WATT MILLIMETER-WAVES FOR OPTIMIZED HEATING OF FUSION PLASMAS	Global Congress on Microwave Energy Applications GCMEA 2008 MAJIC 1st	Aug. 4-8, 2008, Otsu, JAPAN	2007-FT3-6 2008-FT3-1 2009-FT3-3
13	2009	M. Shapiro, E. Kowalski, B. Munroe, E. Nanni, J. Sirigiri, D. Tax, R. Temkin et al.	Losses, Multimode Propagation and Mode Conversion in ECH Transmission Lines	US-EU-JPN RF Heating Technology Workshop 2009	Sept. 16-18, 2009, Fukuoka, Japan	2009-FT3-3
14	2009	T. Shimozuma, H. Takahashi, S. Ito, Y. Mizuno et al.	Improvement of Overall Efficiency in Large Scale ECH System for LHD	26th annual meeting of the Japan Soc. of Plasma Physics and Nuclear Fusion Research	Dec. 1-4, 2009, Kyoto, Japan	2009-FT3-3
15	2009	T. Shimozuma, S. Kubo, Y. Yoshimura, H. Igami, H. Takahashi, R. Ikeda, N. Tamura, S. Kobayashi, S. Ito, Y. Mizuno, Y. Takita, T. Mutoh. R. Minami, T. Kariya, T. Imai, H. Idei, M.A. Shapiro, R.J. Temkin, F. Felici, T. Goodman, and O. Sauter	Activities on Realization of High-Power and Steady-State ECRH System and Achievement of High Performance Plasmas in LHD	18th Topical Conference on Radio Frequency Power in Plasmas	Jun. 24 - 26, 2009, Gent, Belgium	2007-FT3-6 2008-FT3-1 2009-FT3-3

2.4.4 Blankets

1. Journal Paper

No	Year	Authors	Title of Paper	Journal	Vol. (Year) Page (Start) -Page(End) or Identification No.	Year-Category-No.
1	2000	S.Ebara, S.toda and H.Hahsizume	Application of Porous Matrix to High Heat Load Removal	Heat and Mass Transfer	36 (2000) 273-276	2000-FT4-8
2	2000	B. van der Schaaf, D.S. Gelles, S. Jitsukawa, A. Kimura, R.L. Klueh, A. Moslang and G.R. Odette	Progress and Critical Issues of Reduced Activation Ferritic/Martensitic Steel Development	J. Nucl. Mater	283-287 (2000) 52-59	2000 FT4-13 MM-3 MM-25 MM-26
3	2002	S. Satake, T. Kunugi, and S. Smolentsev	Advances in direct numerical simulation for MHD modeling of free surface flows	Fusion Engineering and Design	61-62 (2002) 95-102	2000-FT4-7
4	2005	Masumi Okumura, Kazuhisa Yuki, Hidetoshi Hashizume, Akio Sagara	Evaluation of Flow Structure in Packed-Bed Tube by Visualization Experiment	Fusion Science and Technology	47 (4) (2005) 1089-1093	2000-FT4-6
5	2006	Shin-Ya Chiba, Kazuhisa Yuki, Hidetoshi Hashizume, Saburo Toda,Akio Sagara	Numerical research on heat transfer enhancement for high Prandtl-number Fluid	Fusion Engineering and Design	81 (2006) 513-517	2005-FT5-2
6	2007	Masaaki Satake, Kazuhisa Yuki, Hidetoshi Hashizume	Reproduction of behavior of 2-D channel flow with two rods by using k-e model	Fusion Science and Technology	52 (4) (2007) 817-820	2006-FT5-2
7	2009	H. Hashizume, K. Yuki, N. Seto, A. Sagara	Feasibility Study of Flibe TBM baaed on Thermofluid Analysis	Fusion Science and Technology	56 (2) (2009) 892-896	2008-FT5-1

2. Conference Paper

No	Year	Authors	Title of Paper	Conference Name	Month Date, Year, Place, Country	Year-Category-No.
1	2002	S. Satake, T. Kunugi, and S. Smolentsev	Advances in direct numerical simulation for MHD modeling of free surface flows	Int. Symp. Fusion Nuclear Technology 6	April 7-12, 2002, San Diego, USA	2000-FT4-7
2	2003	K. Yuki, K. Okuyama, S. Toda, H. Hashizume, T. Muramatsu	Investigation of Non-Isothermal Fluid Mixing and Wall Temperature Fluctuation in At-Junction which has a 90-degree Bend in the Upstream Area	NURETH-10	October 5-9, 2003, Seoul, Korea	2000-FT4-6
3	2006	S. Toda, K. Yuki, S. Ebara, Y. Kunikata, J. Abei and H. Hashizume	Development of an Advanced Cooling Device Using Porous Media with Active Boiling Flow Counter to High Heat Flux	Int. Symp. Fusion Nuclear Technology 6	August 13-18, Sydney, Australia	2002-FT4-5

2.4.5 In-Vessel/High Heat Flux Materials and Components

1. Journal Paper

No	Year	Authors	Title of Paper	Journal	Vol. (Year) Page (Start) -Page(End) or Identification No.	Year-Category-No.
1	2001	E. M. Hollmann, D.G. Whyte, D. Nishijima, N. Ohno et al.	Evidence for the importance of radial transport in plasma detachment in the Nagoya University Divertor Simulator (NAGDIS-II)	Physics of Plasmas	8 (2001) 3314-3320	2000-FP5-8
2	2002	R. E. Nygren	Actively cooled plasma facing components for long pulse high power operation	Fusion Engineering and Design	60 (2002) 547-564	2002-FT5-1
3	2002	K. Tokunaga, R. P. Doerner, R. Seraydarian, N. Noda, N. Yoshida, T. Sogabe, T. Kato and B. Schedler	Modification of tungsten coated carbon by low energy and high flux deuterium irradiation	Journal of Nuclear Materials	307-311(2002) 126-129	2000- FT5-10
4	2003	R.P. Doerner, M.J. Baldwin, S.I. Krasheninnikov, D.G. Whyte	Behavior of high temperature liquid surfaces in contact with plasma	Journal of Nuclear Materials	313-316 (2003) 383-387	2002-FT5-1
5	2003	Y. Ueda, K. Tobita, Y. Katoh	PSI issues at plasma facing surfaces of blankets in fusion reactors	Journal of Nuclear Materials	313-316 (2003) 32-41	2002-FT5-1
6	2003	J.P. Sharpe, V. Rohde, the ASDEX-Upgrade experimenta team, A. Sagara, H. Suzuki, A. Komori, O. Motojima and the LHD experimental group	Charactarization of dust collected from ASDEX-Upgrade and LHD	Journal of nuclear materials	313-316 (2003) 455-459	2000-FT6-7

7	2003	K. Tokunaga, R. P. Doerner, R. Seraydarian, N. Noda, Y. Kubota, N. Yoshida, T. Sogabe, T. Kato and B. Schedler	Surface morphology and helium retention on tungsten exposed to low energy and high flux helium plasma	Journal of Nuclear Materials	313-316 (2003) 92-96	2001-FT5-06
8	2004	D. Nishijima, M.Y. Ye, N. Ohno, S. Takamura	Incident ion energy dependence of bubble formation on tungsten surface with low energy and high flux helium plasma irradiation	Journal of Nuclear Materials	313-316 (2004) 97	2004-FT5-3
9	2005	Hisae Togashi, Kazuhisa Yuki, Hidetoshi Hashizume	Heat Transfer Enhancement Technique with Copper Porous Media	Fusion Science and Technology	47 (2005) 740-745	2004-FT5-4
10	2005	K. Tokunaga, M.J. Baldwin, R.P. Doerner, N. Noda, Y. Kubota, N. Yoshida, T. Sogabe, T. Kato and B. Schedler	Blister formation and deuterium retention on tungsten exposed to low energy and high flux deuterium plasma	Journal of Nuclear Materials	337-339 (2005) 887-891	2005-FT5-3 2001-FT5-06
11	2006	R.E. Nygren, M.A. Ulrickson, T.J. Tanaka, D.L. Youchison, T.J. Lutz, J. Bullock, K.J. Hollis	ITER first wall Module 19—The US effort	Fusion Engineering and Design	81 (2006) 387-392	2005-FT5-3
12	2006	S. TAKAMURA, N. OHNO, D. NISHIJIMA and S. KAJITA	Formation of Nanostructured Tungsten with Arborescent Shape due to Helium Plasma Irradiation	Plasma and Fusion Research	1 (2006) 051	2005-FT5-3
13	2007	N. Ohno, S. Kajita, Dai Nishijima, S. Takamura	Surface modification at tungsten and tungsten coated graphite due to low energy and high fluence plasma and laser pulse irradiation	Journal of Nuclear Materials	363-365 (2007) 1153-1159	2007-FT5-1
14	2009	C.P.C. Wong	Innovative tokamak DEMO first wall and divertor material concepts	Journal of Nuclear Materials	390-391 (2009) 1026-1028	2007-FT5-1
15	2009	J.P. Sharpe, R.D. Kolasinski, M. Shimada, P. Calderoni, R.A. Causey	Retention behavior in tungsten and molybdenum exposed to high fluences of deuterium ions in TPE	Journal of Nuclear Materials	390-391 (2009) 709-712	2009-FT5-1
16	2009	M. Miyamoto , D. Nishijima , Y. Ueda , R.P. Doerner , H. Kurishita , M.J. Baldwin , et al.	Observations of suppressed retention and blistering for tungsten exposed to deuterium–helium mixture plasmas	Nuclear Fusion	49 (2009) 065035	2009-FT5-1
17	2009	R.A. Causey, R. Doerner, H. Fraser, R.D. Kolasinski, J. Smugeresky, K. Umstadter, R. Williams	Defects in tungsten responsible for molecular hydrogen isotope retention after exposure to low energy plasmas	Journal of Nuclear Materials	390-391 (2009) 717-720	2009-FT5-1
18	2009	S. Sharafat, A. Takahashi, Q. Hu, N.M. Ghoniem	A description of bubble growth and gas release of helium implanted tungsten	Journal of Nuclear Materials	386-388 (2009) 900-903	2005-FT5-3
19	2010	H. Kurishita, S. Matsuo, H. Arakawa, T. Sakamoto, et al.	Development of re-crystallized W–1.1%TiC with enhanced room-temperature ductility and radiation performance	Journal of Nuclear Materials	398 (2010) 87-92	2009-FT5-1

2. Conference Paper

No	Year	Authors	Title of Paper	Conference Name	Month Date, Year, Place, Country	Year-Category-No.
1	2002	Y. Ueda, K. Tobita, Y. Katoh	PSI issues at plasma facing surfaces of blankets in fusion reactors	15th International Conference on Plasma Surface Interactions in Controlled Fusion Devices	May 27 - May 31, 2002, Gifu, Japan	2002-FT5-1
2	2003	T. Muroga, H. Watanabe, K. Fukumoto, M. Satou, A. Kimura, S.J. Zinkle, N. Hashimoto, D.T. Hoelzer and A.L.Qualls	Summary of the Varying Temperature Irradiation Experiment in HFIR	Proc. of 15th Topical Meeting on the Technology of Fusion Energy (TOFE-15), Fusion Science and Technology	Nov.17-21, 2002, Washington,D.C., USA	2003 FT5-2 MM-30
3	2004	R. P. Doerner, M. J. Baldwin, S. I. Krasheninnikov, and K. Schmid	High temperature erosion of Beryllium	16th International Conference on Plasma Surface Interactions in Controlled Fusion Devices	May 24-28, 2004, Portland, USA	2002-FT5-1

4	2007	Kazuhisa Yuki, Akira Matsui, Hidetoshi Hashizume	Heat removal performance of particle-sintered porous media counter to heat flux input and its phase change characteristics	Second international conference on porous media and its applications in science, engineering and industry	June 17-22,2007,Hawaii, USA	2005-FT5-2
5	2009	H. Kurishita	Markedly Refined W added with TiC Exhibiting Low DBTT and High Radiation Durability	14th International Conference on Fusion Reactor Materials	Sept. 6-11, 2009, Sapporo, Japan	2009-FT5-1
6	2009	R. Nygren	Making Tungsten Work	14th International Conference on Fusion Reactor Materials	Sept. 6-11, 2009, Sapporo, Japan	2009-FT5-1

2.4.6 Others

1. Journal Paper

No	Year	Authors	Title of Paper	Journal	Vol. (Year) Page (Start) -Page(End) or Identification No.	Year-Category-No.
1	2003	R. Tsuji	Flying metal pipe for target transport in inertial fusion energy reactor	Fusion Science and Technol.	43 (2003) 327-333	2002-FT6-5
2	2003	T. Norimatsu, K. Nagai, T. Takeda, K. Mima, and T. Yamanaka	Update for the drag force on an injected pellet and target fabrication for Inertial fusion	Fusion Sci. Technol.	43 (2003) 339-345	2002-FT6-5
3	2005	K. Nagai, H. Azechi, F. Ito, A. Iwamoto, Y. Izawa, T. Johozaki, R. Kodama, K. Mima, T. Mito, M. Nakai, N. Nemoto, T. Norimatsu, Y. Ono, K. Shigemori, H. Shiraga, K. A. Tanaka	Foam materials for cryogenic targets of fast ignition realization experiment (FIREX)	Nucl. Fusion	45 (2005) 1277-1283	2002-FT6-5
4	2006	K. Furuichi, H. Takata, T. Motoshima, S. Satake, M. Nishikawa	Study on behavior of tritium in concrete wall	Journal of Nuclear Materials	350 (2006) 246-253	2002-FT6-7 2004-FT6-3
5	2006	M. Nishikawa, K. Furuichi, H. Takata	Study on permeation behavior of gaseous tritium through concrete walls	Fusion Science and Technology	50 (2006) 521-527	2002-FT6-7 2004-FT6-3
6	2007	K. Furuichi, H. Takata, T. Motoshima, S. Satake, M. Nishikawa	Evaluation of tritium behavior in concrete	Journal of Nuclear Materials	360-370 (2007) 1243-1247	2002-FT6-7 2004-FT6-3
7	2008	T. Goto, Y. Ogawa, K. Okano et al.	Analysis of a core plasma dynamics and dry wall chamber for fast-ignition IFE power plant	Journal of Physics: Conference Series	112 (2008) 032038 (4pp)	2008-FT6-4
8	2009	T. Goto, Y. Someya, Y. Ogawa et al.	Conceptual design of fast-ignition laser fusion reactor FALCON-D	Nuclear Fusion	49 (2009) 075006 (8pp)	2008-FT6-4

2. Conference Paper

No	Year	Authors	Title of Paper	Conference Name	Month Date, Year, Place, Country	Year-Category-No.
1	2003	T. Norimatsu, K. Nagai, T. Yamanaka and Y. Izawa	Experimental Simulation on Protection of Final Optics from Metal Vapor in a Wet-Wall Laser Fusion Reactor	Inertial Fusion Science and Application	Monterey, USA	2002-FT6-5
2	2004	T. Norimastu, H. Azechi, et al.	Development of Key Technologies in DPSSL System for Fast-ignition, Laser Fusion Reactor - FIREX, HALNA, and Protection of Final Optics	20th IAEA Fusion Energy Conference	1-6 Nov. (2004), Vilamoura, Porutogal, FT/2-1Rb	2002-FT6-5
3	2007	T. Goto, Y. Someya, Y. Ogawa et al.	Analysis of a core plasma dynamics and dry wall chamber for fast-ignition IFE power plant	The fifth International Conference on Inertial Fusion Sciences and Applications (IFSA2007)	9-14 September 2007, Kobe, Japan	2007-FT6-4
4	2008	T. Goto, Y. Someya, Y. Ogawa et al.	Conceptual design of fast-ignition laser fusion reactor FALCON-D	22nd IAEA FEC	13-18 October 2008, Geneva, Switzerland	2007-FT6-4

CHAPTER 3 FPPC

The publication lists in the four categories of 3.4.1 Steady-state Operation, 3.4.2 MHD and High Beta, 3.4.3 Confinement, 3.4.4 Diagnostics are combined into the following list, because some papers are difficult to be sorted into one category.

1. Journal Paper

No	Year	Authors	Title of Paper	Journal	Vol. (Year) Page (Start) -Page(End) or Identification No.	Year-Category-No.
1	2000	Y. Ono and M. Inomoto	Ultra-High Beta Spherical Tokamak Formation by Use of Oblate Field-Reversed Configuration	Physics of Plasmas	7 (2000) 1863-1869	2000-FP2-14
2	2001	Y.Oka, Y.Takeiri, K.Tsumori, M.Osakabe, O.Kaneko, K.Ikeda, M.Hamabe, E.Asano, T.Kawamoto, L.Grisham	Performance of LHD-NBI H-ion source	Rev.Sci.Instrum.	73 (2002) 1054-1057	2001-FP4-04
3	2001	M. Ono, M.G. Bell, M. Nagata, et al.	Overview of the initial NSTX experimental results	Nuclear Fusion	41 (2001) 1435-1447	2000-FP4-8 2000-FP4-9
4	2001	N.Iwasawa, A.Ishida, L.C.Steinhauer	Linear Gyroviscous Stability of Field-Reversed Configurations with Static Equilibrium	Physics of Plasmas	8 (2001) 1240-1247	2001-FP2-1
5	2001	Y. Ono, M. Inomoto, Y. Ueda, T. Matsuyama and Y. Murata	Fast Compression of Current Sheet during Externally Driven Magnetic Reconnection	Earth, Planets and Space	53 (2001) 521-526	2001-FP2-8
6	2001	L.C.Steinhauer, H.Yamada, A.Ishida	Two-Fluid Flowing Equibliria of Compact Plasmas	Physics of Plasmas	8 (2001) 4053-4061	2001-FP2-1
7	2001	Y. Ono, M. Inomoto, T. Matsuyama, T. Murakami and T. Tawara	Ultra-High-Beta Spherical Tokamak Experiment by Use of Torus Plasma Merging in TS-3 Spherical Torus Device	Nuclear Fusion	41 (2001) 971-980	2001FP2-8
8	2001	Y. Ono, M. Inomoto, Y. Ueda and T. Matsuyama	Fast Magnetic Reconnection with Anomalous Resistivity and Its Application	Science and Technology of Advanced Material	2 (2001) 473-482	2001-FP2-8
9	2001	Y. Ueda and Y. Ono	High-Power Heating of Spherical Tori by Use of Merging / Reconnection Phenomena	Earth, Planets and Space	53 (2001) 527-531	2000-FP2-8 2000-FP2-9
10	2001	Y. Ueda and Y. Ono	Experimental Comparison of Compact RFPs, Spheromaks, and STs Using Controlled Current Drive	Nuclear Fusion	41 (2001) 981-984	2000-FP2-9
11	2002	Y.Torii, R.Kumazawa, T.Watari et al.	ICRF Heating on LHD using Folded Waveguide Antenna	Journal of Plasma Fusion Research	SERIES 5 (2002) 310-313	2000-FP4-6
12	2002	Y.Torii, R.Kumazawa, T.Seki et al.	Plasma Production Experiments using a Folded Waveguide Antenna on LHD	Nuclear Fusion	42, 6 (2002) 679-688	2000-FP4-6
13	2002	A. L. Balandin and Y. Ono	Tomographic Determination of Plasma Velocity with the Use of Ion Doppler Spectroscopy	European Physical Journal D	17 (2002) 337-344	2002FP2-1
14	2002	R Sakamoto, H Yamada et al.	Ablation and subsequent Density Redistribution of Fueling Pellets Injected into LHD Plasmas	29th EPS Conference on Plasma Physics and Controlled Fusion	ECA 26B (2002) P1.074	2001-FP2-17
15	2003	P.R. Goncharov, J.F. Lyon, T. Ozaki, S. Sudo and LHD Experimental Group	A Numerical Approach to the Localization of Passive Line Integrated Neutral Particle Measurements on LHD	Journal of Plasma and Fusion Research Series	6 (2003)	2003-FP5-15
16	2003	P.R. Goncharov, T. Saida, N. Tamura, T. Ozaki, M. Sasao, M. Isobe, S. Sudo, K.V. Khlopenkov, A.V. Krasilnikov, V.Yu. Sergeev, and LHD Experimental Groups	Development and Initial Operation of the Pellet Charge Exchange Diagnostic on LHD Heliotron	Review of Scientific Instruments	74 (2003) 1869-1872	2003-FP5-15
17	2003	Tetsuo Ozaki, Sadayoshi Murakami, et al.	Spatial resolved high energy particle diagnostic system using time-of-flight neutral particle energy analyzer in Large Helical Device	Review of Scientific Instruments	74-3 (2003) 1878-1882	2003-FP5-15
18	2003	D. Mueller, M. Ono, M.G. Bell, …, M. Nagata,…,et al.	Results of NSTX Heating Experiments	IEEE Trans. Plasma Science	31 (2003) 60-67	2001-FP4-07 2001-FP4-8 2002-FP4-6 2002-FP5-37

19	2003	M.Gilmore, W.A.Peebles., S.Kubota, X.V.Nguyen, and A.Ejiri	Progress toward a practical magnetic field diagnostic for low-field fusion plasmas based on dual mode correlation reflectometry	Rev. Sci. Instrum.	74 (2003) 1469-1472	2002-FP5-37
20	2003	Y.Oka, K.Tsumori, Y.Takeiri, K.Ikeda, O.Kaneko, K.Nagaoka, M.Osakabe, E.Asano, T.Kawamoto, T.Kondo, M.Sato, L.Grisham, A.Honda, N.Umeda, T.Yamamoto	Studied of H- source for large helical device-neutral beam injector(invited)	Rev.Sci.Instrum.	75 (2004) 1803-1808	2003-FP4-1
21	2003	J.R. Wilson, et al.	Exploration of high harmonic fast wave heating on the National Spherical Tokamak Experiment	Phys. Plasmas	10 (2003) 1733-1738	2001-FP4-8 2002-FP4-6
22	2003	A. L. Balandin, Y. Ono and Y. Murata	Radial Velocity Profile Reconstruction by Ion Doppler Spectroscopy Measurements	European Physical Journal D	27 (2003) 125-130	2003FP2-8
23	2003	E.J. Synakowski, M.G. Bell, …,M. Nagata,…, et al.	The national spherical torus experiment (NSTX) research programme and progress towards high beta, long pulse operating scenarios	Nucl. Fusion	43 (2003) 1653-1664	2001-FP4-8 2001-FP4-7 2002-FP4-6
24	2003	M. Ono, M.G. Bell,…,M. Nagata,…, et al.	Progress towards high-performance, steady-state spherical torus	Plasma Phys. Control. Fusion	45 (2003) A335-A350	2001-FP4-7 2001-FP4-8 2002-FP4-6
25	2003	Y. Ono, T. Kimura, E. Kawamori, Y. Murata, S. Miyazaki, Y. Ueda, M. Inomoto, A. L. Balandin and M. Katsurai	First and Second-Stable Spherical Tokamaks in Reconnection Heating Experiments	Nuclear Fusion	43 (2003) 789-794	2003FP4-4
26	2003	Y. Ono, T. Kimura, T. Murata, S. Miyazaki, Y. Ueda, M. Inomoto, K. Arimoto, A. L. Balandin	High-Beta Characteristics of First and Second-Stable Spherical Tokamaks in Reconnection Heating Experiments of TS-3	Fusion Energy 2002	(2003) EX/P3-15	2002FP4-5
27	2003	Y. Ono, T. Matsuyama, K. Umeda and E. Kawamori	Spontaneous and Artificial Generation of Sheared Flow in Oblate FRCs	Nuclear Fusion	43 (2003) 649-654	2003FP2-8
28	2003	M. Isobe, D.S. Darrow, J. Kotani, A. Shimizu, C. Suzuki, Y. Yoshimura, T. Minami, C. Takahashi, K. Nagaoka, S. Nishimura, K. Toi, K. Matsuoka, S. Okamura, and the CHS group	Energy and pitch angle-resolved measurements of escaping helically trapped energetic ions at small major radius side of CHS	Review of Scientific Instruments	74 (2003) 1739-1742	2003-FP-2-4
29	2003	H. Gota, K. Fujimoto, Y. Ohkuma, T. Takahashi, and Y. Nogi	Separatrix shapes and internal structures of a field-reversed configuration plasma	Phys. Plasmas	10 (2003) 4763-4770	2004-FP5-37
30	2003	H. Gota, T. Akiyama, K. Fujimoto, Y. Ohkuma, Ts. Takahashi, and Y. Nogi	Separatrix shape measurement on field-reversed configuration plasmas	Rev. Sci. Instrum.	74 (2003) 2318-2323	2004-FP5-37
31	2004	P.R. Goncharov, T. Ozaki, S. Sudo, N. Tamura, et al.	Digital Processing of Solid State Detector Signals in Pellet Charge Exchange Measurements on LHD	Review of Scientific Instruments	75 (2004) 3613-3615	2003-FP5-15
32	2004	T.Ozaki, P.Goncharov, S.Murakami, S.Sudo, H.Sanuki, et al.	Two-dimensional scanning high-energy particle diagnostic system in Large Helical Device	Review of Scientific Instruments	75-10 (2004) 3604-3606	2003-FP5-15
33	2004	H. Nakanishi, T. Hochin, M. Kojima, LABCOM group	Search and retrieval method of similar plasma waveforms	Fusion Engineering and Design	71 (2004) 189-193	2004-FP5-39
34	2004	M. Ignatenko, A. Mase, L. Bruskin et al.	Microwave Imaging Reflectometry of Corrugated Metal Targets	J. Plasma Fusion Res	80, 2 (2004) 87-89	2004-FP5-18
35	2004	M. Ignatenko, A. Mase, L. G. Bruskin et al.	Effects of Asymmetry and Target Location on Microwave Imaging Reflectometry	Rev. Sci. Instrum	75, 10 (2004) 3810-3812	2004-FP5-18
36	2004	Y. Kogi, K. Uchida, A. Mase et al.	Ultrashort-Pulse Reflectometer on LHD	Rev. Sci. Instrum	75, 10 (2004) 3837-3839	2004-FP5-18

37	2004	A. Ishida, C. O. Harahap, L. C. Steinhauer, Y-K.M. Peng	Ellipticity Criterion for Flowing two-fluid High Equilirium	Physics of Plasmas	11 (2004) 5297-5301	2003-FP2-12
38	2004	E. Kawamori and Y. Ono	Ion Kinetic Relaxation of Two Merging Spheromaks to an FRC	Journal of Plasma and Fusion Research	79 (2004) 1109-1110	2004FP2-1
39	2004	R Sakamoto, H Yamada et al.	Observation of pellet ablation behaviour on the large helical device	Nuclear Fusion	44 (2004) 624-630	2001-FP2-17
40	2004	Y. Ono and K. Umeda	FRC Formation Process of Two Colliding Spheromaks with Counterhelicity	IEEJ Transactions on Fundamentals and Materials	124-A (2004) 62-67	2004FP2-1
41	2004	M. Nishiura, M. Isobe, T. Saida, M. Sasao and D.S. Darrow	Scintillator probe diagnostic for high energy particles escaped from Large Helical Device	Review of Scientific Instruments	75 (2004) 3646-3648	2003-FP-2-4
42	2004	D. Kalinina, S. Sudo, D. Stutman, M. Finkenthal, N. Tamura, K. Sato, A. Matsubara and LHD Experimental Group	Development of the Ultrasoft X-Ray Diagnostic for Impurity Transport Studies with a Tracer-Encapsulated Solid Pellet Injection on LHD	Journal of Plasma and Fusion Research	80 (2004) 545-546	2004-FP5-26
43	2004	Ts. Takahashi, H. Gota, T. Fujino, M. Okada, T. Asai, K. Fujimoto, Y. Ohkuma, and Y. Nogi	Multichannel optical diagnostic system for field-reversed configuration plasmas	Rev. Sci. Instrum.	75 (2004) 5205-5212	2005-FP2-1
44	2005	S. Sudo, N. Tamura, D.V. Kalinina, K. Sato, A. Matsubara, S. Inagaki, P.R. Goncharov, T. Ozaki, et al.	New Multi-functional Diagnostic Method with Tracer-encapsulated Pellet Injection on LHD	AIP Conference Proc	771 (2005) 13-22	2004-FP5-19
45	2005	M. Ignatenko, A. Mase, L. Bruskin et al.	Numerical Study of Microwave Imaging Reflectometer for a Tandem Mirror Device	Trans. Fusion Sci. Tech	47, 1T (2005) 183-186	2004-FP5-18
46	2005	Y. Nagayama, A. Mase	Microwave Imaging	J. Plasma Fusion Res	81, 5 (2005) 337-348	2004-FP5-18
47	2005	M. Ignatenko, A, Mase, Y. Kogi et al.	Numerical Study of the Location of the Microwave Imaging Reflectometry Object Plane	J. Plasma Fusion Res	81, 6 (2005) 419-420	2004-FP5-18
48	2005	Y. Kogi, A. Mase, K. Kudo et al.	Development of New Detector for Millimeter-Wave Imaging	Proc. Joint 30th Int. Conf. on Infrared and Millimeter Waves and 14th Int. Conf. on Terahertz Electronics, Williamsburg	(2005) 604-605	2004-FP5-18
49	2005	M. Ignatenko, A. Mase, L. Bruskin et al.	Numerical Study of Microwave Imaging Reflectometry for Measurements of Density Fluctuations Spectra for GAMMA10 Geometry	Proc. 12th Int. Symp. on Laser-Aided Plasma Diagnostics	(2005) 371-376	2004-FP5-18
50	2005	Y.Oka, K.Ikeda, Y.Takeiri, K.Tsumori, O.Kaneko, K.Nagaoka, M.Osakabe, E.Asano, T.Kondo, M.Sato, M.Shibuya, L.Grisham, N.Umeda, A.Honda, Y.Ikeda, T.Yamamoto	Doppler-shift spectra of Ha lines from negative-ion-based neutral beams for large helical device neutral beam injection	Rev.Sci.Instrum.	77 (2006) 03A538-1-4	2005-FP4-1
51	2005	S.M. Kaye, et al.	Progress towards high performance plasmas in the National Spherical Torus Experiment (NSTX)	Nucl. Fusion	45 (2005) S168-S180	2003-FP4-3 2004-FP4-4
52	2005	D. Gates, et al.	Progress towards steady state on NSTX	Nucl. Fusion	46 (2006) S22–S28	2003-FP4-3 2004-FP4-4
53	2005	A. Ishida, C.Z.Cheng, Y-K.M.Peng	Properties of low and medium frequency modes in two-fluid plasma	Physics of Plasmas	12 (2005) 052113 (9 pages)	2004-FP2-12
54	2005	A. L. Balandin and Y. Ono	The method of series expansion for 3-D vector tomography reconstruction	Jounal of Computational Physics	202 (2005) 52-64	2005FP2-1
55	2005	D. Gates, et al.	Progress towards steady state on NSTX	Nucl. Fusion	46 (2006) S22–S28	2003-FP4-3 2004-FP4-4
56	2005	E. Kawamori and Y. Ono	Effect of Ion Skin Depth on Relaxation of Merging Spheromaks to a Field-Reversed Configuration	Physical Review Letters	95 (2005) 085003	2005FP2-1

57	2005	E. Kawamori, Y. Murata, K. Umeda, D. Hirota, T. Ogawa, T. Sumikawa, T. Iwama, K. Ishii, T. Kado, T. Itagaki, M. Katsurai, A. Balandin, Y. Ono,	Ion kinetic effect on bifurcated relaxation to a field-reversed configuration in TS-4 CT experiment	Nucl. Fusion	45 (2005) 843-848	2005FP2-1
58	2005	M. Ono, M.G. Bell, R.E. Bell, …,M.Nagata,…, et al.	Status and Plans for the National Spherical Torus Experimental Research Facility	IEEJ Trans. FM	125 (2005) 868-880	2003-FP4-5 2004-FP4-3
59	2005	R. Raman, T. R. Jarboe, M.G. Bell, D. Mueller, B.A. Nelson, B. Leblanc, C. Bush, M. Nagata, T. Biewer	Solenoid-free plasma startup in NSTX using coaxial helicity injection	IEEJ Trans. FM	125 (2005) 895-901	2003-FP4-5 2004-FP4-3
60	2005	Y. Ono and M. Inomoto	Heating Properties of Merging/ Reconnection Startup of High-Beta ST	IEEJ Transactions on Fundamentals and Materials	125-A (2005) 958-959	2004FP4-5
61	2005	Y. Ono, K. Umeda and A. L. Balandin,	Direct Access to Burning Spherical Tokamak Experiment by Pulsed High-Power Heating of Magnetic Reconnection	Fusion Energy 2004	(2005) ICP6/44	2004FP4-5
62	2005	D. Stutman, M. Finkenthal, L. Delgado-Aparicio, K. Tritz, N. Tamura, D. Kalinina, A. Matsubara, K. Sato and S. Sudo	High throughput ultrasoft x-ray polychromator for embedded impurity pellet injection studies	Review of Scientific Instruments	76 (2005) 013508	2006-FP5-22
63	2005	T. Asai, M. Nagata, H.Koguchi, S.Kiyama, Y, Hirano, Y.Yagi, H. Sakakita	Fiest Results of Magnetized Plasma Flow Injection on the TPE-RX Reversed -Field Pinch	JPFR	81 (2005) 335-336	2005-FP2-1
64	2006	Ozaki T., Goncharov P., Sudo S., Seki T., Murakami S., Veschev E., Lyon J	Horizontal, vertical and radial high-energy particle distribution measurement system in Large Helical Device	Review of Scientific Instruments	77 (2006) 10E917	2004-FP5-19
65	2006	T.Ozaki, P.Goncharov, T.Amano, I.Yamada, T.Saida, S.Murakami, S.Sudo, et al	Neutral particle measurement in high Z plasma in Large Helical Device	JPFR Series	7 (2006) 22-26	2004-FP5-19
66	2006	Goncharov P.R., Ozaki T., Sudo S., Tamura N., Veshchev E.A., Sergeev V.Yu., Krasilnikov A.V.	Local pellet based and line-integrated non perturbing charge exchange measurements with a compact neutral particle analyzer on Large Helical Device	Review of Scientific Instruments	77 (2006) 10F119	2004-FP5-19
67	2006	Goncharov P.R., Ozaki T., Sudo S., Tamura N., Kalinina D.V., Veshchev E.A., Sergeev V.Yu.	Active Neutral Particle Diagnostics on LHD by Locally Enhanced Charge Exchange on an Impurity Pellet Ablation Cloud	Fus. Sci. and Tech.	50 (2) (2006) 222-228	2004-FP5-19
68	2006	P.R. Goncharov, T. Ozaki, J.F. Lyon, S. Sudo and LHD Experimental Group	Diagnostics of Charge Exchange Neutrals from Multi-Ion-Species NBI-Heated Plasmas on LHD	Journal of Plasma and Fusion Research Series	7 (2006) 18-21	2004-FP5-19
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158	2009	K. Yoshikawa, K. Masuda, T. Takamatsu, Y. Yamamoto, H. Toku, T. Fujimoto, E. Hotta, K. Yamauchi, M. Ohnishi, H. Osawa, S. Shiroya, T. Misawa, Y. Takahashi, Y. Kubo and T. Doi	Results of the Development of the Humanitarian Landmine Detection System by a Compact Fusion Neutron Source and Dual Sensors	AIP Conference Proceedings	1099 (2009) 652-655	2009-FP5-1
159	2009	K. Masuda, T. Takamatsu, K. Yoshikawa, T. Misawa, S. Shiroya, Y. Takahashi, T. Fujimoto, T. Nakagawa, T. Kajiwara and K. Nagasaki	Research and Development of Compact Neutron Sources based on Inertial Electrostatic Confinement Fusion	AIP Conference Proceedings	1099 (2009) 652-655	2008-FP5-8
160	2009	K.Tomiyasu, K.Yokoyama, K.Yamauchi, M.Watanabe, A.Okino, and E.Hotta	Effects of Cusp Magnetic Field in a Cylindrical Radially Convergent Beam Fusion Device	Fusion Science and Technology	56 (2009) 967-971	2008-FP5-8
161	2009	Y. Yamamoto, A. Ishidou, K. Noborio, S. Konishi	Neutron Beam Generation by the Cylindrical Fusion Neutron Source	Fusion Science and Technology	56 (2009) 761-765	2008-FP5-8

162	2009	A. Mase, Y. Kogi, N. Ito et al.	Advanvement of Microwave Diagnostics for Magnetically Confined Plasmas	Plasma Devices and Operations	17, 2 (2009) 98-116	2007-FP5-6
163	2009	K. Akaki, A. Mase, Y. Kogi et al.	Study of Dual-Dipole Antenna Array for Millimeter Wave Imaging	Proc. 34th Int. Conf. on Infrared, Millimeter, and Terahertz Wave	(2009) R5E41-0055	2009-FP5-2
164	2009	A. Sanpei, K. Oki, R. Ikezoe, et al.	Equilibrium reconstruction and estimation of neoclassical effect in low-aspect-ratio RFP experiments on RELAX	J. Phys. Soc. Jpn	78, No.1(2009) 013501	2006-FP2-8
165	2009	A. Sanpei, K. Oki, R. Ikezoe, et al.	Characterization of equilibria in a low-aspect-ratio RFP	J. Plasma Fusion Res. SERIES	8 (2009) 1066	2006-FP2-8
166	2009	R. Raman, T.R. Jarboe, M.Nagata, et al.	Solenoid-free plasma start-up in NSTX using transient CHI	Nucler Fusion	49 (2009) 65006-65011	2006-FP4-3 2007-FP3-5
167	2009	T. Asai, Y. Matsuzawa, N. Yamamoto, K. Takao, H. Tamura, M. Hiyoshi, T. Sasaki, Ts. Takahashi, Y. Nogi, M. Inomoto, To. Takahashi, J. Miyazawa, Y. Narushima	Translation of Field-Reversed Configuration into a Confinement Region Filled with Neutral Gas	Journal of Plasma and Fusion Research SERIES (JPFR SERIES)	8 (2009) 1058-1061	2009-FP3-3
168	2009	Y. Matsuzawa, T. Asai, Ts. Takahashi, To. Takahashi, et al.	Particle and Energy Recovery Process of a High-Beta Compact Toroid Translated Along an Asymmetric Mirror Field	Fusion Science and Technology	55(2T) (2009) 76-81	2008-FP4-1
169	2009	N. Yamamoto, Y. Matsuzawa, T. Asai, Ts. Takahashi, To. Takahashi, et al.	Self-Generated Toroidal Flow in a High-Beta Compact Toroid with Mirror Configuration	Fusion Science and Technology	55(2T) (2009) 87-90	2008-FP4-1
170	2010	H. Nakanishi, et al.	Clustered Data Storage for Multi-site Fusion Experiments	Plasma and Fusion Research	5 (2010) S1042	2008-FP5-7

2. Conference Paper

No	Year	Authors	Title of Paper	Conference Name	Month Date, Year, Place, Country	Year-Category-No.
1	2000	A. L. Balandin, Y. Ono	3-D tomography diagnostic system for spherical tokamaks	43rd Annual Meeting of the Division of Plasma Physics, APS	Nov. 2000, Quebec Canada	2000-FP2-14
2	2000	Y. Ono, T. Murakami, M. Inomoto, Y. Ueda, T. Matsuyama, and H. Hayashiya	Fast Reconnection Mechanisms in TS-3 Merging Experiment	University of Tokyo Symposium 2000 on Magnetic Reconnection in Space and Laboratory Plasmas,	Feb.-Mar., 2000, Tokyo, Japan	2000-FP2-8
3	2000	Y. Ono, Y. Ueda, T. Matsuyama, M. Tsuruda, M. Inomoto, H. Hayashiya, M.Katsurai	Formation of Compact RFP, Spheromak and ST in TS-3 Device and Their Merging Magnetic Reconnection	43rd Annual Meeting of the Division of Plasma Physics, APS	Nov. 2000, Quebec, Canada	2000-FP2-9
4	2000	Y.Torii, R.Kumazawa, T.Watari et al.	Ray tracing calculation of shear Alfven wave on LHD	13th International Toki Conference on Plasma Physics and Contrlooed Nuclear Fusion	Dec.9-12, 2000, Toki, Japan	2000-FP4-6
5	2001	B.P. LeBlanc, et al.	High-Harmonic Fast-Wave Heating in NSTX	14th Top. Conf. on Radio Frequency Power in Plasmas	2001, Oxnard, California	2000-FP4-8
6	2001	Y.Torii, R.Kumazawa, T.Watari et al.	Ion Berstein wave heating using folded waveguide antenna on LHD	Joint Conference of 12th InternationaToki Conference on Plasma Physics and Contrlooed Nuclear Fusion and 3rd General Scientific Assembly of Asia Plasma and Fusion Associationl	Dec.11-14, 2001, Toki, Japan	2000-FP4-6
7	2001	J.R. Wilson, et al.	Plasma Response to the Application of 30 MHz RF Power in the NSTX Device	14th Top. Conf. on Radio Frequency Power in Plasmas	2001, Oxnard, California	2000-FP4-8
8	2001	Y. Ono	Recent Progress of Laboratory Reconnection Experiment at TS-3/ 4	US-Japan Workshop on Physics of Plasma Merging and Magnetic Reconnection	May, 2001, Princeton, USA	2001-FP2-8

9	2001	Y. Ono	Recent Progress of Laboratory Reconnection Experiments at TS-3 and 4	IPELS(Interrelation between Plasma Experiments in Laboratory and Space) '01	Jul. 2001, Niseko, Japan	2001-FP2-8
10	2001	J.C. Hosea, et al.	Results of High Harmonic Fast Wave Heating Experiments on NSTX	28th EPS Conf. on Controlled Fusion and Plasma Physics	June 18-22, 2001, Funchal, Portugal	2000-FP4-8
11	2001	Y. Ono, Y. Ueda, T. Matsuyama, T. Murata, M. Inomoto and M. Katsurai	Ultra-High-Beta Spherical Tokamak Experiments in TS-3 and 4	Joint Meeting of the 2nd International Atomic Energy Agency Technical Committee Meeting on Spherical Tori and 7th International Spherical Torus Workshop	Aug, 2001, Sao Jose dos Campos, Brazil	2001-FP4-6
12	2002	R. Raman, M. Bell,…,M. Nagata,…, et al.	Coaxial Helicity Injection for plasma start-up in NSTX	29th European Physical Society Meeting on Controlled Fusion and Plasma Physics	June 17-21, 2002, Montreux, Switzerland	2001-FP4-07
13	2002	Y. Ono	Current Sheet Structures in TS-3 and 4 Reconnection Experiments	US-Japan Symposium on Plasma Merging and Magnetic Reconnection (MR2002)	Nov. 2002, Hakone, Japan	2002-FP2-1
14	2002	A. Mase, Y. Kogi, M. Ohashi et al.	Electron Cyclotron Emission Imaging on LHD	The 14th Topical Conference on High- Temperature Plasma Diagnostics	Jul. 8-11, 2002, Madison, USA	
15	2002	Y. Ono, E. Kawamori, T. Matsuyama, M. Tsuruda, T. Kimura, K. Sato, T. Okazakio	Helicity Evolutions of Merging spheromaks with Co- and Counter-Helicity in TS-3 and 4 Experiments	34th Science Assembly of the Committee on Space Research (COSPER)	Oct. 2002, Houston, TX, USA	2002-FP2-1
16	2002	A. Mase, Y. Kogi, K. Kawahata et al.	Progress in Millimeter-Wave Imaging Diagnostics	The 4th International Conference on Open Magnetic Systems for Plasma Confinement	Jul. 1-4, 2002, Jeju, Korea	
17	2002	T.R. Jarboe, R. Raman,…,M. Nagata,…, et al.	Progress with Helicity Injection Current Drive	The 19th IAEA Fusion Energy Conference	Oct. 14-19, 2002, Lyon, France	2001-FP4-07
18	2002	Y. Ono	Reconnection Startup/ Heating of High-Beta Spherical Tokamaks (STs) in TS-3/ 4 Experiments	45th Annual Meeting of the Division of Plasma Physics, APS	Nov. 2002, Orlando, FL, USA	2002-FP4-5
19	2002	E.J. Synakowski, M.G. Bell, …,M. Nagata,…, et al.	The National Spherical Torus Experiment (NSTX) Research Program and Progress Towards High Beta, Long Pulse Operating Scenarios	The 19th IAEA Fusion Energy Conference	Oct. 14-19, 2002, Lyon, France	2001-FP4-07
20	2003	Y. Ono and TS-3/4 group	Current Sheet / Plasmoid Ejections and Plasma Heating in TS-3 and 4 Reconnection Experiments	MR2003 Symposium / Fifth US-Japan Symposium on Magnetic Reconnection, Plasma Merging and Magnetic Jet	Nov. 2003, Los Angeles, CA, U.S.A.	2003-FP2-8
21	2003	M. Isobe, H. Matsushita, D.S. Darrow, Y. Yoshimura, T. Minami, A. Shimizu, K. Nagaoka, M. Nishiura, C. Suzuki, S. Nishimura, T. Akiyama, K. Ida, K. Toi, K. Matsuoka and S. Okamura	Experimental study on losses of energetic ions by use of diagnostic neutral beam in CHS	8th IAEA Technical Meeting on Energetic Particles in Magnetic Confinement Systems	Oct. 6-8, 2003, San Diego, USA	2003-FP-2-4
22	2003	Y. Ono	Formation and stability of compact RFP in TS-3 and 4 experiment	The 9th-IEA/RFP-Workshop	Mar. 2003, Tsukubas, Japan	2002-FP4-5
23	2003	A. Ishida, C.O. Harahap, L.C. Steinhauer, Y.-K. M. Peng	Improved formalism for flowing two-fluid equilibrium and its application to ST	The 13th Toki Conference	December 9-12, 2003, Toki, Japan	2003-FP2-12
24	2003	Y. Ono	Ion Heating Characteristics of Magnetic Reconnection in TS-3 and 4 Merging Experiments	Seventh International Workshop on the Interrelationship between Plasma Experiments in the Laboratory and in Space	July, 2003, Whitefish, MN, U.S.A.	2003-FP2-8

25	2003	Y. Ono	Japanese Reconnection COE Project	General Meeting of Center for Magnetic Self-Organization in Laboratory and Astrophysical Plasmas,	Nov., 2003, Chicago, IL, U.S.A	2003-FP2-8
26	2003	S. Kubota, W.A. Peebles, X.V. Nguyen, A. Ejiri, R. Kaita, A.L. Roquemore, G. Taylor	Millimeter-Wave Measurements on NSTX	APS Division of Plasma Physics Meeting 2003	Oct. 27-31, 2003, Albuquerque, USA	2002-FP5-37
27	2004	M. Isobe, H. Matsushita, Y. Yoshimura, K. Nagaoka, T. Minami, T. Akiyama, C. Suzuki, S. Nishimura, M. Nishiura, K. Toi, K. Matsuoka, S. Okamura, D.A. Spong and D.S. Darrow	Collisional ripple transport of neutral beam-injected energetic ions in low aspect ratio helical system CHS	46th Annual Meeting of the Division of Plasma Physics	November 15-19, 2004 Savannah, GA, USA	2003-FP-2-4
28	2004	M. Ignatenko, A. Mase, L. Bruskin et al.	Effects of asymmetry and target location on microwave imaging reflectometry	The 16th Topical Conference on High-Temperature Plasma Diagnostics	Apr. 19-22, 2004, San Diego, USA	2004-FP5-18
29	2004	M. Ignatenko, A. Mase, L. Bruskin, Y. Kogi, H. Hojo	Numerical Study of Microwave Imaging Reflectometer for a Tandem Mirror Device	The 5th International Conference on Open Magnetic Systems for Plasma Confinement	Jul. 7-9, 2004, Novosibirsk, Russia	2004-FP5-18
30	2004	Y. Ono and TS-3/4 group	Transient and Intermittent Magnetic Reconnections in TS-3/ 4 Tokamak Merging Experiments	International workshop on "Explosive Phenomena in Magnetized Plasma - New Development of Reconnection Research	Mar. 2004, Kyoto, Kyoto, Japan	2004-FP2-1
31	2004	Y. Kogi, K. Uchida, A. Mase et al.	Ultrashort-pulse reflectometer on LHD	The 15th Topical Conference on High-Temperature Plasma Diagnostics	Apr. 19-22, 2004, San Diego, USA	2004-FP5-18
32	2005	Y. Kogi, A. Mase, K. Kudo et al.	Development of New Detector for Millimeter-Wave Imaging	The 30th International Conference on Infrared and Millimeter Waves	Sept. 19-23, 2005, Williamsburg, USA	2004-FP5-18
33	2005	S.P. Gerhardt, M. Yamada, H. Ji, M. Inomoto	Equilibrium Reconstruction Techniques Applied to Compact Toroid Plasmas in MRX	American Physics Society, 47th Annual Meeting of the Division of Plasma Physics	Oct. 24–28, Denver, USA	2005-FP4-5
34	2005	Y. Ren, M. Yamada, S.P. Gerhardt, H. Ji, R. Kulsrud, A. Kuritsyn, M. Inomoto	Experimental Studies of the Hall Effect and Fluctuations in MRX	American Physics Society, 47th Annual Meeting of the Division of Plasma Physics	Oct. 24–28, Denver, USA	2005-FP4-5
35	2005	Y. Ono and TS-3/4 Group	Heating Properties of Merging Startup in TS-3/4/5 High-Beta ST Experiments	48th Annual Meeting of the Division of Plasma Physics, APS	2005 Denver, Co, USA	2004-FP4-5
36	2005	Y. Ono	Heating Properties of Merging/ Reconnection Startup in TS-3/4 High-Beta ST Experiments	Joint Meeting of the 3rd IAEA Technical Meeting of Spherical Tori and the 11th International Workshop on Spherical Torus	Oct. 2005 St. Petersburg, Russia	2005-FP2-4
37	2005	T.Ozaki, P.Goncharov, S.Murakami, E.Veschev, S.Sudo, et al.	Horizontal and Vertical Structure of the High-Energy Particle Distribution in large Helical Device	Proceedings of a Technical Meeting Takayama	Nov. 9-11, 2005, IAEA-TM-27024	2003-FP5-15
38	2005	A. Mase, L. Bruskin, Y. Kogi et al.	Microwave Imaging and Reflectometry for LHD Plasma	US-Japan Workshop on Study of Advanced Fluctuation Diagnostic Method	Mar. 21-23, 2005, Princeton, USA	2004-FP5-18
39	2005	M. Ignatenko, A. Mase, L. Bruskin et al.	Numerical Study of Microwave Imaging Reflectometry for Measurements of Density Fluctuations Spectra for GAMMA10 Geometry	The 12th International Symposium on Laser-Aided Plasma Diagnostics	Sept. 26-29, 2005, Snowbird, USA	2004-FP5-18
40	2005	M. Inomoto, S. P. Gerhardt, Y. Yamada, H. Ji, B. McGeehan, A. Kuritsyn, Y. Ren, E. Belova	Reconnection and Ion Acceleration Processes during Counter Helicity Merging of Spheromaks in the MRX	American Physics Society, 47th Annual Meeting of the Division of Plasma Physics	Oct. 24–28, Denver, USA	2005-FP4-5

41	2005	S.P. Gerhardt, M. Inomoto, M. Yamada, H. Ji, A.J. Carver, A. Kuritsyn, B. McGeehan, Y. Ren	Stability Studies of Compact Toroid Plasmas in MRX	American Physics Society, 47th Annual Meeting of the Division of Plasma Physics	Oct. 24–28, Denver, USA	2005-FP4-5
42	2005	M. Isobe, K. Toi1, H. Matsushita, K. Goto, N. Nakajima1, S. Yamamoto, S. Murakami, A. Shimizu, C. Suzuki, K. Nagaoka, Y. Yoshimura, T. Akiyama, T. Minami, M. Nishiura, S. Nishimura, K. Matsuoka, S. Okamura, D.S. Darrow, D.A. Spong, K. Shinohara, M. Sasao and CHS team	Studies on fast ion transport induced by energetic particle modes using fast particle diagnostics with high time resolution in CHS	9th IAEA Technical Meeting on Energetic Particles in Magnetic Confinement Systems	November 9 - 11, 2005, Takayama, Japan	2003-FP-2-4
43	2005	M. Yamada, H. Ji, S. Gerhardt, M. Inomoto, R. Kulsrud, A. Kuritsyn, Y. Ren	Study of Two-Fluid Effects during Magnetic Reconnection in a Laboratory Experiment	American Physics Society, 47th Annual Meeting of the Division of Plasma Physics	Oct. 24–28, Denver, USA	2005-FP4-5
44	2005	E.V. Belova, R.C. Davidson, H. Ji, M. Yamada, S.P. Gerhardt, M. Inomoto	Three-dimensional Hall-MHD simulations of counter-helicity spheromak merging and FRC formation	American Physics Society, 47th Annual Meeting of the Division of Plasma Physics	Oct. 24–28, Denver, USA	2005-FP4-5
45	2005	Y.Hasegawa, et al.	Wobble Motion Field Reversed Configuration Plasmas	The American Physical Society Division Plasma Physics	Oct. 24-28, Denver, USA	2004-FP5-37
46	2006	N. Ito, A. Mase, Y. Kogi et al.	Advanced Fabrication Method of Planar Components for Plasma Diagnostics	The 16th International Toki Conference	Dec. 5-8, 2006, Toki, Japan	2004-FP5-18
47	2006	N. C. Luhmann, Jr., C.W. Domier, N. Ito, Y. Liang, A. Mase, H. Park, E. Sakata, Z. Shen, W. Tsai, Z. G.. Xia, Lu Yang, P. Zhang	Advanced Microwave/Millimeter-Wave Imaging Technology	The 16th International Toki Conference	Dec. 5-8, 2006, Toki, Japan	2004-FP5-18
48	2006	H. Kiguchi, et. al.	Application of magnetized coaxial plasma gun for external control of field revered configuration	The American Physical Society Division Plasma Physics	Oct.30-Nov.2, 2006, Philadelphia, USA	2006-FP2-3
49	2006	L. C. Steinhauer, T. Kanki, A. Ishida	Computation of Two-Fluid, Flowing Equilibria	48th Annual Meeting of the Division of Plasma Physics	Oct. 30-Nov. 3 2006, Philadelphia, USA	2006-FP2-7
50	2006	K. Yoshikawa, K. Masuda, T. Takamatsu, S. Shiroya, T. Misawa, Y. Takahashi, M. Ohnishi, H. Osawa, E. Hotta and K. Yamauchi	Current Status of Humanitarian Landmine Detection with a Compact Water-Cooled IEC Device	8th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	May 10-12, 2006, Osaka, Japan	2006-FP5-1
51	2006	K.Yamauchi, S.Ohura, K.Nozaki, M.Watanabe, A.Okino, T.Kohno and E.Hotta	D-D and D-3He Proton Measurements of Cylindrical Inertial Electrostatic Confinement Fusion	8th US-Japan IEC Workshop	May 10-12, 2006, Osaka, Japan	2006-FP5-1
52	2006	K.Yamauchi, S.Ohura, K.Nozaki, M.Watanabe, A.Okino, T.Kohno, E.Hotta, and M.Yuura	D-D and D-3He Proton Measurements of Cylindrical Radially Convergent Beam Fusion	33rd IEEE International Conference on Plasma Science	June 4-8, 2006, Traverse City, Michigan, USA	2006-FP5-1
53	2006	K. Masuda, S. Ohkawa, T. Takamatsu and K. Yoshikawa	Development of a Two-Dimensional Code for Simulating IEC Discharges	8th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	May 10-12, 2006, Osaka, Japan	2006-FP5-1
54	2006	Y. Kogi, T. Sakoda, A. Mase et al.	Development of ECE Imaging System on LHD	The 16th International Toki Conference	Dec. 5-8, 2006, Toki, Japan	2004-FP5-18
55	2006	N. Ito, A. Mase, N. Seko et al.	Development of Low-Loss Millimeter-Wave Antennas on Fluorine Substrate Using Electro-Fine-Forming Fabrication	The 2006 Asia-Pacific Microwave Conference	Dec. 13-15, 2006, Yokohama, Japan	2004-FP5-18

56	2006	H. Osawa, S. Yoshimura, T. Tabata, M. Ohnishi	Discharge Characteristics of Anode Size in an Inertial Electrostatic Confinement Fusion	22nd Int. Symp. on Discharges and Electrical Insulation in Vacuum	Sep. 25-29, 2006, Matsue, Japan	2006-FP5-1
57	2006	K. Noborio, Y. Yamamoto, Y. Ueno, S. Konishi	Evaluation of the Reaction Rate between Beam Particles and Adsorbed Particles on the Electrode of IECF Device	8th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	May 10-12, 2006, Osaka, Japan	2006-FP5-1
58	2006	M. Yamada, Y. Ren, H. Ji, S. Gerhardt, M. Inomoto, R. Kulsrud, S. Dorfman	Experimental Study of Two-fluid Effects on Magnetic Reconnection	American Physics Society, 48th Annual Meeting of the Division of Plasma Physics	Oct. 30–Nov. 3, Philadelphia, USA	2005-FP4-5
59	2006	M. Isobe, K. Toi, K. Nagaoka, C. Suzuki, K. Goto, T. Akiyama, T. Minami, S. Murakami, N. Nakajima, S. Nishimura, M. Nishiura, A. Shimizu, S. Yamamoto, Y. Yoshimura, M. Sasao, K. Matsuoka, S. Okamura and D.A. Spong	Fast-ion-driven MHD instabilities and consequent fast ion losses in the compact helical system	21st IAEA Fusion Energy Conference	Oct. 16-21, 2006, Chengdu, China	2003-FP-2-4
60	2006	J. W. Berkery, T. S. Pedersen, J. P. Kremer, R. G. Lefrancois, Q. R. Marksteiner, A. H. Boozer, H. E. Mynicreiersen, F. Dahlgreen, H. Himura, and X. Sarasola	First studies of pure electron plasmas in the Columbia Non-neutral Torus	The 8th International Workshop on Non-Neutral Plasmas	June 16-20, 2006, Aarhus, Denmark	2005-FP5-17
61	2006	T. Ozaki, P. Goncharov, N. Tamura et al.	High Energy Particle Measurement using Compact Neutral Particle Energy Analyzer in Large Helical Device	International Conference on Research and Applications of Plasmas 2005	January, 2006, Opole,Poland	2004-FP5-19
62	2006	D. Stutman, K. Tritz, L. Delgado-Aparicio, M. Finkenthal, G. Suliman, L. Roquemore, R. Kaita, H. Kugel, D. Johnson, N. Tamura, K. Sato, S. Sudo, C. Tarrio	High throughput measurements of soft x-ray impurity emission using a multilayer mirror telescope	High Temperature Plasma Diagnostics	May. 7-11, 2006, Williamsburg, USA	2006-FP5-22
63	2006	T. Nishi, K. Yoneda, K. Masuda and K. Yoshikawa	Highly Efficient Production of Excited Neutral Helium Beams for Spectroscopic Diagnostics of Electric Fields in IEC Plasma	2nd JGSEE and Kyoto Joint International Conference on Sustainable Energy and Environment	Nov. 21-23, 2006, Bangkok, Thailand	2006-FP5-1
64	2006	T. Nishi, K. Yoneda, K. Masuda and K. Yoshikawa	Highly Efficient Production of Excited Neutral Helium Beams for Spectroscopic Diagnostics of Electric Fields in IEC Plasma	8th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	May 10-12, 2006, Osaka, Japan	2006-FP5-1
65	2006	H. Osawa, M. Ohnishi, T. Furukawa, T. Suma, T. Takamatsu, K. Masuda, K. Yoshikawa	Improvement of Discharge Stability of Inertial electrostatic Confinement Fusion Device	Seventeenth American Nuclear Society Topical Meeting on the Technology of Fusion Energy	Nov. 12-15, 2006,Albuquerque,NM,USA	2006-FP5-1
66	2006	T. Takamatsu, T. Oishi, K. Masuda and K. Yoshikawa	Improvement of Inertial Electrostatic Confinement Device by Low Operating Gas Pressure using Magnetron- Discharge-Based Ion Source	IEEE 22nd International Symposium on Discharges and Electrical Insulation in Vacuum	Sept. 25-29, 2006, Matsue, Japan	2006-FP5-1
67	2006	A. Mase, Y. Kogi, N. Ito et al.	Industrial Applications of Microwave Active Diagnostics	Int. Workshop on Microwave Devices, Systems and their Applications	Dec. 12-13 2006, Fukuoka, Japan	2004-FP5-18
68	2006	T. Fujimoto, T. Oishi, H. Zen, T. Takamatsu, K. Masuda and K. Yoshikawa	Intensity Distribution of D-3He Fusion Reaction Rate in an IEC Device	IEEE/NPSS 22nd Symposium on Fusion Engineering	Jun. 17-21, 2007, Albuquerque, NM, USA	2006-FP5-1
69	2006	S. PAUL, R. KAITA, A.L. ROQUEMORE and N. NISHINO	Ion velocity measurements on NSTX using the SWIFT diagnostic (Shifted Wavelength/Interference Filter Technique)	APS-DPP06	Oct. 30–November 3 2006; Philadelphia, Pennsylvania	2007-FP5-7

70	2006	K. Yoshikawa, K. Masuda, T. Takamatsu, S. Shiroya, T. Misawa, M. Ohnishi, H. Osawa, E. Hotta and K. Yamauchi	Landmine detection by a compact fusion neutron source	International Workshop on " Humanitarian Landmine Detection and Detection of Illicit Materials"	Mar. 7-9, 2007, Kyoto, Japan	2006-FP5-1
71	2006	A. Mase, Y. Kogi, N. Ito et al.	Microwave Diagnostics	The 3rd Japan-Korea Seminar on Advanced Diagnostics for Steady-State Fusion Plasma	Aug. 31-Sept. 3, 2006, Matsushima, Japan	2004-FP5-18
72	2006	H. Osawa, S. Yoshimura, M. Ohnishi	Neutron Production of the IECF Device in Different Size of Anode	8th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	May 10-12, 2006, Osaka, Japan	2006-FP5-1
73	2006	Y.Matsuzawa, et al.	Optical diagnostic System for Neural Particle Deensity of Field reversed Configuration	The American Physical Society Division Plasma Physics	May 7-11, Williamburg, USA	2006-FP2-3
74	2006	M. Ohnishi, H. Osawa	Overview of IEC research in Kansai University	8th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	May 10-12, 2006, Osaka, Japan	2006-FP5-1
75	2006	O.Mitarai	Plasma current ramp-up and ignition in the Component Test Facility (CTF)	US-Japan workshop	Jan. 24-25, 2006，University of Los Angels (San Diego),USA	2006-FP2-6
76	2006	K.Nozaki, K.Yamauchi, S.Ohura, M.Watanabe, A.Okino, and E.Hotta	Preliminary Study of Beam-Beam Reactions in IEC Fusion Device	22nd Int. Symp. on Discharges and Electrical Insulation in Vacuum	Sep. 25-29, 2006, Matsue, Japan	2006-FP5-1
77	2006	A. Mase, Y. Kogi, H. Hojo et al.	Progress in Microwave Diagnostics and Physics Issues in Magneticall Confined Plasmas	The 6th International Conference on Open Magnetic Systems for Plasma Confinement	Jul. 17-21, 2006, Tsukuba, Japan	2004-FP5-18
78	2006	Z. Shen, N. Ito, C.W. Domier, N.C. Luhmann, Jr., A. Mase, E. Sakata	Protection Filters in ECEI Systems for Plasma Diagnostics	The 16th International Toki Conference	Dec. 5-8, 2006, Toki, Japan	2004-FP5-18
79	2006	T. Takamatsu, T. Oishi, S. Ogawa, K. Masuda and K. Yoshikawa	Recent R&D in IEC Neutron Source at Kyoto University	8th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	May 10-12, 2006, Osaka, Japan	2006-FP5-1
80	2006	T.Yamada, A. Ejiri,et al.	Reflectometry for Density Fluctuationand Profile Measurements in TST-2	16th Internat. Toki Conf.	Dec. 5-8, 2006, Toki, Japan	2005-FP5-21
81	2006	A. Mase, Y. Yokota, K. Uchida et al.	Remote Experiment of Ultrashort-Pulse Reflectometry on LHD	The 16th APS Topical Conference on High Temperature Plasma Diagnostics	May 7-12, 2006, Williamsburg, USA	2004-FP5-18
82	2006	K. Yoshikawa, K. Masuda, Y. Yamamoto and T. Takamatsu	Research and Development on a Compact Discharge-Based Fusion Neutron/Proton Source for Advanced Technologies	3rd Symposium on Sustainable Energy System	Aug. 30-Sept. 1, 2006, Kyoto, Japan	2006-FP5-1
83	2006	K. Yoshikawa, K. Masuda, T. Takamatsu, S. Shiroya, T. Misawa, Y. Takahashi, E. Hotta, K. Yamauchi, M. Ohnishi and H. Osawa	Research and Development on a Compact Discharge-Driven D-D Fusion Neutron Source for Explosive Detection	2nd JGSEE and Kyoto Joint International Conference on Sustainable Energy and Environment	Nov. 21-23, 2006, Bangkok, Thailand	2006-FP5-1
84	2006	K. Masuda, S. Ogawa, T. Takamatsu and K. Yoshikawa	Simultaneous Measurements of Neutrons and Energetic Protons from D-D and D-3He Fusion Reactions in an Inertial Electrostatic Confinement Device	IEEE 22nd International Symposium on Discharges and Electrical Insulation in Vacuum	Sept. 25-29, 2006, Matsue, Japan	2006-FP5-1
85	2006	T. Oishi, S. Ogawa, T. Takamatsu, H. Zen, K. Masuda and K. Yoshikawa	Spatial Distribution of D-3He Advanced Fuels Fusion Reactions in an Inertial Electrostatic Confinement Device	8th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	May 10-12, 2006, Osaka, Japan	2006-FP5-1
86	2006	K. Masuda, K. Yoshikawa, T. Ohishi, S. Ogawa, H. Zen and T. Takamatsu	Spatial Distribution of D-D/D-3He Advanced Fuels Fusion Reactions in an Inertial Electrostatic Confinement Device	21st IAEA Fusion Energy Conference	Oct, 16-21, 2006, Chengdu, China	2006-FP5-1

87	2006	Eiki Hotta and Tokyo Tech IEC Group	Status and Prospect of Inertial Electrostatic Confinement Devices as Neutron/Proton Sources	The 3rd International Symposium on Sustainable Energy System	Aug, 30–Sep. 1, 2006, Kyoto, Japan	2006-FP5-1
88	2006	S.P. Gerhardt, M. Inomoto, E. Belova, M. Yamada, H. Ji, Y. Ren, S. Dorfman, E. Martin	Studies of Equilibrium and Stability of Oblate FRCs in the Magnetic Reconnection Experiment	American Physics Society, 48th Annual Meeting of the Division of Plasma Physics	Oct. 30–Nov. 3, Philadelphia, USA	2005-FP4-5
89	2006	S.P. Gerhardt, M. Inomoto, E.V. Belova, M. Yamada, H. Ji, Y. Ren	Studies of Free-Boundary Field-reversed Configurations with Improved Stability in the Magnetic Reconnection Experiment	21st IAEA Fusion Energy Conference	Oct. 16-21, 2006, Chengdu, China	2005-FP4-5
90	2006	K. Saito, S. Murakami, M. Osakabe, M.Nishimura, T.Seki, T.Ozaki et al.	Study of High-energy Ion Tail Formation with Second Harmonic ICRF Heating and NBI in LHD	IAEA Fusion Energy conference 2006	October, 2006, IAEA-CN-149, EX/P6-17	2004-FP5-19
91	2006	Kanamaru, et al.	Tilt instabilty at formation phase	The American Physical Society Division Plasma Physics	Oct.30-Nov.2, Philadelphia	2006-FP2-3
92	2006	Y. Ono	Transient and Intermittent Magnetic Reconnections in TS-3/4 Merging Experimentsand Their Extension to UTST High-Beta ST Experiment	Petschek Memorial Conference	March 2006, College Park, Maryland, USA	2005-FP2-4
93	2006	Y. Ono	US/Japan Cooperation in Fusion Energy Research	2006 US/Japan Workshop on Compact Torus Plasmas, The Role of Flow in Compact Torus Plasmas	Nov. 2-4, 2006, , Swarthmore College PA, USA	2006-FP4-5
94	2007	L. Yang, N. Ito, C. W. Domier, N. C. Luhmann, Jr., A Mase	20 GHz to 40 GHz Beam Shaping/Steering Phased Antenna Array System using Fermi Tapered Slot Antenna	The IEEE MTT-S International Microwave Symposium	Jun. 3-8, 2007, Honolulu, USA	2004-FP5-18
95	2007	Z. Shen, C. W. Domier, N. C. Luhmann, Jr. N. Ito, A. Mase, A. J. H. Donne, H. Park	2-D Passive Millimeter wave Imaging System for Plasma Diagnostics	The 2007 Asia Pacific Microwave Conerence	Dec. 11-14, 2007, Bangkok, Thailand	2007-FP5-6
96	2007	K. Yoshikawa, K. Masuda, T. Takamatsu, S. Shiroya, T. Misawa, Y. Takahashi, E. Hotta,K. Yamauch, M. Ohnishi, H. Osawa	Anti-Personnel Landmine Detection by Use of an IEC Neutron Source	9th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	May 22-24, 2007, Argonne, IL, USA	2006-FP5-1
97	2007	M.Ohnishi, Y. Tsuji, N. Yoshida, H. Osawa	Characteristics in Pulse Operation of IEC Device with Confronting Two Plasma Sources	9th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	May 22-24, 2007, Argonne, IL, USA	2006-FP5-1
98	2007	T. Oosako, et al.	Combline Antenna for Lower Hybrid Current Start-up Experiments in Tokyo Spherical Tokamak-2	Korea-Japan workshop on heating technology of Fusion plasmas	Oct.16-17, 2007, Jeju, Korea	2005-FT3-2 2006-FT3-2
99	2007	Y. Ono	Current Sheet Dynamics in TS-3 and TS-4 Tokamak Reconnection Experiments	The 9th International Workshop on the Interrelationship between Plasma Experiments in Laboratory and Space	Aug. 2007, Palm Cove Resort, Cairns, Australia	2007-FP3-2
100	2007	Y. Ono , Y. Hayashi, H. Imanaka and R. Imazawa:	Current Sheet Dynamics in TS-4 Tokamak Reconnection Experiment	50th Annual Meeting of the Division of Plasma Physics, APS	Nov. 2007, Orland, FL, USA	2007-FP3-2
101	2007	Z. Shen, N. Ito, E. Sakata, C. W. Domier, N. C. Luhmann, Jr. A. Mase	D-Band Double Dipole Antenna for Use in Millimeter Wave Imaging Systems	The 2007 IEEE International Symposium on Antenna and Propagation	Jun. 9-15, 2007, Honolulu USA	2004-FP5-18
102	2007	K.Tomiyasu and E.Hotta	Design for Medical Radioisotope Production Using a Compact Fusion Proton Source	The Second MIT-Tokyo Tech Symp. on Innovative Nuclear Energy System (TM-INES2)	Jul. 2007, Kamakura, Japan	2006-FP5-1
103	2007	N.Yoshida, Y. Tusji, H. Osawa, M. Ohnishi	Development of Fast Numerical Code Based on Direct Interaction of Charged Particles	9th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	May 22-24, 2007, Argonne, IL, USA	2006-FP5-1

104	2007	A. Mase, Y. Kogi, N. Ito et al.	Development of Microwave Diagnostic Systems and their Application	U.S.-Japan Workshop on Millimeter-Wave Plasma Diagnostics	Feb. 25-27, 2008, UC Davis, USA	2007-FP5-6
105	2007	N. Ito, A. Mase, Y. Kogi et al.	Development of Planar Components Using Advanced Fabrication	The Joint 32nd International Conference on Infrared and Millimeter Waves and 15th International Conference on Terahertz Electronics	Sept. 2-7, 2007, Cardiff, U.K.	2007-FP5-6
106	2007	K. Masuda, K. Yoshikawa, T. Misawa, K. Yamauchi, Y. Takahashi, S. Shiroya, E. Hotta, M. Ohnishi and H. Osawa	Directional detection of nitrogen and hydrogen in explosives by use of a DD-fusion-driven thermal neutron source	NATO Advanced Research Workshop on "Detection of Liquid Explosives and Flammable Agents in Connection with Terrorist Actions"	Oct. 17-19, 2007, Saint-Petersburg, Russia	2006-FP5-1
107	2007	H. Osawa, N. Yoshida, M. Ohnishi	FDTD Simulation on RF Ion Source for IEC	9th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	May 22-24, 2007, Argonne, IL, USA	2006-FP5-1
108	2007	Tetsuo OZAKI, Pavel R.GONCHAROV, Evgeny VESHCHEV, et al.	Helium ion observation during 3rd harmonic ion cyclotron heating in Large Helical Device	International Toki Conference	Oct. 16-19, 2007, Toki, Japan	2004-FP5-19
109	2007	T.Ozaki, P.Goncharov, E.Veschev, S.Sudo, N.Tamura, et al.	Helium measurements simulating alpha-particle diagnostics by the pellet charge exchange in Large Helical Device	Proc. of INTERNATIONAL WORKSHOP ON BURNING PLASMA DIAGNOSTICS	September 24 - 28, 2007, Varenna, Italy	2004-FP5-19
110	2007	H. Horibe, M. Ohnishi, H. Osawa	High Voltage Pulse Modulator	9th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	May 22-24, 2007, Argonne, IL, USA	2006-FP5-1
111	2007	Y.Tsujii, N. Yoshida, H. Osawa, M. Ohnishi	IEC Research of Kansai University	9th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	May 22-24, 2007, Argonne, IL, USA	2006-FP5-1
112	2007	N. Tamura, K. Sato, H. Funaba, S. Sudo, K. Tritz, D. Stutman, L. Delgado-Aparicio, M. Finkenthal, H. Kugel, R. Kaita, L. Roquemore, M. Bell, V. Soukhanovskii	Impact of a tracer-encapsulated solid pellet injection on NSTX plasmas	13th International Workshop on Spherical Torus	Oct. 10-12, 2007, Fukuoka, Japan	2007-FP5-15
113	2007	T. Fujimoto, T. Oishi, H. Zen, T. Takamatsu, K. Masuda and K. Yoshikawa	Intensity Distribution of D-3He Fusion reaction Rate in an IEC Device	9th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	May 22-24, 2007, Argonne, IL, USA	2006-FP5-1
114	2007	Y. Takase, et al.	LHCD Scenarios for Spherical Tokamak Plasmas	17th Top. Conf. on Radio Frequency Power in Plasmas Clearwater, 2007	May 7-9, 2007, Clearwater, Florida, USA	2006-FP4-4
115	2007	K.Yamauchi, K.Nozaki, M.Watanabe, A.Okino and E.Hotta	Low Pressure IECF Operation Using Differentially-Pumped Ion Sources	9th US-Japan IEC Workshop on Small Plasma and Accelerator Neutron Sources	May 22-24, 2007 Argonne, USA	2006-FP5-1
116	2007	A. Mase, Y. Kogi, N. Ito et al.	Microwave Imaging for Plasma Diagnostics and Its Applications	The 13th International Symposium on Laser-Aided Plasma Diagnostics	Sept. 18-21, 2007, Takayama, Japan	2007-FP5-6
117	2007	A. Sanpei, S. Masamune, R. Ikezoe, et al.	Neoclassical RFP equilibria with reactor regime parameters	12th IEA/RFP Workshop	Mar 26-28, 2007, Kyoto, Japan	2006-FP2-8
118	2007	A. Ishida, L.C. Steinhauer, Y.-K. M. Peng	Numerical computation for two-fluid MHD equilibria with flow	The 13th International Workshop on Spherical Tori 2007	October 10-12, 2007, Fukuoka, Japan	2006-FP2-4
119	2007	K.Yamauchi, K.Tomiyasu, M.Watanabe, A.Okino and E.Hotta	Overview of IECF Research at Tokyo Institute of Technology	9th US-Japan IEC Workshop on Small Plasma and Accelerator Neutron Sources	May 22-24, 2007, Argonne, USA	2006-FP5-1
120	2007	T. Kanki, L. C. Steinhauer, M. Nagata	Partially Relaxed Two-Fluid Flowing Equilibria in Helicity-Driven Spherical Tours	US-Japan Workshop on Innovative Active Control for High Performance Confinement of Compact Toroid	Sep. 18-20 2007, Tokyo, Japan	2006-FP2-7

121	2007	K. Yoshikawa, S. Shiroya, E. Hotta, M. Ohnishi, T. Misawa and K. Masuda	Research and Development of a Compact Discharge-Driven D-D Fusion Neutron Source And Advanced Gamma-ray Detection System for the Detection of Explosives	2nd Research Coordination Meeting of the IAEA's Coordinated Research Project on "Neutron Based Techniques for the Detection of Illicit Materials and Explosives"	Nov. 12-16, 2007, Mumbai, India	2006-FP5-1
122	2007	K. Yoshikawa, K. Masuda, T. Misawa, T. Takamatsu, K. Yamauchi, Y. Takahashi, S. Shiroya, E. Hotta, M. Ohnishi and H. Osawa	Research and Development of Humanitarian Landmine Detection System by a Compact Discharge-Type Fusion Neutron Source	SPIE Defense and Security Symposium	Apr. 9-13, 2007, Orlando, Florida, USA	2006-FP5-1
123	2007	T. Misawa, K. Yoshikawa, K. Masuda, T. Takamatsu, T. Fujimoto, K. Yamauchi, E. Hotta, Y. Takahashi, T. Yagi, Y. Yamamoto, S. Shiroya, M. Ohnishi, H. Osawa, Y. Kubo, M. Tabei, Y. Sugihara and T. Doi	Research and Development of Landmine Detection System using a Compact Fusion Neutron	IAEA Technical Meeting on Use of Combined Devices for Humanitarian Demining and Explosives Detection	Nov. 26-30, 2007, Vienna, Austria	2006-FP5-1
124	2007	Y. Ono	Transient and Explosive Magnetic Reconnections in TS-3 and 4 Merging Experiments	The US-Japan Symposium on Plasma Merging and Magnetic Reconnection	Mar. 2007 St. Michael MD, USA	2007-FP3-2
125	2007	Y. Ono	Transient and Intermittent Magnetic Reconnections in TS-3 Spherical Tokamak Merging Experiment	National Cheng Kung University Symposium	Jan. 4-7, 2007, Tainan, Taiwan	2007-FP3-2
126	2007	T. Kanki, L. C. Steinhauer, M. Nagata	Two-Fluid Flowing Equilibria of Helicity Injected Spherical Torus with Non-Uniform Density	Joint Conference of the 17th International Toki Conference on Physics of Flows and Turbulence in Plasmas and the16th International Stellarator/Heliotron Workshop 2007	15-19 Oct. 2007, Toki, Japan	2006-FP2-7
127	2007	Z. Shen, N. Ito, Z. Xia, C. W. Domier, A. Mase, and N. C. Luhmann, Jr.	Wide Bandwidth Mixer Array Development in Millimeter Wave Imaging Systems for Plasma Diagnostics	The Joint 32nd International Conference on Infrared and Millimeter Waves and 15th International Conference on Terahertz Electronics	Sept. 2-7, 2007, Cardiff, U.K.	2007-FP5-6
128	2007	P. Zhang, C. W. Domier, Z. Shen, N. C. Luhmann, Jr., H. K. Park, A. J. H. Donne, N. Ito, A. Mase	Wideband ECEI Upgrade for Increased Plasma Coverage	The 13th International Symposium on Laser-Aided Plasma Diagnostics	Sept. 18-21, 2007, Takayama, Japan	2007-FP5-6
129	2008	A. Mase, Y. Kogi, N. Ito et al.	Advancement of Microwave/ Millimeter-Wave Diagnostics in Magnetically Confined Plasma	The 2008 Int. Workshop on Frontiers in Space and Fusion Energy Sciences	Nov. 6-8, 2008, Tainan, Taiwan	2007-FP5-6
130	2008	A. Mase, Y. Kogi, N. Ito et al.	Advancements of Microwave Diagnostics and Their Applications	The 11th IEEE International Conference on Communication Technology	Nov. 10-12, 2008, Hangzhou, PR China	2007-FP5-6
131	2008	A. Sanpei, K. Oki, R. Ikezoe, et al.	Characterization of equilibria in a low-aspect-ratio RFP	ICPP2008	Sep. 8-12, 2008, Fukuoka, Japan	2006-FP2-8
132	2008	T.Ozaki, Pavel R. Goncharov, Evgeny A. Veshchev, Shigeru Sudo, Tsuguhiro Watanabe, High-Energy Particle Group and LHD Experimental Group	Comparison of neutral particle flux decay times on the NBI plasmas in Large Helical Device	International Toki Conference	2008.12.9-12 Toki, Japan	2004-FP5-19
133	2008	R. Raman, B.A. Nelson,…,M. Nagata,…, et al.	Coupling solenoid-free Coaxial Helicity Injection started discharges to induction in NSTX	The 4th IAEA Technical Meeting on Spherical Tori and 14th International Workshop on Spherical Torus	Oct. 7-10, 2008, Roma, Italy	2006-FP4-3 2007-FP3-5

134	2008	K.Yokoyama, K.Tomiyasu, M.Watanabe and E.Hotta	Development of a Coaxial Double Cylindrical Inertial Electrostatic Confinement Device	10th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	Dec. 2008, Kyoto, Japan	2008-FP5-8
135	2008	T. Nakagawa, K. Masuda, T. Kajiwara, H. Zen, K. Yoshikawa and K. Nagasaki	Development of an IEC Device Driven by a Magnetron Ion Source for Low Pressure Operation	10th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	Dec. 9-11, 2008, Kyoto, Japan	2008-FP5-8
136	2008	N. Ito, A. Mase, Y. Kogi et al.	Development of Planar Devices Using Low-Loss Materials	The 11th IEEE International Conference on Communication Technology	Nov. 10-12, 2008, Hangzhou, PR China	2007-FP5-6
137	2008	Y. Yokota, A. Mase, Y. Kogi et al.	Development of Ultrashort-Pulse Reflectometry for Density Profile Measurement in LHD	The International Congree on Plasma Physics 2008	Sept. 8-12, 2008, Fukuoka, Japan	2007-FP5-6
138	2008	T. Kajiwara, K. Masuda, T. Nakagawa, H. Zen and K. Nagasaki	Double-grid IEC for Energy Recovery from Escaping Electron Beams	10th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	Dec. 9-11, 2008, Kyoto, Japan	2008-FP5-8
139	2008	K.Tomiyasu, K.Yokoyama, M.Watanabe, A.Okino and E.Hotta	Effects of Cusp Magnetic Field in a Cylindrical Radially Convergent Beam Fusion Device	18th Topical Mtg. on the Technology of Fusion Energy	Sep. 2008, California, USA	2008-FP5-8
140	2008	K. Noborio, T. Kanagae, Y. Yamamoto, S. Konishi	Generation of Neutron Beam by the Cylindrical Fusion Neutron Source -- Designing by using MCNP Transport Code --	10th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	Dec. 9-11, 2008, Kyoto, Japan	2008-FP5-8
141	2008	Y.Yamamoto, A. Ishidou, K. Noborio, S. Konishi	Generation of Neutron Beam by the Cylindrical Fusion Neutron Source -- Objective and Targets --	10th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	Dec. 9-11, 2008, Kyoto, Japan	2008-FP5-8
142	2008	H. Horibe, M. Ohnishi, H. Osawa	High Voltage Power Supply -some plasma pllications-	10th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	Dec. 9-11, 2008, Kyoto, Japan	2008-FP5-8
143	2008	A. Ishida, L.C. Steinhauer, Y.-K. M. Peng	Multi-fluid MHD equilibria for ST plasmas with near-sonic flow and reduced trapped ion fraction	35th EPS Plasma Physics Meeting	9-13 June, 2008, Hersonissos, Crete, Greece	2008-FP3-6
144	2008	A. Sanpei, S. Masamune, R. Ikezoe, et al.	Neoclassical Equilibrium in a Low-Aspect Ratio RFP Machine RELAX	35th EPS Meeting	June 9-13, 2008, Hersonissos, Greek	2006-FP2-8
145	2008	M. Inomoto, Y. Ono	Nonlinear mode couplings in linear plasmas	The US-Japan Workshop on Magnetic Reconnection 2008,	Mar. 2008. 52, Okinawa, Japan	2008-FP3-1
146	2008	K. Masuda, Y. Yamamoto, K. Noborio, T. Nakagawa, T. Kajiwara, H. Zen, K. Nagasaki and K. Yoshikawa	Overview of IEC Research at Kyoto University	10th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	Dec. 9-11, 2008, Kyoto, Japan	2008-FP5-8
147	2008	K.Tomiyasu, K.Yokoyama, M.Watanabe, and E.Hotta	Particle-in-Cell Simulation of Magnetic-assist Electrostatic Confinement Fusion	10th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	Dec. 9-11, 2008, Kyoto, Japan	2008-FP5-8
148	2008	T.Ozaki, P.Goncharov, E.Veshchev, N.Tamura, S.Sudo, T.Seki, H.Kasahara, high Energy Particle Groupe, Wave Heating Group and LHD Experimental Group	Pellet charge exchange helium measurement using neutral particle analyzer in Large Helical Device	High Temperature Plasma Diagnostics	May 11-15, 2008, Albuquerque, NM, USA	2004-FP5-19
149	2008	K. Sakuraba,et al.	Plasma Dynamics in Translation Process of Field Reversed Configuration	The American Physical Society Division Plasma Physics	Nov. 12-16,Orland, USA	2007-FP3-1

150	2008	Tetsuo OZAKI, Pavel R.GONCHAROV, Evgeny VESHCHEV, Naoki TAMURA, Shigeru SUDO, Tetsuo SEKI, Hiroshi KASAHARA, High Energy Particle Group	Radial Profiles of High-Energy Particles in NBI and ICH Plasmas Measured by Pellet Charge Exchange Technique on Large Helical Device	ICPP	Sep. 8-12, 2008 Fukuoka, Japan	2004-FP5-19
151	2008	Y. Ono	Recent Progress in TS-4 and UTST ST Merging	51st Annual Meeting of the Division of Plasma Physics, APS	Nov. 2008, Dallas, TX, USA	2008-FP3-1
152	2008	Y. Ono, Toru Ii, Y. Hayamshi, T. Yamada. M. Inomoto	Recent Progress of TS-4 Magnetic Reconnection Experiment	The First International Workshop on "Frontiers In Space and Fusion Energy Sciences	Nov. 2008. Tainan, Taiwan	2008-FP3-1
153	2008	H. Himura, K. Nakamura, D. Sugimoto, A. Sanpei, S. Masamune, M. Isobe, F. Sano	Recent progress on toroidal nonneutral plasmas confined on heliotron magnetic surfaces	The 9th International Workshop on Non-Neutral Plasmas	June. 16-20, 2008, NY, USA	2008-FP4-2
154	2008	Y. Yokota, A. Mase, Y. Kogi et al.	Reconstruction of Edge Density Profiles on LHD Using Ultrashort-Pulse Reflectometry	The 17th APS Topical Conference on High-Temperature Plasma Diagnostics	May 11-15, 2008, Albuquerque, USA	2007-FP5-6
155	2008	S. Takaichi, A. Mase, Y. Kogi et al.	Simulation Study and Experiment of Breast Cancer Detection Using an Ultrashort-Pulse Radar	The 2008 Asia Pacific Microwave Conference	Dec. 16-19, 2008, Hong Kong, China	2007-FP5-6
156	2008	R. Raman, T.R. Jarboe, M. Nagata, et al.	Solenoid-free Plasma Start-up in NSTX using Transient CHI	The 22nd IAEA Fusion Energy Conference	Oct. 13-18, 2008, Geneva, Swiss	2006-FP4-3 2007-FP3-5
157	2008	N. NISHINO, S. PAUL, R. KAITA and A.L. ROQUEMORE	Status of Two-Dimensional Ion Velocity Measurement System in NSTX	Int. Conference of Plamsa Physics 2008	Sep. 8-12, 2008, Fukuoka, Japan	2008-FP5-4-2007-FP5-7
158	2008	Q. R. Marksteiner, T. S. Pedersen, J. W. Berkery, M. S. Hahn, J. M. Mendez, B. D. de Gevigney, P. Ennever, D. Boyle, M Shulman, and H. Himura	Studies of a parallel force balance breaking instability in a stellarator	The 9th International Workshop on Non-Neutral Plasmas	June. 16-20, 2008, NY, USA	2008-FP4-2
159	2008	H. Osawa, T. Miyashita, K. Kitagawa, M. Ohnishi	Two Ion Sources Operation on Inertial Electrostatic Confinement Fusion Device	10th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	Dec. 9-11, 2008, Kyoto, Japan	2008-FP5-8
160	2008	T. Kanki, L. C. Steinhauer, M. Nagata	Two-Fluid Flowing Equilibria of Spherical Torus Sustained by Coaxial Helicity Injection	49th Annual Meeting of the Division of Plasma Physics	Nov. 12-16, 2007, Orlando, USA	2006-FP2-7
161	2008	Y. Yokota, A. Mase, Y. Kogi et al.	Ultra-Wide Band Radar Reflectometer for Measurement of Plasma Density Profiles	The 11th IEEE International Conference on Communication Technology	Nov. 10-12, 2008, Hangzhou, PR China	2007-FP5-6
162	2009	Y. Ono	3-D Fast Reconnection in TS-3 and 4 Merging Experiments	2009 US - Japan Workshop on Reconnection	Oct. 5 - 7 2009, Madison, WI, USA	2009-FP4-1
163	2009	K. Masuda, T. Nakagawa, T. Kajiwara, K. Yoshikawa and K. Nagasaki	An Inertial Electrostatic Confinement Fusion Device Driven by a Built-In Ring-Shaped Ion Source in Low Pressure Regime	2nd Int. Conf. on Microelectronics and Plasma Technology	Sep. 2009, Busan, Korea	2008-FP5-8
164	2009	T. Ozaki, M. Koga, H. Shiraga, R. Kato, S. Kashiwagi, G. Isoyama, H. Sakagami and FIREX group	Calibration of the compact electron spectrometer for FIREX-I project in Gekko XII	ITC19	Dec. 8-11, 2009 Toki, Japan	2004-FP5-19
165	2009	T. Yamamoto, Y. Nagayama, H. Nakanishi, et al.	Configuration of the Virtual Laboratory for Fusion Researches in Japan	7th IAEA Technical Meeting on Control, Data Acquisition, and Remote Participation for Fusion Research	Jun. 15-19, 2009, Aix-en-Provence, France	2008-FP5-7
166	2009	T. Ozaki, M. Koga, H. Shiraga, H. Azechi, H. Sakagami and FIREX Group	DEVELOPMENT OF THE COMPACT ELECTRON SPECTROMETER FOR THE FIREX-I PROJECT IN GEKKO XII	Inertial Fusion Science and Application	Sep 6-11, 2009 San Francisco, CA	2004-FP5-19

167	2009	K. Tomiyasu, K. Yokoyama, M. Watanabe, A. Okino and E. Hotta	Discharge Characteristics of Magnetic-assisted Electrostatic Confinement Device	2nd Int. Conf. on Microelectronics and Plasma Technology	Sep. 2009, Busan, Korea	2008-FP5-8
168	2009	T. Kajiwara, K. Masuda, K. Yoshikawa and K. Nagasaki	Double-grid IEC for Energy Recovery from Escaping Electron Beams	2nd International Conference on Microelectronics and Plasma Technology	Sept. 23-25, 2009, Busan, Korea	2008-FP5-8
169	2009	T. Kajiwara, K. Masuda, J. Kipritidis and K. Nagasaki	Double-grid IEC for Recovery of Energy from Escaping Electron Beams	11th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	Oct. 12-13, 2009, Madison, Wisconsin, USA	2009-FP5-1
170	2009	K. Kitagawa, T. Miyashita, A. Maeda, I. Nakano, H. Osawa, M. Ohnishi	Drawing Out Electrode of Ion Beam for IEC	11th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	Oct. 12-13, 2009, Madison, Wisconsin, USA	2009-FP5-1
171	2009	M. Isobe, K. Ogawa, K. Toi, M. Osakabe, K. Nagaoka, A. Shimizu, D.A. Spong, CHS and LHD experiment groups	Effect of energetic-ion-driven MHD instabilities on energetic-ion-transport in Compact Helical System and Large Helical Device	17th International Stellarator/Heliotron Workshop	Oct. 12-16, 2009, Princeton, New Jersey, USA	2003-FP-2-4
172	2009	K.Tomiyasu, K.Yokoyama, Y.Jinushi, M.Watanabe, and E.Hotta	Experimental Study of Magnetic-Assisted Electrostatic Confinement	11th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	Oct.12-14, 2009, Madison, WI, USA	2009-FP5-1
173	2009	T. Hochin, Y. Yamauchi, H. Nomiya, H. Nakanishi, M. Kojima	Fast Subsequence Matching in PlasmaWaveform Databases	5th International Conference on Intelligent Information Hiding and Multimedia Signal Processing (IIHMSP2009)	Sep. 12-14, 2009, Kyoto, Japan	2004-FP5-39
174	2009	K. Noborio, T. Kanagae, Y. Yamamoto, S. Konishi	Generation of Sharp and Thermalized Neutron Beam using Cylindrical Fusion Neutron Source	11th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	Oct. 12-13, 2009, Madison, Wisconsin, USA	2009-FP5-1
175	2009	A. Maeda, T. Miyashita, K. Kitagawa, I. Nakano, H. Osawa, M. Ohnishi	High Current Operation on IEC	11th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	Oct. 12-13, 2009, Madison, Wisconsin, USA	2009-FP5-1
176	2009	T. Hochin, Y. Yamauchi, H. Nakanishi, M. Kojima, H. Nomiya	Indexing of Plasma Waveforms for Accelerating Search and Retrieval of Their Subsequences	7th IAEA Technical Meeting on Control, Data Acquisition, and Remote Participation for Fusion Research	Jun. 15-19, 2009, Aix-en-Provence, France	2004-FP5-39
177	2009	H. Nakanishi, T. Yamamoto, M. Emoto, Y. Nagayama, K. Kawahata, et al.	LABCOM/X Experiment Data Platform and Fusion Virtual Laboratory in Japan	7th IAEA Technical Meeting on Control, Data Acquisition, and Remote Participation for Fusion Research	Jun. 15-19, 2009, Aix-en-Provence, France	2008-FP5-7
178	2009	K.Yokoyama, Y.Jinushi, K.Tomiyasu, M.Watanabe and E.Hotta	Neutron Flux Distribution in a Coaxial Double Cylindrical Device	11th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	Oct.12-14, 2009, Madison, WI, USA	2009-FP5-1
179	2009	H. Osawa, T. Miyashita, A. Maeda, I. Nakano, M. Ohnishi	Neutron Production with Confronting Ion Sources on Inertial Electrostatic Confinement Fusion Device	2nd Int. Conf. on Microelectronics and Plasma Technology	Sep. 2009, Busan, Korea	2008-FP5-8
180	2009	J. Kipritidis, J. Khachan and K. Masuda	Optical diagnostics and numerical modeling of a gaseous discharge Inertial Electrostatic Confinement device	11th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	Oct. 12-13, 2009, Madison, Wisconsin, USA	2009-FP5-1
181	2009	K. Masuda, J. Kipritidis, T. Kajiwara, T. Nakagawa, K. Nagasaki, Y. Yamamoto, K. Noborio and T. Kanagae	Overview of Kyoto University Research and Considerations for an IEC Device Driven by a Built-In Ring-Shaped Ion Source	11th US-Japan Workshop on Inertial Electrostatic Confinement Fusion	Oct. 12-13, 2009, Madison, Wisconsin, USA	2009-FP5-1
182	2009	Y. Ono	Physics and applications of impulsive 3-D magnetic reconnection	2009 International Workshop on Frontiers In Space and Fusion Energy Sciences (2009 FISFES)	Nov. 30-Dec. 3, 2009, Tainan, Taiwan	2009-FP4-1

183	2009	Y. Haraguchi, H. Hojo, Y. Ishii et al.	Preliminary Simulation Study for Microwave Imaging Reflectometry	The 19th International Toki Conference (ITC-19)	Dec. 8-11, 2009, Toki, Japan	2009-FP5-2
184	2009	A. Mase, N. Ito, D. Zhang et al.	Progress in Microwave Diagnostics and their Applications	The 2009 International Workshop on Frontiers in Space and Fusion Energy Sciences	Nov. 30-Dec. 3, 2009, Tainan, Taiwan	2009-FP5-2
185	2009	A. Mase, Y. Kogi, N. Ito et al.	Progress in Microwave Diagnostics Related to LHD Collaborative Research	The 8th Japan-Australia Plasma Diagnostics Workshop	Feb. 2-5, 2009, Murramarang, Australia	2007-FP5-6
186	2009	T. Yamamoto, Y. Nagayama, H. Nakanishi, et al.	Progress of the Virtual Laboratory for Fusion Researches in Japan	12th International Conference on Accelerator and Large Experimental Physics Control Systems (ICALEPCS2009)	Oct. 12-16, 2009, Kobe, Japan	2008-FP5-7
187	2009	Y. Yokota, A. Mase Y. Kogi et al.	Reconstruction Method of X-Mode Ultrashort-Pulse Reflectometry in LHD	The 14th International Symposium on Laser Aided Plasma Diagnostics	Sept. 21-24, Castelbrando, Italy	2009-FP5-2
188	2009	Y. Takase, et al.	RF Experiments on TST-2	51st Annual Meeting of APS/DPP	Nov. 2-6, 2009, Atlanta, Georgia	2009-FP2-4
189	2009	K. Akaki, A. Mase, Y. Kogi et al.	Study of Dual-Dipole Antenna Array for Millimeter Wave Imaging	The. 34th Int. Conf. on Infrared, Millimeter, and Terahertz Wave	Sept. 11-15, 2009, Busan, Korea	2009-FP5-2
190	2009	J.A. Stillerman, W. Burke, B. Labombard	Sub-sample Time-base Resolution in a Heterogeneous Distributed Data Acquisition Environment	12th International Conference on Accelerator and Large Experimental Physics Control Systems (ICALEPCS2009)	Oct. 12-16, 2009, Kobe, Japan	2009-FP5-13
191	2009	Y. Ono	Three dimensional magnetic reconnection in torus plasma merging experiments	US-Japan Workshop on Physics of Plasma Merging and Magnetic Reconnection	Mar. 2-4, 2009, Princeton, NJ, USA	2009-FP4-1
192	2009	H. Horibe, M. Ohnishi, H. Osawa	Useful Information for High Voltage Power Supply	2nd International Conference on Microelectronics and Plasma Technology	Sept. 23-25, 2009, Busan, Korea	2008-FP5-8
193	2010	A. Mase, N. Ito, D. Zhang et al.	Application of Microwave Diagnostic Systems to Medical and Assisted Technology	International Workshop on Microwave Devices, Systems, and their Applications 2010	Mar. 16-17, 2010, Fukuoka, Japan	2009-FP5-2

3.4.5 High Energy Density Science

1. Journal Paper

No	Year	Authors	Title of Paper	Journal	Vol. (Year) Page (Start) -Page(End) or Identification No.	Year-Category-No.
1	2000	K. Fujita, A. Sunahara, K.A. Tanaka, N. Isumi, T. Jitsuno, N. Miyanaga, T. Miyakoshi, H. Otani, M. Fukao, H. Heya, Y. Ochi, Y. Kitagawa, R. Kodama, K. Mima, H. Nishimura, T. Norimatsu, Y. Sentoku, H. Takane, T. Yamanaka	Model experiments of fast ignition with coaxial high-power laser beams	SPIE	4424 (2000) 37-44	2000-FP5-18
2	2000	T. Kadono, M. Yoshida, E. Takahashi, I. Matsushima, Y. Owadano, N. Ozaki, K. Fujita, M. Nakano, K.A. Tanaka, H. Takenaka and K. Kondo	Flyer acceleration by a high-power KrF laser with a long pulse duration	Journal of Applied Physics	88 (2000) 2943-2947	2000-FP5-18

3	2000	K.A. Tanaka, M.M. Allen, A. Pukhov, R. Kodama, H. Fujita, Y. Kato, T. Kawasaki, Y. Kitagawa, K. Mima, N. Morio, H. Shiraga, M. Iwata, T. Miyakoshi, and T. Yamanaka	Evidence of relativistic laser beam filamentation in back-reflected images	Phys. Rev. E	62 (2000) 2672-2677	2000-FP5-18
4	2000	K.A. Tanaka, R. Kodama, H. Fujita, M. Heya, N. Izumi, Y. Kato, Y. Kitagawa, K. Mima, N. Miyanaga, T. Norimatsu, A. Pukhov, A. Sunahara, K. Takahashi, M. Allen, H. Habara, T. Iwatani, T. Matusita, T. Kawasaki, T. Komeno, O. Maekawa, S. Matsuo, T. Shozaki, Ka Suzuki, H. Yoshida, T. Yamanaka, Y. Sentoku, F. Webeer, T.W. Barbee,Jr., and L. DaSilva	Studies of ultra-intense laser plasma interactions for fast ignition	Physics of Plasmas	7 (2000) 2014-2022	2000-FP5-18
5	2000	K. Wakabayashi, S. Hattori, T. Tange, Y. Fujimoto, M. Yoshida, N. Kozu, K.A. Tanaka, N. Ozaki, Y. Sasatani, H. Takenaka, K.G. Nakamura and K. Kodo	Laser-induced shock compression of tantalum to 1.7 Tpa	Jpn.J.Appl.Phys.	39 (2000) 1815-1816	2000-FP5-18
6	2000	T. Miyakoshi, K.A. Tanaka, R. Kodama, K. Mima, T. Yamanaka, Y. Kitagawa, H. Fujita, N. Miyanaga, T. Norimatsu, T. Kawasaki, N. Izumi, J. Sunahara, Y. Sentoku, K. Tahakashi, H. Habara, M. Mori, T. Matsushita, T. Sonomoto, H. Setoguchi, T. Koase, T. Iwatani, Y. Tohyama, M. Tanpo, PWM group, Go group, Mt group and T group	Study of ultra-intense laser propagation with measurement of back-scattered light image and spectrum	SPIE	3886 (2000) 505-512	2000-FP5-18
7	2000	K. Takahashi, R. Kodama, K.A. Tanaka, H. Hashimoto, Y. Kato, K. Mima, F.A. Weber, T.W. Barbee,Jr, and L.B. Da Silva	Laser-Hole Boring into Overdense Plasmas Measured with Soft X-Ray Laser Probing	Phys.Rev.Lett.	84 (2000) 2405-2408	2000-FP5-18
8	2000	K. Mima, K.A. Tanaka and R. Kodama	Experimental research on Fast Ignitor	Inertial Fusion Sciences and Application, edited by C. Labaune,W J. Hogan, K.A. Tanaka	(2000) 381-391	2000-FP5-18
9	2000	K.A. Tanaka, M. Hara, N. Ozaki, Y. Sasatani, S.I. Anisimov, K. Kondo, M. Nakano, K. Nishihara, H. Takenaka, M. Yoshida and K. Mima	Multi-layered flyer accelerated by laser induced shock waves	Phys. of Plasmas	7 (2000) 676-681	2000-FP5-18
10	2000	R. Kodama, K.A. Tanaka, Y. Sentoku, T. Matsushita, K. Takahashi, H. Fujita, Y. Kitagawa, Y. Kato, T. Yamanaka, and K. Mima	Long-Scale Jet Formation with Specularly Reflected Light in Ultraintense Laser-Plasma Interactions	Phys.Rev.Lett.	84 (2000) 674-677	2000-FP5-18
11	2000	K.A. Tanaka, R. Kodama, N. Izumi, K.Tahakashi, M. Heya, H. Fujita, Y. Kato, Y. Kitagawa, K. Mima, N. Miyanaga, T. Norimatsu, Y. Sentoku, A. Sunahara, H. Takabe, T. Yamanaka, T. Koase, T.I watani, F. Ohtani, T. Miyakoshi, H. Habara, M. Tanpo, S. Tohyama, F.A. Weber, T.W. Barbee Jr. , and L.B. Dasilva	Self-focusing and its related interactions at very high laser intensities for fast ignition at Osaka University	C.R.Acad.Sci.Paris,t.1,Serie IV	2000 (2000) 737-744	2000-FP5-18

12	2001	Y. Kitagawa, Y. Sentoku, S. Akamatsu, M. Mori, Y. Tohyama, R. Kodama, K. A. Tanaka, H. Fujita, H. Yoshida, S. Matsuo, T. Jitsuno, T. Kawasaki, S. Sakabe, H. Nishimura, Y. Izawa, K. Mima, and T. Yamanaka	Progress of fast ignitor studies and Petawatt laser construction at Osaka University	Physics of Plasmas	9-5 (2001) 2202-2207	2002-FP5-30
13	2001	T. Kadono, M. Yoshida, N. K. Mitani, T. Matsumura, E. Takahashi, I. Matsushima, Y. Owadano, Y. Sasatani, K. Fujita, N.Ozaki, K. Takamatsu, M.Nakano, K. A. Tanaka, H. Takenaka, H. Ito, and K. Kondo	Flyer acceleration experiments using a KrF laser system with a long pulse duration and pressure and thickness of isobaric zone induced in impacted materials	Laser and Particle Beams	19 (2001) 623-630	2002-FP5-30
14	2001	Yoshihiro Murakami, Yoneyoshi Kitagawa, Yasuhiko Sentoku, Michiaki Mori, Ryosuke Kodama, Kazuo A. Tanaka, Kunioki Mima,and Tatsuhiko Yamanaka	Observation of proton rear emission and possible gigagauss scale magnetic fileds from ultra-intense laser illuminated plastic target	Physics of Plasmas	8-9 (2001) 4138-4143	2002-FP5-30
15	2001	R. Kodama, P.A. Norreys, K. Mima, A. Evans, R.G. Evans, H. Fujita, Y. Kitagawa, K. Krushelnick, T. Miyakoshi, N. Miyanaga, T. Norimatsu, S.J. Rose, T. Shozaki, K. Shigemori, A. Sunahara, M. Tanpo, K.A. Tanaka, Y. Tohyama, T. Yamanaka and M. Zepf	Fast heating of ultrahigh-density plasma as a step towards laser fusion ignition	Nature	412 (2001) 798-802	2002-FP5-30
16	2001	Il Woo Choi, H. Daido, N. Sakaya, Y. Tohyama, N. Izumi, R. Kodama, Y. Kitagawa, K.A.Tanaka and K. Mima	Prepulse Effect for Recombining Plasma Produced by Ultrashort High-Intensity Lasers	Jpn.J.Appl.Phys.	40 (2001) 1443-1447	2002-FP5-30
17	2001	N. Ozaki,Y. Sasatani, K. Kishida, M. Nakano, M. Miyanaga, K. Nagai, K. Nishihara, T. Norimatsu, K.A. Tanaka, Y. Fujimoto, K. Wakabayashi, S. Hattori, T. Tange, K. Kondo, M. Yoshida, N. Kozu, M. Ishiguchi, H. Takenaka	Planar shock wave generated by uniform irradiation from two overlapped partially coherent laser beams	J. Appl. Phys.	89 (2001) 2571-2575	2002-FP5-30
18	2001	R. Kodama, K. Mima, K. A. Tanaka, Y. Kitagawa, H. Fujita, K. Takahashi, A. Sunahara, K. Fujita, H. Habara, T. Jitsuno, Y. Sentoku, T. Matsushita, T. Miyakoshi, N. Miyanaga, T. Norimatsu, H. Setoguchi, T. Sonomoto, M. Tanpo, Y. Toyama, and T. Yamanaka	Fast Ignitor research at the Institute of Laser Engineering, Osaka University	Physics of Plasmas	8-5 (2001) 2268-2274	2002-FP5-30
19	2001	J. Sasaki, T. Nakamura, Y. Uchida, T. Someya, K. Shimizu, M. Shitamura, T. Teramoto, A. B. Blagoev and S. Kawata	Beam Non-Uniformity Smoothing Using Density Valley Formed by Heavy Ion Beam Deposition in Inertial Confinement Fusion Fuel Pellet	Jpn. J. Appl. Phys.	40 (2001) 968-971	2000-FP5-1
20	2001	M. Ogawa, Y. Oguri, U. Neuner, K. Nishigori, A. Sakumi, K. Shibata, J. Kobayashi, M. Kojima, M. Yoshida and J. Hasegawa	Laser Heated dE/dX Experiments in Japan	Nucl. Instrum. Methods Phys. Res., Sect. A	464 (2001) 72-79	2000-FP5-1
21	2001	K. Shibata, A. Sakumi, R. Sato, K. Tsubuku, T. Nishimoto, J. Hasegawa, M. Ogawa and Y. Oguri	Experimental Investigation of the Coulomb Logarithm in Beam-Plasma Interaction	Nucl. Instrum. Methods Phys. Res., Sect. A	464 (2001) 225-230	2000-FP5-1

22	2001	A. Sakumi, K. Shibata, R. Sato, K. Tsubuku, T. Nishimoto, J. Hasegawa, M. Ogawa, Y. Oguri and T. Katayama	Energy Dependence of the Stopping Power of MeV 16O Ions in a Laser-Produced Plasma	Nucl. Instrum. Methods Phys. Res., Sect. A	464 (2001) 231-236	2000-FP5-1
23	2001	M. Kojima, K. Nishigori, M. Yoshida, A. Sakumi, J. Hasegawa, U. Funk, U. Neuner, Y. Oguri and M. Ogawa	Laser Plasma Induced from Solid Hydrogen for Beam-Plasma Interaction	Nucl. Instrum. Methods Phys. Res., Sect. A	464 (2001) 262-266	2000-FP5-1
24	2001	J. Hasegawa, Y. Nakajima, K. Sakai, M. Yoshida, S. Fukuda, K. NIshigori, M. Kojima, Y. Oguri, M. Nakajima, K. Horioka, M. Ogawa, U. Neuner and T. Murakami	Energy Loss of 6MeV/u Iron Ions in Partially Ionized Helium Plasma	Nucl. Instrum. Methods Phys. Res., Sect. A	464 (2001) 440-444	2000-FP5-1
25	2001	M. Yoshida, J. Hasegawa, Y. Oguri, M. Ogawa, M. Nakajima, K. Horioka and M. Shiho	A simple Time-Resolved Emittance Measurement of a Laser Ion Source with a Digital Camera	Nucl. Instrum. Methods Phys. Res., Sect. A	464 (2001) 582-586	2000-FP5-1
26	2001	M. Ogawa, Y. Oguri, J. Hasegawa, T. Aoki, U. Neuner, A. Sakumi, K. Nishigori, K. Shibata, M. Kojima, M. Yoshida, Y. Nakajima, M. Nakajima and K. Horioka	Stopping Power of Heavy Ions in Hot Dense Plasmas	Acta Physica Polonica B	32 (2001) 945-956	2000-FP5-1
27	2002	R.Kodama,K.A.Tanaka,S.Fujioka,H.Fujita,H.Habara,Y.Izawa,T.Jitsuno,Y.Kitagawa,K.Krushelnick,K.Mima,N.Miyanaga,K.Nagai,P.Norreys,T.Norimatsu,K.Shigemori,H,Shiraga,Y.Toyama,M.Zepf and T.Yamanaka	Fast heating of super-solid density plasmas towards laser fusion ignition	Plasma Physics And Controlled Fusion	44 (2002) B109-B119	2002-FP5-30
28	2002	H. Shiraga, K. Shigemori, Y. Toyama, S. Fujioka, H. Azechi, H. Fujita, H.Habara, T. Hall, Y. Izawa, T. Jitsuno, Y. Kitagawa, K. M. Krushelnics, K. L. Lancaster, K. Mima, K. Nagai, M. Nakai, H. Nishimura, T.Norimatsu, P. A. Norreys, S.Sakabe, K. A. Tanaka, A. Youssef, M. Zepf, T. Yamanaka	Fast heating scalable to laser fusion ignition	Nature	418 (2002) 933-934	2002-FP5-30
29	2002	Keiji Nagai, Takayoshi Norimatsu, Tatsuhiko Yamanaka, Tsutomu Nishibe, Norimasa Ozaki, Kikuo Takamatsu, Takatoshi Ono, Motohiro Nakano, and Kazuo A. Tanaka	Single Molecular Membrane Glue Technique for Laser Driven Shock Experiments	Jpn. J. Appl. Phys.	41 (2002) L1184-L1186	2002-FP5-30
30	2002	T. Miyakoshi, M. S. Jovanovic, Y. Kitagawa, R. Kodama, K. Mima, A. A. Offenberger, K. A. Tanaka, and T. Yamanaka	Stimulated Raman back-scattering from a mm-scale inhomogeneous plasma irradiated with ultra-intense laser pulse	Physics of Plasmas	9-8 (2002) 3552-3557	2002-FP5-30
31	2002	Jian Zheng, K. A. Tanaka, T. Miyakoshi, Y. Kitagawa, R. Kodama, T.Kurahashi, and T. Yamanaka	Spectrum of transition radiation from hot electrons generated in ultra-intense laser plasma interaction	Physics of Plasmas	9-8 (2002) 3610-3616	2002-FP5-30
32	2002	Jian Zheng, K. A. Tanaka, Y. Sentoku, A. A. Offenberger, Y. Kitagawa, R. Kodama, T. Kurahashi, K. Mima, and T. Yamanaka	Harmonic emission with cyclotron satellite structure due to strong magnetic fields produced by ultra-intense laser-plasma interaction	Physics of Plasmas	9-8 (2002) 3193-3196	2002-FP5-30

33	2002	N. Izumi, Y. Sentoku, H. Habara, K. Takahashi, F. Ohtani, T. Sonomoto, R. Kodama, T. Norimatsu, H. Fujita, Y. Kitagawa, K. Mima, K. A. Tanaka, and T. Yamanaka	Observation of neutron spectrum produced by fast deuterons via ultraintense laser plasma interactions	Physical Review E	65 (2002) 036413-1-036413-10	2002-FP5-30
34	2002	S. Morita, M. Goto, S. Kubo et al.	Behaviour of ion temperature in electron and ion heating regimes observed with ECH, NBI and ICRF discharges of LHD	Nuclear Fusion	42 (2002) 1179–1183	2002-FP5-10
35	2002	S. Morita, Y. Shirai, M. Goto et al.	Observation of ablation and acceleration of impurity pellets in the presence of energetic ions in the CHS heliotron/torsatron	Nuclear Fusion	42 (2002) 876–880	2002-FP5-10
36	2002	T. Norimatsu, K. Nagai, T. Yamanaka, T. Endo, H. Yoshida, Y. Sakagami	Activities on target fabrication and injection toward laser fusion energy in Japan	Fusion Eng. Desig.	63 (2002) 587-596	2001-FP5-37
37	2002	I. Golovkin, R. Mancini, S. Louis, Y. Ochi, K. Fujita, et al.	Spectroscopic Determination of Dynamic Plasma Gradients in Implosion Cores	Physical Review Letters	88 (2002) 0450021-0450024	2000-ML-1
38	2002	Y. Ochi, I. Golovkin, R. C. Mancini, M. Fukao, A. Sunahara, et al.	Diagnostics of Electron Temperature and Density Gradients in Laser Imploded Core Plasmas	Inertial Fusion Science and Application 2001	136-139	2000-ML-1
39	2002	K. Shibata, K. Tsubuku, T. Nishimoto, J. Hasegawa, M. Ogawa, Y.Oguri and A. Sakumi	Experimental Study on the Feasibility of Hot Plasmas as Stripping Media for MeV Heavy Ions	J. Appl. Phys.	91 (2002) 4833-4839	2001-FP5-19
40	2002	M. Kojima, M. Mitomo, T. Sasaki, J. Hasegawa and M. Ogawa	Charge-State Distribution and Energy Loss of 3.2-MeV Oxygen Ions in Laser Plasma Produced from Solid Hydrogen	Laser Part. Beams	20 (2002) 475-478	2001-FP5-19
41	2002	T. Kikuchi, M. Nakajima and K. Horioka	Bunching Dynamics and Transport Window of Intense Ion Beams in Final Beam Buncher	Laser Part. Beams	20 (2002) 589-593	2001-FP5-19
42	2002	K. Horioka, M. Nakajima, M. Watanabe, E. Hotta, M. Shiho, M. Ogawa and J. Hasegawa	Repetitive Induction Voltage Modulator for Heavy Ion Fusion	Laser Part. Beams	20 (2002) 609-612	2001-FP5-19
43	2002	K. Takayama, J. Kishiro, Makoto Sakuda, Y. Shimosaki and M. Wake	Superbunch Hadron Colliders	Phys. Rev. Lett.	88 (2002) 144801-1-4	2001-FP5-19
44	2002	T. Kikuchi, M. Nakajima and K. Horioka	A Concept of Quasi-Equilibrium, Recirculating Bunch Compressor for Heavy Ion Fusion	J. Plasma Fusion Res. Seires	20 (2002) 589-593	2001-FP5-19
45	2002	T. Kikuchi, M. Nakajima and K. Horioka	A Quasi-Equilibrium Beam Compression in a Recirculator for Heavy Ion Inertial Fusion	Phys. Plasmas	9 (2002) 3476-3482	2001-FP5-19
46	2002	M. Masnavi, M. Nakajima and K. Horioka	Effect of Opacity on Neon-like Argon, and Krypton Line Intensity Ratios in Static, and Cylindrically Imploding High-Density Plasmas	Jpn. J. Appl. Phys.	41 (2002) 5392-5398	2001-FP5-19
47	2002	M. Watanabe, M. Nakajima, M. Shiho, K. Takayama, J. Kishiro and K. Horioka	Magnetic Core Characteristics for High Rep-rate Induction Modulator	Rev. Sci. Instrum.	73 (2002) 1756-1760	2001-FP5-19
48	2002	T.Zh. Esirkepov, S.V. Bulanov, K. Nishihara, T. Tajima, F. Pegorano, V.S. Khoroshkov, K. Mima, H.Daido, Y.Kato, Y. Kitagawa, K. Nagai, and S. Sakabe	Proposed Double-Layer Target for the Generation of High-Quality Laser-Accelerated Ion Beams	Phys. Rev. Lett.	89 (2002) 175003-1-4	2002-FP5-11
49	2003	Jian Zheng, K. A. Tanaka, T. Miyakoshi, Y. Kitagawa, R. Kodama, T. kurahashi, and T. Yamanaka	Theoretical study of transition radiation from hot electrons generated in the laser-solid interaction	Physics of Plasmas	10- (2003) 2994	2003-FP5-32
50	2003	H. Habara,R. Kodama, Y. Sentoku, N. Izumi, Y. Kitagawa, K. A. Tanaka,K. Mima,and T. Yamanaka	Momentum distribution of accelerated ions in ultra-intense laser–plasma, interactions via neutron spectroscopy	Physics of Plasmas	10- (2003) 3712	2003-FP5-32

51	2003	N. Ozaki, K. A. Tanaka, Y. Sasatani, K. Fujita, K. Takamatsu, and M. Nakan, M. Yoshida, K. Okada, E. Takahashi, and Y. Owadano, H. Takenaka, and K. Kondo	Hugoniot measurements for polyimide with laser and explosives	Physics of Plasmas	10-6 (2003) 2475	2003-FP5-32
52	2003	R.B.Stephens, S.P.Hatchett, R. E. Turner, K.A. Tanaka, R. Kodama	Implosion of Indirectly Driven Reentrant-Cone Shell Target	Physical Review Letters	91-18 (2003) 185001-1-185001-4	2003-FP5-32
53	2003	K. Takamatsu, N. Ozaki, K. A. Tanaka, T. Ono, K. Nagai, M. Nakai, T. Watari, A. sunahara, M. Nakano, T. Kataoka, H. Takenaka, M. Yoshida, K. Kondo, and T. Yamanaka	Equation-of-state measurements of polyimide at pressures up to 5.8 TPa using low-density foam with laser-driven shock waves	Physical Review E	67 (2003) 056406-1-5	2003-FP5-32
54	2003	K. A. Tanaka, R. Kodama, K. Mima, Y. Kitagawa, H. Fujita, N. Miyanaga, K. Nagai, T. Norimatsu, T. Sato, Y. Sentoku, K. Shigemori, A. Sunahara, T. Shozaki, M. Tanpo, S. Tohyama, T. Yabuuchi, J. Zheng, and T. Yamanaka	Basic and Integrated studies for fast ignition	Physics of Plasmas	10-5, Part2, (2003) 1925-1930	2003-FP5-32
55	2003	K. Okada, K. Wakabayashi, H. Takenaka, H. Nagao, K. Kondo, T. Ono, K. Takamatsu, N. Ozaki, K. Nagai, M. Nakai, K. A. Tanaka, and M. Yoshida	Experimental Technique for Launching miniature flying plates using laser pulses	Int. Jour. Impact Eng.	29 (2003) 497	2003-FP5-32
56	2003	H.Nishimura, T.Kawamura, R.Matsui et al.	Ka spectroscopy to study energy transport in ultrahigh-intensity laser produced plasmas	Journal of Quantitative Spectroscopy & Radiative Transfer	81 (2003) 327–337	2003-FP5-9
57	2003	H. Yoneda, H. Morikami, K. Ueda et al.	Ultrashort-Pulse Laser Ellipsometric Pump-Probe Experiments on Gold Targets	Physical Review Letters	91 (2003) 075004-1 - 075004-4	2003-FP5-9
58	2003	T. Norimatsu, K. Nagai, T. Takeda, K. Mima, and T. Yamanaka	Update for the drag force on an injected pellet and target fabrication for Inertial fusion	Fusion Sci. Technol.	43 (2003) 339-345	2001-FP5-37
59	2003	Y. Ochi, I. Golovkin, R.C. Mancini, I. Uschmann, A. Sunahara, et al.	Temporal evolution of temperature and density profiles of a laser compressed core	Review of Scientific Instruments	74 (2003) 237-246	2000-ML-1
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225	2008	Y. Izawa, N. Miyanaga, J. Kawanaka, K. Yamakawa	High Power Lasers and Their New Applications	J. Opt. Soc. Korea	12-3 (2008) 178-185	2005-FP5-27
226	2008	Ryo Yasuhara, Toshiyuki Kawashima, Takashi Sekine, Takashi Kurita, Tadashi Ikegawa, Osamu Matsumoto, Masahiro Miyamoto, Hirofumi Kan, Hidetsugu Yoshida, Junji Kawanaka, Masahiro Nakatsuka, Noriaki Miyanaga, Yasukazu Izawa, and Tadashi Kanabe	213W average power of 2.4 GW pulsed thermally controlled Nd:glass zigzag slab laser with a stimulated Brillouin scattering mirror	Opt. Lett	33-15 (2008) 1711-1713	2005-FP5-27
227	2008	D. R. Farley, K. Shigemori, M. Murakami, and H. Azechi	Non-Dimensional Scaling of Impact Fast Ignition Experiments	J. Phys.: Conf. Ser.	112 (2008) 022071:1-6	2009-FP6-3
228	2008	S. Kawata, K. Miyazawa, A.I. Ogoyskii, T. Kikuchi, Y. Akasaka and Y. Iizuka	Direct-Indirect Hybrid Mode Implosion in Heavy Ion Inertial Fusion	J. Phys. Conf. Ser.	112 (2008) 032028-1-4	2007-FP6-3
229	2008	T. Sasaki, Y. Yano, M. Nakajima, T. Kawamura and K. Horioka	A Comparative Study of Equation of State and Conductivity for Warm Dense Matter Using Pulsed-Power Wire Discharges in Water	J. Phys. Conf. Ser.	112 (2008) 042026-1-4	2007-FP6-3
230	2008	T. Sasaki, T. Kikuchi, M. Nakajima, T. Kawamura and K. Horioka	Tamped Target for Warm Dense Matter Experiments Using Intense Heavy Ion Beam	J. Phys. Conf. Ser.	112 (2008) 042027-1-4	2007-FP6-3
231	2008	K. Kondo, M. Nakajima, K. Kawamura and K. Horioka	Relaxation Layer in Electro-Magnetically Driven Strong Shocks	J. Phys. Conf. Ser.	112 (2008) 042028-1-3	2007-FP6-3
232	2008	S. Kawata, M. Nakamura, Q. Kong, Y. Nodera, N. Onuma and T. Kikuchi	Collimated Ion Beam by a Tailored Target Illuminated by an Intense Short Pulse Laser	J. Phys. Conf. Ser.	112 (2008) 042044-1-4	2007-FP6-3
233	2008	S.Kawata, M.Nakamura, R.Sonobe, S.Miyazaki, N.Onuma, Y.Nodera and T.Kikuchi	Collimated Ion Beam by a Laser-Illuminated Tailored Hole Target	IEEE Trans. Plasma Sci.	36 (2008) 363-369	2007-FP6-3
234	2008	Y. Nodera, S. Kawata, N. Onuma, J. Limpouch, O. Klimo and T. Kikuchi	Improvement of Energy Conversion Efficiency from Laser to Proton Beam in a Laser-Foil Interaction	Phys. Rev. E	78 (2008) 046401-1-6	2007-FP6-3

235	2008	K. Katagiri, J. Hasegawa, S. Nishinomiya, H. Ikagawa and Y. Oguri	Development of a Coaxial Tapered Electromagnetic Shock Tube for Beam-Plasma Non-Linear Interaction Experiments	Nucl. Instrum. Methods Phys. Res., Sect. B	266 (2008) 2161-2164	2007-FP6-3
236	2008	S. Nishinomiya, K. Katagiri, T. Niinou, J. Kaneko, H. Fukuda, J. Hasegawa, M. Ogawa and Y. Oguri	Time-Resolved Measurement of Energy Loss of Low-Energy Heavy Ions in a Plasma Using a Surface-Barrier Charged-Particle Detector	Prog. Nucl. Energy	50 (2008) 606-610	2007-FP6-3
237	2008	T. Sasaki, Y. Yano, M. Nakajima, T. Kawamura and K. Horioka	Evaluation of Copper Conductivity in Warm Dense State Using Exploding Wire in Water	Prog. Nucl. Energy	50 (2008) 611-615	2007-FP6-3
238	2008	M. H. Key et al.	Fast ignition relevant study of the flux of high intensity laser-generated electrons via a hollow cone into a laser-imploded plasma	Physics of Plasmas	15 (2008) 022701	2007-FP6-10
239	2008	Y. Ueno, G. Soumagne, A. Sumitani, A. Endo, T. Higashiguchi, and N. Yugami	Reduction of debris of a CO2 laser-produced Sn plasma extreme ultraviolet source using a magnetic field	Applied Physics Letters	92 (2008) 211503	2006-FP5-23
240	2009	A.L.Lei et al.	Study of ultraintense laser propagation in overdense plasmas of fast ignition	Physics of Plasmas	16 (2009) 056307	2008-FP6-7
241	2009	Y. Mori, Y. Sentoku, K. Kondo, K. Tsuji, N. Nakanii, S. Fukumochi, M.Kashihara, K. Kimura, K. Takeda, K. A. Tanaka, T. Norimatsu, Tsuyoshi Tanimoto, H. Nakamura, M. Tampo, R. Kodama, E. Miura, K. Mima, and Y. Kitagawa	Autoinjection of electrons into a wake field using a capillary with attached cone	Physics of Plasmas	16 (2009) 123103	2008-FP6-7
242	2009	T. Yabuuchi, A. Das, G. R. Kumar, H. Habara, P. K. Kaw, R. Kodama, K. Mima, P. A. Norreys, S. Sengupta, and K. A. Tanaka	Evidence of anomalous resistivity for hot electron propagation through a dense fusion core in fast ignition experiments	New Journal of Physics	11 (2009) 093031 (9pp）	2008-FP6-7
243	2009	Kazuo A. Tanaka	Summary of inertial fusion sessions	Nuclear Fusion	49 (2009) 104004 (8pp)	2008-FP6-7
244	2009	Tsuyoshi Tanimoto, H. Habara, R. Kodama, M. Nakatsutsumi, Kazuo A. Tanaka, K. L. Lancaster, J. S. Green, R. H. H. Scott, M. Sherlock, Peter A. Norreys, R. G. Evans, M. G. Haines, S. Kar, M. Zepf, J. King, T. Ma, M. S. Wei, T. Yabuuchi, F. N. Beg, M. H. Key, P. Nilson, R. B. Stephens, H. Azechi, K. Nagai, T. Norimatsu, K. Takeda, J. Valente, and J. R. Davies	Measurements of fast electron scaling generated by petawatt laser systems	Physics of Plasmas	16 (2009) 062703	2008-FP6-7
245	2009	Y. Mori, Y. Sentoku, K. Kondo et al.	Autoinjection of electrons into a wake field using a capillary with attached cone	Physics of Plasmas	16 (2009) 123103-1 -123103-6	2005-FP5-9
246	2009	K. L. Lancaster, M. Sherlock, J. S. Green, C. D. Gregory, P. Hakel, K. U. Akli, F. N. Beg, S. N. Chen,,R. R. Freeman, H. Habara, R. Heathcote, D. S. Hey, K. Highbarger, M. H. Key, R. Kodama,,K. Krushelnick, H. Nakamura, M. Nakatsutsumi, J. Pasley, R. B. Stephens, M. Storm, M. Tampo, W. Theobald, L. Van Woerkom, R. L. Weber, M. S. Wei, N. C. Woolsey, T. Yabuuchi, and P. A. Norreys	Effect of reentrant cone geometry on energy transport in intense laser-plasma interactions	Physical Review E	80 (2009) 045401	2006-FP5-26 2007-FP6-17

247	2009	S. A. Reed, T. Matsuoka, S. Bulanov, M. Tampo, V. Chvykov, G. Kalintchenko, P. Rousseau, V. Yanovsky, R. Kodama, D. W. Litzenberg, K. Krushelnick, and A. Maksimchuk	Relativistic plasma shutter for ultraintense laser pulses	Applied Physics Letters	94 (2009) 201117	2006-FP5-26 2007-FP6-17
248	2009	T. Kikuchi, K. Horioka	Beam Behavior under a Non-Stationary State in High-Current Heavy-Ion Beams	Nuclear Instruments and Methods in Physics Research	A 606 (2009) 31-36	2009-FP6-4 2009-FP6-8
249	2009	S.M. Lund, T. Kikuchi, R.C. Davidson	Generation of initial kinetic distributions for simulation of long-pulse charged particle beams with high space-charge intensity	Physical Review Special Topics - Accelerator and Beams	12 (2009) 114801-1-50	2008-FP6-1 2009-FP6-4 2009-FP6-8
250	2009	Hong-bo Cai1, Kunioki Mima1, Wei-min Zhou1, Tomoyuki Jozaki1, Hideo Nagatomo1, Atsushi Sunahara1, and Rodney J. Mason2	Enhancement of the number of high energy electrons deposited to the compressed pellet via double cone in fast ignition	Physical Review Latters	102 (2009) 1245001	2005-FP5-10
251	2009	S.Yu. Gus'kov and M. Murakami	Fast ignition by detonating hydrodynamic flow	J. Russian Laser Research	30 (2009) 279-295	2009-FP6-3
252	2009	T. Sasaki, T. Asai, T. Takahashi, T. Kikuchi, M. Nakajima, K. Horioka and K. Takayama	Planned for High Energy Density Physics Based on All Ion Accelerator Facility	J. Plasma Fusion Res. Seires	8 (2009) 174-178	2008-FP6-1
253	2009	Y. Iizuka, S. Kawata T. Kodera, A.I. Ogoyski and T. Kikuchi	Direct-Indirect Hybrid Implosion in Heavy Ion Inertial Fusion	J. Plasma Fusion Res. Seires	8 (2009) 1200-1203	2008-FP6-1
254	2009	T. Kikuchi and K. Horioka	Halo Formation and Emittance Growth during Bunch Compression of High-Current Heavy Ion Beams	J. Plasma Fusion Res. Seires	8 (2009) 1230-1233	2008-FP6-1 2009-FP6-4 2009-FP6-8
255	2009	K. Horioka, T. Kawamura, M. Nakajima, T. Sasaki, K. Kondo, Y. Oguri, J. Hasegawa, M. Ogawa, S. Kawata, T. Kikuchi, M. Murakami and K. Takayama	Activities on Heavy Ion Inertial Fusion and Beam-Driven High Energy Density Science in Japan	Nucl. Instrum. Methods Phys. Res., Sect. A	606 (2009) 1-5	2008-FP6-1
256	2009	T. Kikuchi and K. Horioka	Beam Behavior under a Non-Stationary State in High-Current Heavy-Ion Beams	Nucl. Instrum. Methods Phys. Res., Sect. A	606 (2009) 31-36	2008-FP6-1
257	2009	S. Kawata, Y. Iizuka, Y. Kodera, A.I. Ogoyski and T. Kikuchi	Robust Fuel Target in Heavy Ion Inertial Fusion	Nucl. Instrum. Methods Phys. Res., Sect. A	606 (2009) 152-156	2008-FP6-1
258	2009	T. Sasaki, T. Kikuchi, M. Nakajima, T. Kawamura and K. Horioka	Quasi-Statically Tamped Target for Warm Dense Matter Experiments Based on All Ion Accelerator	Nucl. Instrum. Methods Phys. Res., Sect. A	606 (2009) 161-164	2008-FP6-1
259	2009	Y. Iizuka, T. Kikuchi, S. Kawata and A.I. Ogoyski	Study on Target Structure for Direct-Indirect Hybrid Implosion Mode in Heavy Ion Inertial Fusion	Nucl. Instrum. Methods Phys. Res., Sect. A	606 (2009) 165-168	2008-FP6-1
260	2009	J. Hasegawa, H. Ikagawa, S. Nishinomiya, T. Watahiki and Y. Oguri	Beam-Plasma Interaction Experiments Using Electromagnetically Driven Shock Waves	Nucl. Instrum. Methods Phys. Res., Sect. A	606 (2009) 205-211	2008-FP6-1
261	2009	K. Kondo, M. Nakajima, T. Kawamura and K. Horioka	Atomic Process in Electro-Magnetically Driven Shock Wave	Nucl. Instrum. Methods Phys. Res., Sect. A	606 (2009) 223-225	2008-FP6-1
262	2009	T. Kikuchi and K. Horioka	Static Analysis of Possible Emittance Growth of Intense Charged Particle Beams with Thermal Equilibrium Distribution	Phys. Plasmas	16 (2009) 050703-1-4	2008-FP6-1 2009-FP6-4 2009-FP6-8
263	2009	Y. Aoyama, M. Nakajima and K. Horioka	Counter-Facing Plasma Focus System as a Repetitive and/or Long-Pulse High Energy Density Plasma Source	Phys. Plasmas	16 (2009) 110701-1-3	2008-FP6-1
264	2009	S. Kawata, Y. Nodera, J. Limpouch and O. Klimo	Efficient Production of Proton Beam in Laser-Illuminated Tailored Microstructured Target	IEEE Trans. Plasma Sci.	37 (2009) 481-486	2008-FP6-1

265	2009	A. Andreev, K. Platonov and S. Kawata	Ion Acceleration by Short High Intensity Laser Pulse in Small Target Sets	Laser Part. Beams	27 (2009) 449-457	2008-FP6-1
266	2009	Takeshi Higashiguchi and Noboru Yugami	Short-pulse, high-power microwave source with a laser-induced sheet plasma mirror	Journal of Applied Physics	105 (2009) 093301	2006-FP5-23
267	2009	Makoto Nakagawa, Ryosuke Kodama, Takeshi Higashiguchi, and Noboru Yugami	Generation of terahertz radiation via an electromagnetically induced transparency at ion acoustic frequency region in laser-produced dense plasmas	Physical Review E	80 (2009) 025402	2006-FP5-23
268	2010	Hideaki Habara, Kazuhide Ohta, and Kazuo A. Tanaka, G. Ravindra Kumar, M. Krishnamurthy, Subhendu Kahaly, Sudipta Mondal, Manoj kumar Bhuyan, and R. Rajeev, Jian Zheng	Direct, Absolute, and In Situ Measurement of Fast Electron Transport via Cherenkov Emission	Physical Review Letters	104（2010）055001	2008-FP6-7
269	2010	Hideaki Habara, Kazuhide Ohta, Kazuo A. Tanaka, G. Ravindra Kumar, M. Krishnamurthy, Subhendu Kahaly, Sudipta Mondal, Manoj kumar Bhuyan, R. Rajeev, and Jian Zheng	Measurement of high energy density electrons via observation of Cherenkov radiation	Phys. Plasmas	17 (2010) 056306	2008-FP6-7

2. Conference Paper

No	Year	Authors	Title of Paper	Conference Name	Month Date, Year, Place, Country	Year-Category-No.
1	2000	I. Golovkin, R. Mancini, S. Louis, Y. Ochi, K. Fujita, et al.	A Spectroscopy Diagnostics of Plasma Gradients In ICF Imploded Cores	Topical Conference on High Temperature Plasma Diagnostics	June 18-22, 2000, Tucson, USA	2000-ML-1
2	2000	Y. Ochi, K. Fujita, M. Fukao, I. Niki, H. Nishimura, et al.	Diagnostics of imploded core plasma dynamics using time-resolved x-ray spectra and x-ray monochromatic images	APS 42nd annual meeting of DPP	Oct. 23-27, 2000, Quebec, Canada	2000-ML-1
3	2000	I. Golovkin, R. Mancini, S. Louis, Y. Ochi, K. Fujita, et al.	Spectroscopic determination of plasma gradients in ICF imploded cores	Radiative Properties of Hot Dense Matter	Oct.30-Nov.3, 1999, Santa Barbara, USA	2000-ML-1
4	2001	H.Nishimura, Y.Ochi, T.Kawamura, K.Fujita, I.Golovkin, R.Mancini, et al.	X-ray spectroscopic measurement of laser imploded hot core and its extension to fast igniter experiments	5th Fast Ignitor Workshop	Jne 18-22, 2001, Madeira, Portugal	2000-ML-1
5	2001	Y. Ochi, K. Fujita, M. Fukao, A. Sunahara, H. Nishimura, et al.	Diagnostics of Electron Temperature and Density Gradients in Laser Imploded Core Plasmas	2nd International Conference on Inertial Fusion Sciences and Applications	Sep.10-14, 2001, Kyoto, Japan	2000-ML-1
6	2001	Y. Ochi, K. Fujita, M. Fukao, H. Nishimura, A. Sunahara, et al.	X-ray spectroscopic measurements of temporal variation of ICF core plasma gradients	APS 43rd annual meeting of DPP	Oct.29-Nov.2, 2001, Long Beach, USA	2000-ML-1
7	2001	T. Nakamura, M. Shitamura, Y. Uchida and S. Kawata	Constrained Interpolation Profile Scheme for Solving the Hyper-Dimensional Vlasov-Maxwell System in Laser-Plasma	The 2nd International Conference on Inertial Fusion Sciences and Applications (IFSA2001)	Sep. 9-14, 2001, Kyoto, Japan	2000-FP5-1
8	2001	Y. Uchida, T. Nakamura, K. Shimizu, M. Shitamura and S. Kawata	Direct Numerical Solution of Collision Term in the Fokker-Planck Equation Toward a Laser-Plasma Interaction	The 2nd International Conference on Inertial Fusion Sciences and Applications (IFSA2001)	Sep. 9-14, 2001, Kyoto, Japan	2000-FP5-1
9	2001	J. Hasegawa, Y. Nakajima, K. Sakai, Y. Oguri, M. Nakajima, K. Horioka and M. Ogawa	Development of High-Brightness Ion Sources Using Moderate Power Lasers	The 2nd International Conference on Inertial Fusion Sciences and Applications (IFSA2001)	Sep. 9-14, 2001, Kyoto, Japan	2000-FP5-1
10	2001	Y. Oguri, K. Tsubuku, K. Shibata, T. Nishimoto, J. Hasegawa and M. Ogawa	Charge-Changing Processes of Low-Energy Heavy Ions in a Dense Non-Hydrogenic Plasma	The 2nd International Conference on Inertial Fusion Sciences and Applications (IFSA2001)	Sep. 9-14, 2001, Kyoto, Japan	2000-FP5-1
11	2002	Y. Ochi, I. Golovkin, R.C. Mancini, I. Uschmann, A. Sunahara, et al.	Evolution of Temperature and Density Profiles of a Laser Compressed Core	Topical Conference on High-Temperature Plasma Diagnostics	Jul. 8-11, 2002, Madison, USA	2000-ML-1
12	2003	H. Shiraga, S. Fujioka, R. Kodama, K.A. Tanaka, R.B. Stephens, P. Jaanimagi, C. Stoeckl, T.C. Sangster, D. D. Meyerhofer, S.P. Hatchett	10-ps X-Ray Imaging of Cone-Shell Target Implosion at OMEGA laser	3rd International Conference on Inertial Fusion Science and Applications	September 8-12, 2003, Double Tree Hotel, Monterey, California, USA	2002-FP5-33 2003-FP5-28
13	2003	T. Kikuchi, T. Katayama, M. Nakajima and K. Horioka	Emittance Growth and Particle Distributions during Final Beam Bunching in Heavy Ion Fusion Driver	Asian Particle Accelerator Conference (APAC2004)	Mar. 22-26, 2004, Gyeongju, Korea	2001-FP5-19
14	2003	T. Kikuchi, S.M. Lund and T. Katayama	Possible Parameters for Bunch Compression in a Ring in Future RIKEN Projects	Asian Particle Accelerator Conference (APAC2004)	Mar. 22-26, 2004, Gyeongju, Korea	2001-FP5-19
15	2003	S. Kawata, Shuji Miyazaki, Qing Kong, Koichi Miyauchi, Jiri Limpouch and A.A. Andreev	High Energy Particle Acceleration by High-Power Laser	The 9th Conference on Laser Optics (LO2003)	Jun. 30-Jul. 4, 2003, St. Petersburg, Russia	2001-FP5-19
16	2004	Hiroyuki Shiraga	Multi-Imaging X-Ray Streak Camera for Diagnosing Laser-Imploded Core Plasmas (invited)	15th Topical Conference on High-Temperature Plasma Diagnostics	April 19-22, 2004, San Diego, USA	2002-FP5-33 2003-FP5-28 2003-FP5-29
17	2004	Hiroyuki Shiraga	Dynamics of imploded shell target with cone for fast ignition observed with Multi-Imaging X-ray Streak Camera (invited)	International Workshop on Fast Ignition and High Field Physics 2004	April 25-29, 2004, Kyoto, Japan	2002-FP5-33 2003-FP5-28 2003-FP5-29

18	2004	H. Shiraga, S. Fujioka, H. Nagatomo, R. Kodama, K.A. Tanaka, H. Azechi, R.B. Stephens, P. Jaanimagi, C. Stoeckl, D. D. Meyerhofer, S.P. Hatchett	Imploded Core Plasma Dynamics of Cone-Shell Targets	46th Annual Meeting of the Division of Plasma Physics, American Physical Society	Nov. 15-19, 2004, Savannah, GA, USA	2002-FP5-33 2003-FP5-28 2003-FP5-29
19	2004	H. Shiraga	A new approaach toward time- and space-resolved measurements of fast ignition	Japan-US Workshop on High Irradiance Laser and Plasma Diagnostic Technologies	Nov. 29-Dec. 1, 2004, Osaka, Japan	2002-FP5-33 2003-FP5-28 2003-FP5-29
20	2004	K. Koyama, E. Miura, S. Kato, N. Saito, M. Adachi, A. Ogata, S. Masuda, and M. Tanimoto	Generation of Quasi-monoenergetic High-energy Electron Beam by Plasma Wave	Eleventh Advanced Accelerator Concepts Workshop	Jun. 21-26, 2004, Stony Brook, New York, USA	2004-FP5-28
21	2004	Yoshio Wada, Yasuo Shigemoto, and Atsushi Ogata	Ion Production Enhancement by Rear-Focusing and Prepulse in Ultrashort-Pulse Laser Interaction with Foil Targets	Eleventh Advanced Accelerator Concepts Workshop	Jun. 21-26, 2004, Stony Brook, New York, USA	2004-FP5-28
22	2004	Yoneyoshi Kitagawa, Mitsuru Uesaka, Kazuyoshi Koyama, Kaszuhisa Nakajima, Toshiki Tajima, Hiroyuki Daido, Atsushi Ogata, Koshichi Nemoto, Yasushi Nishida, Noboru Yugami, Shuji Miyamoto, and Katsuhiro Dobashi	Review of Advanced Accelerator Concepts R & D in Japan	Eleventh Advanced Accelerator Concepts Workshop	Jun. 21-26, 2004, Stony Brook, New York, USA	2004-FP5-28
23	2004	S. Kawata, T. Someya, T. Kikuchi and A.I. Ogoyski	Final Transport and Target Illumination	The 15th International Symposium on Heavy ion Inertial Fusion	Jun. 7-11, 2004, Princeton, NJ, USA	2004-FP5-17
24	2004	T.kikuchi, T.Someya, S. Kawata, N. Nakajima, K. Horioka and T. Katayama	Beam Dynamics Simulation during Final Bunching and Transport for Heavy Ion Inertial Fusion	International Computational Accelerator Physics (ICAP2004)	Jun. 29-Jul. 2, 2004, St. Petersburg, Russia	2004-FP5-17
25	2005	K.Kasuya, T.Norimatsu, S. Nakai, A.Prokopiuk and W.Mroz	IFE Chamber Wall Ablations with High-Flux Pulsed Beams Including Ions and UV Laser Lights	Third Technical Meeting on Physics and Technology of Inertial Fusion Energy Targets and Chambers	October 11-13, 2004, KAIST, Daejon, Republic of Korea	2005-FP5-27
26	2005	K.Kasuya, T.Notimatsu, K.Nagai, et al.	Observation of Various Material Surfaces Irradiated and Cratered with Focused ArF Laser Lights	15th International Symposium on Gas Flow and Chemical Lasers & High Power Laser Conference	30 August-3 September 2004, Prague, Czech Republic	2005-FP5-27
27	2005	K.Kasuya, T.Notimatsu, S.Nakai, T.J.Renk, and W. Mroz	Material Surface Ablation with Light and Medium-Mass Pulsed Ion Beams for Future IFE Reactor Design	Eighth Japan-China Symposium on Materials for Advanced Energy Systems and Fission & Fusion Engineering	October 4-8, 2004, Sendai, Miyagi, Japan, 47-52 (2005)	2005-FP5-27
28	2005	H. Shiraga, H. Nagatomo, S. Fujioka, R. Kodama, K.A. Tanaka, R.B. Stephens, P. Jaanimagi, C. Stoeckl	Nonuniform Core and Jet Formation in Cone-Shell Implosion	4th International Conference on Inertial Fusion Sciences and Applications	September 4-9, 2005, Biarritz, France	2002-FP5-33 2003-FP5-28 2003-FP5-29
29	2005	T. Kikuchi, T. Someya, S. Kawata, M. Nakajima and K. Horioka	Instability and Emittance Growth in High-Current Heavy Ion Beam Bunching	The 32nd IEEE International Conference on Plasma Science 2005 (ICOPS2005)	Jun. 13-17, 2005, Monterey, CA, USA	2004-FP5-17
30	2005	T. Kikuchi, T. Someya, S. Kawata, M. Nakajima and K. Horioka	Emittance Growth and Instability induced by Space Charge Effect during Final Beam Bunching in HIF Accelerator System	The 4th International Conference on Inertial Fusion Sciences and Applications (IFSA2005)	Sep. 4-9, 2005, Biarritz, France	2004-FP5-17
31	2005	T. Kikuchi, T. Someya, M. Seino, K. Miyazawa, S. Kawata, M. Nakajima and K. Horioka	Effect of Dipole Mode Oscillation during High-Current Heavy Ion Beam Transport and Longitudinal Compression	The 47th Annual Meeting of the American Physical Society Division of Plasma Physics	Oct. 24-28, 2005, Denver, CO, USA	2004-FP5-17
32	2005	T. Kikuchi, S. Kawata, T. Someya, K. Horioka, M. Nakajima and T. Katayama	Beam Dynamics and Pulse Duration Control During Final Beam Bunching in Driver System for Heavy Ion Inertial Fusion	2005 Particle Accelerator Conference (PAC05)	May 16-20, 2005, Knoxville, TN, USA	2004-FP5-17

33	2006	S. Kawata, K. Horioka, M. Murakami, Y. Oguri, J. Hasegawa, K. Takayama, H. Yoneda, T. Kikuchi, T. Kawamura and M. Ogawa	Studies on Heavy Ion Fusion and High Energy Density Physics in Japan	The 16th International Symposium on Heavy Ion Inertial Fusion	Jul. 9-14, 2006, Saint-Malo, France	2005-FP5-1
34	2006	K. Li, K. Ninomiya, T. Higashiguchi and N. Yugami	Generation EM Waves by Laser Plasma Interaction Experiments in Utsunomiya University	12th Advanced Accelerator Concepts Workshop	July 10–15, 2006, Lake Geneva, Wisconsin, USA	2006-FP5-23
35	2006	N. Ohata, T. Higashiguchi, H. Kawanago, K. Yaegashi, I. Takano, K. Li and N. Yugami	Experiments of Frequency Upshift by Use of a Laser-Produced Ionization Front	12th Advanced Accelerator Concepts Workshop	July 10–15, 2006, Lake Geneva, Wisconsin, USA	2006-FP5-23
36	2007	K.Kasuya, S.Ozawa, S.Suzuki, K.Esato, M.Akiba, W.Mroz, A.Prokopiuk, M.Sato, K.Shimoda, T.Norimatsu, M.Nakai, K.Nagai, T.Ohshige, H.Furukawa	Applications of Laser and Particle Beam Apparatuses to Fusion Reactor Plasma Facing Furface Research Works	4th IAEA Technical Meeting on Physics and Technology of IFE Targets and Chambers	September 13, 2007, Kobe, Japan	2005-FP5-27
37	2007	T. Kikuchi, S. Kawata and K. Horioka	Particle Dynamics at Stagnation Point during Longitudinal Bunch Compression of High Current Beams	2007 Particle Accelerator Conference (PAC07)	Jun. 25-29, 2007, Albuquerque, NM, USA	2006-FP5-10 2007-FP6-20
38	2007	T. Kikuchi, S. Kawata and K. Takayama	Half-Mini Beta Optics with a Bunch Rotation for Warm Dense Matter Science Facility in KEK	2007 Particle Accelerator Conference (PAC07)	Jun. 25-29, 2007, Albuquerque, NM, USA	2006-FP5-10 2007-FP6-20
39	2007	S. Kawata, M. Nakamura, R. Sonobe, S. Miyazaki, N. Onuma and T. Kikuchi	Collimated Ion Beam by a Laser-Illuminated Tailored Target	2007 IEEE Pulsed Power and Plasma Science Conference	Jun. 17-22, 2007, Albuquerque, New Mexico, USA	2006-FP5-10
40	2007	S. Kawata, K. Miyazawa, A.I. Ogoyskii, T. Kikuchi, Y. Akasaka and Y. Iizuka	Direct-Indirect Hybrid Mode Implosion in Heavy Ion Inertial Fusion	The 5th International Conference on Inertial Fusion Sciences and Applications (IFSA2007)	Sep. 9-14, 2007, Kobe, Japan	2006-FP5-10
41	2007	Nobuo Ohata, Kun Li, Hiroshi Kawanago, Kenta, Yaegashi, Takeshi Higashiguchi, and Noboru Yugami	High power, 1-THz source based on a femtosecond laser-pumped DC to AC Radiation Converter scheme	CLEO EUROPE	June 17-22, 2007, Munich, Germany	2006-FP5-23
42	2007	Kun Li, Tsukasa Oshima, Masafumi Hikita, Takeshi Higashiguchi, and Noboru Yugami	Optical guiding in gas-filled capillary discharge plasmas waveguide for electron acceleration application	CLEO EUROPE	June 17-22, 2007, Munich, Germany	2006-FP5-23
43	2007	Nobuo Ohata, Kenta Yaegashi, Kun Li, Takeshi Higashiguchi, and Noboru Yugami	THz radiation from a DARC source via a laser-produced relativistic ionization front	SPIE Optics East	Sep. 2007, Boston, USA	2006-FP5-23
44	2008	N. Ozaki (invited)	Extreme Off-Hugoniot Generated by Reverberating Shock Compression	International Workshop on Warm Dense Matter	Mar. 15-19, 2009, Hakone, Japan	2006-FP5-26 2007-FP6-17
45	2008	S. Kawata, Y. Nodera, N. Onuma, M. Nakamura, R. Sonobe, T. Kikuchi, Q. Kong, P.X. Wang, J. Limpouch, O. Klimo and A. Andreev	Laser-Produced Collimated Proton Beam by a Tailored Thin Foil Target	The 35th IEEE International Conference on Plasma Science (ICOPS2008)	Jun. 15-19, 2008, Karlsruhe, Germany	2007-FP6-3
46	2008	S. Kawata, Y. Nodera, J. Limpouch, O. Klimo and A. Andreev	Efficient Collimated-Proton Beam Generation by an Intense-Laser-Illuminated Tailored Target	The 12th International Conference on Laser Optics	Jun. 23-28, 2008, St. Petersburg, Russia	2007-FP6-3
47	2008	S. Kawata, Y. Iizuka, Y. Kodera, A.I. Ogoyski and T. Kikuchi	Robust Fuel Target in heavy ion inertial fusion	The 17th International Symposium on Heavy Ion Inertial Fusion (HIF2008)	Aug. 4-8, 2008, Tokyo, Japan	2007-FP6-3
48	2008	K. Horioka, T. Kawamura, M. Nakajima, T. Sasaki, K. Kondo, Y. Oguri, J. Hasegawa, M. Ogawa, S. Kawata, T. Kikuchi, M. Murakami and K. Takayama	Activities on Heavy Ion Inertial Fusion and Beam-Driven High Energy Density Science in Japan	The 17th International Symposium on Heavy Ion Inertial Fusion (HIF2008)	Aug. 4-8, 2008, Tokyo, Japan	2007-FP6-3

49	2008	H. Habara et al.	Electron acceleration in ultra-intense laser (>1018 Wcm-2) interactions with sub-micron structured targets	The 50th Annual meeting of Division of Plasma Physics, American Physical Society	Nov. 17-21, 2008, Dallas, USA	2008-FP6-5
50	2008	H. Habara et al.	Study of ultra-intense laser propagation in overdense plasmas for fast ignition (invited)	The 50th Annual meeting of Division of Plasma Physics, American Physical Society	Nov. 17-21, 2008, Dallas, USA	2008-FP6-5
51	2008	Takeshi Higashiguchi, Hiromitsu Terauchi, Jin-xiang Bai, and Noboru Yugami	Plasma Parameter of a Capillary Discharge-Produced Plasma Channel to Guide an Ultrashort Laser Pulse	13th Advanced Accelerator Concept Workshop	July, 2008, Santa Cruz, USA	2006-FP5-23
52	2008	Masashi Kudo, Takeshi Higashiguchi, and Noboru Yugami	Compression of An Ultrashort Laser Pulse via Self-Phase Modulation in An Argon Channel	13th Advanced Accelerator Concept Workshop	July, 2008, Santa Cruz, USA	2006-FP5-23
53	2008	Takeshi Higashiguchi, Hideyuki Hasegawa, Hirofumi Nishimai, Noboru Yugami, and Patric Muggli	Frequency Upshift and Radiation of the THz Electromagnetic Wave via an Ultrashort-Laser-Produced Ionization Front	13th Advanced Accelerator Concept Workshop	July, 2008, Santa Cruz, USA	2006-FP5-23
54	2009	Hideaki Habara, Masashi Yamamoto, Takahiro Kurahashi, Kenji Kida and Kazuo A. Tanaka	Development of High-Order Harmonic Light Spectrometer for Observation of Strong Magnetic Field Generated by Fast Electrons in Laser-Plasma Interactions	Proceedings of the 14th International Congress on Plasma Physics (ICPP2008)	2009.9.8-12, Fukuoka, Japan	2008-FP6-7
55	2009	A. Okabayashi, T. Yabuuchi, H. Habara, and K. A. Tanaka	Monte-Carlo Simulations for Heating of Superdense Matter by Relativistic Electrons	Proceedings of the 14th International Congress on Plasma Physics (ICPP2008)	2009.9.8-12, Fukuoka, Japan	2008-FP6-7
56	2009	H. Nakamura, Y. Arikawa, H. Habara, M. Isobe, R. Kodama, M. Koga, M. Nakai, H. Nishimura, T. Ozaki, Y. Sakawa, N. Sarukura, H. Shiraga, KA. Tanaka, H. Azechi	Developments of nuclear diagnostics for fast ignition experiments in laser fusion (invited)	The 238th ACS National Meeting & Exposition Fall 2009	Aug. 16-20,2009, Washington DC, USA	2006-FP5-26 2007-FP6-17
57	2009	N. Ozaki (invited)	Extreme off-Hugoniot experimens using high-power laser	International Conference on High Pressure Science and Technology (AIRAPT 2009)	July 26-31, 2009, Tokyo, Japan	2006-FP5-26 2007-FP6-17
58	2009	N. Ozaki, K. Miyanishi, T. Sano, T. Kimura, T. Endo, Fumio Kawamura, A. Hirose, R. Kodama, E. Brambrink, A. Benuzzi-Mounaix, A. Diziere, H. Wei, M. Koenig, Tommaso Vinci, R. Smith, O. Sakata, Youichi Sakawa	Attempts of pressure standard material's isentrope measurement and semiconductor/metal sample recovery using laser-driven ramp compression	16th. American Physical Society Topical Conreference on Shock Compression on Condensed Matter	June 28- July 3, Nashvile, USA	2006-FP5-26 2007-FP6-17
59	2009	T. Kikuchi, K. Horioka	Possible emittance growth due to nonuniform particle distribution in beams with thermal equilibrium condition	Particle Accelerator Conference 2009 (PAC09)	May 4-8, 2009, Vancouver, Canada	2009-FP6-4 2009-FP6-8
60	2009	T. Kikuchi, T. Sasaki, Nob. Harada, A. Namprom, C. Buttapeng, K. Horioka, K. Takayama	Beamline for warm dense matter experiment using the KEK digital accelerator	Particle Accelerator Conference 2009 (PAC09)	May 4-8, 2009, Vancouver, Canada	2009-FP6-4 2009- FP6-8
61	2009	M.Murakami, H.Nagatomo	Progress on impact ignition	7th Direct Drive and Fast Ignition Workshop	Nov 2-6, 20090, Washington DC, USA	2009-FP6-3
62	2009	T. Kikuchi and K. Horioka	Possible Emittance Growth due to Nonuniform Particle Distribution in Beams with Thermal Equilibrium Condition	Particle Accelerator Conference 2009 (PAC09)	May 4-8, 2009, Vancouver, Canada	2008-FP6-1
63	2009	T. Kikuchi, T. Sasaki, Nob. Harada, A. Namprom, C. Buttapeng, K. Horioka and K. Takayama	Beamline for Warm Dense Matter Experiment Using the KEK Digital Accelerator	Particle Accelerator Conference 2009 (PAC09)	May 4-8, 2009, Vancouver, Canada	2008-FP6-1

64	2009	S. Kawata	Efficient Laser Ion Beam Generation	The 7th Direct Drive and Fast Ignition Workshop	May 3-6, 2009, Prague, Czech Republic	2008-FP6-1
65	2009	S. Kawata, Y. Nodera, K. Takahashi, Y. Ma, Z. Sheng, O. Klimo, J. Limpouch, Q. Kong, A. Andreeve and P. Wang	Efficient Laser Ion acceleration in an Intense-Short Pulse Laser Foil Interaction	The 8th Pacific Rim Conference on Lasers and Electro-Optics	Aug. 31-Sep. 3, 2009, Shanghai, China	2008-FP6-1
66	2009	J. Hasegawa, Y. Oguri, K. Horioka, T. Kikuchi, T. Sasaki, S. Kawata and K. Takayama	A Beam-Driven Warm-Dense-Matter Experiment Using Quasi-Isentropically Compressed Targets	The 6th International Conference on Inertial Fusion Sciences and Applications (IFSA2009)	Sep. 6-11, 2009, San Francisco, CA, USA	2008-FP6-1
67	2009	Noboru Yugami, Takeshi Higashiguchi, and Ryosuke Kodama	Possibility of high power THz radiation via electromagnetically induced transparency at ion acoustic frequency region in laser-produced dense plasmas	SPIE Europe	Apr. 2009, Prague, Czech Republic	2006-FP5-23
68	2009	Takeshi Higashiguchi, Hiromitsu Terauchi, Jin-xiang Bai, Noboru Yugami, and Toyohiko Yatagai	Plasma diagnostics of a capillary plasma using pulse power	SPIE Europe	Apr. 2009, Prague, Czech Republic	2006-FP5-23
69	2009	Takeshi Higashiguchi, Masashi Kudo, Noboru Yugami, and Eiji J. Takahashi	Compression of an ultrashort laser pulse via self-modulation in argon gas	SPIE Europe	Apr. 2009, Prague, Czech Republic	2006-FP5-23

CHAPTER 4 JIFT

1. Journal Paper

No	Year	Authors	Title of Paper	Journal	Vol. (Year) Page (Start) -Page(End) or Identification No.	Year-Category-No.
1	2000	W. C. Chou, R. Matsumoto, T. Tajima, M. Umekawa, and K. Shibata	Dynamics of the Parker-Jeans instability in a galactic gaseous disk	Ap. J.	538 (2000) 710-727	2000-JF1-06
2	2000	N. Mizuguchi, T. Hayashi, and T. Sato	Convective loss of heat energy excited in the edge region of spherical tokamak	Contributions to Plasma Physics	40-3-4 (2000) 316-321	2000-JF1-07
3	2000	N.N. Gorelenkov, S. Bernabei, C. Z. Cheng, K. Hill, R. Nazikian, S. Kaye, Y. Kusama, G. J. Kramer, K. Shinohara, T. Ozeki, and M. V. Gorelenkova	Stability properties of toroidal Alfvén modes driven by fast particles	Nucl. Fusion	40-7 (2000) 1311-1323	2000-JF2-05
4	2000	S. M. Mahajan and Z. Yoshida	A collisionless self-organizing model for the high-confinement (H-mode) boundary layer	Phys. Plasmas	7-2 (2000) 635-649	2000-JF1-01
5	2000	G. Rewoldt, L.-P. Ku, W. M. Tang, H. Sugama, N. Nakajima, K. Y. Watanabe, S. Murakami, H. Yamada, and W. A. Cooper	Drift mode calculations for the Large Helical Device	Phys. Plasmas	7 (2000) 4942-4297	2000-JF1-04
6	2000	H. Sugama	Gyrokinetic field theory	Phys. Plasmas	7 (2000) 466-480	2000-JF2-06
7	2000	A. Zhidkov, A. Sasaki, and T. Tajima	Emission of MeV multiple-charged ions from metallic foils irradiated with an ultrashort laser pulse	Phys. Rev. E	61-3 (2000) R2224-R2227	2000-JF1-06
8	2000	A. Zhidkov, A. Sasaki, T. Utsumi, I. Fukumoto, T. Tajima, et al.	Prepulse effects on the interaction of intense femtosecond laser pulses with high-Z solids	Phys. Rev. E	62-5 (2000) 7232-7240	2000-JF1-06
9	2000	A. Zhidkov, A. Sasaki, and T. Tajima	Energetic multiple charged ion source on short pulse laser irradiated foils	Rev. Sci. Instr.	71 (2000) 931-934	2000-JF1-06
10	2001	S. Ohsaki, N. Shatashvili, Z. Yoshida and S. M. Mahajan	Magnetofluid coupling: Eruptive events in the Solar Corona	Astrophys. J.	559 (2001) L61-L65	2000-JF1-09
11	2001	Shuichi Ohsaki, Zensho Yoshida, Nana Shatashvili, and Swadesh M. Mahajan	Eruptive events in the solar atmosphere	Institute for Fusion Studies	Report No. IFS-927 (2001)	2000-JF1-01
12	2001	T.-H Watanabe, H. Sugama, and T. Sato	A nondissipative simulation method for the drift kinetic equation	J. Phys. Soc. Jpn.	70-12 (2001) 3565-3576	2001-JF2-08
13	2001	Hantao Ji, Jeremy Goodman, and Akira Kageyama	Magnetorotational instability in a rotating liquid metal annulus	Mon. Not. R. Astron. Soc.	325 (2001) L1–L5	2000-JF1-11
14	2001	A. Maluckov, N. Nakajima, M. Okamoto, S. Murakami, and R. Kanno	Statistical properties of the particle radial diffusion in a radially bounded irregular magnetic field	National Institute for Fusion Science	Report No. NIFS-715 (2001)	2001-JF1-10
15	2001	K. Shinohara, Y. Kusama, G. J. Kramer, M. Takechi, A. Morioka, M. Ishikawa, N. Oyama, K. Tobita, T. Ozeki, S. Takeji, S. Moriyama, T. Fujita, T. Oikawa, T. Suzuki, T. Nishitani, T. Kondoh, S. Lee, M. Kuriyama, N. N. Gorelenkov, R. Nazikian, G. Y. Fu, C. Z. Cheng, and A. Fukuyama	Alfvén eigenmodes driven by Alfvénic beam ions in JT-60U	Nucl. Fusion	41 (2001) 603	2001-JF1-05

16	2001	K. Ichiguchi, M. Wakatani, T. Unemura, T. Tatsuno, and B. A. Carreras	Improved stability due to local pressure flattening in stellarators	Nucl. Fusion	41-2 (2001) 181-187	2001-JF1-13
17	2001	B. A. Carreras, V. E. Lynch, K. Ichiguchi, M. Wakatani, and T. Tatsuno	On the application of local asymptotic criteria to stellarator stability	Phy. Plasmas	8-3 (2001) 990-996	2001-JF1-13
18	2001	S. M. Mahajan, R. Miklaszewski, K. I. Nikol'skaya, and N. L. Shatashvili	Formation and primary heating of the solar corona: Theory and simulation	Phys. Plasmas	8-4 (2001) 1340-1357	2000-JF1-01
19	2001	J. Q. Dong, W. Horton, and Y. Kishimoto	Gyrokinetic study of ion temperature gradient instability in vicinity of flux surfaces with reversed magnetic shear	Phys. Plasmas	8-1 (2001) 167-173	2000-JF1-02
20	2001	H. Sugama, T.-H Watanabe, and W. Horton	Collisionless kinetic-fluid closure and its application to the three-mode ion temperature gradient driven system	Phys. Plasmas	8-6 (2001) 2617-2628	2001-JF1-08
21	2001	Z. Yoshida, S. M. Mahajan, S. Ohsaki, M. Iqbal, and N. Shatashvili	Beltrami fields in plasmas: High-confinement mode boundary layers and high beta equilibria	Phys. Plasmas	8-5 (2001) 2125-2131	2001-JF1-09
22	2001	A. G. Zhidkov, A. Sasaki, I. Fukumoto and T. Tajima, et al.	Pulse duration effect on the distribution of energetic particles produced by intense femtosecond laser pulses irradiating solids	Phys. Plasmas	8-8 (2001) 3718-3723	2001-JF2-04
23	2001	F. Volponi, Z. Yoshida, and S. Mahajan	Asymptotic analysis and renormalized perturbation theory of non-Hermitian dynamics	Phys. Rev. E	64 (2001) 026312-1-6	2000-JF1-01
24	2001	T. Tatsuno, V. Berezhiani, and S. M. Mahajan	Vortex solitons: Mass, energy, and angular momentum bunching in relativistic electron-positron plasmas	Phys. Rev. E	63 (2001) 046403-1-7	2000-JF1-01
25	2001	Francesco Volponi, Swadesh M. Mahajan, and Zensho Yoshida	Asymptotic analysis and renormalized perturbation theory of the non-Hermitian dynamics of an inviscid vortex	Phys. Rev. E	64 (2001) 026312	2001-JF1-09
26	2001	T. Tajima, Y. Kishimoto, and T. Masaki	Cluster fusion	Physica Scripta	T89 (2001) 45-48	2001-JF2-04
27	2001	A. Maluckov, N. Nakajima, M. Okamoto, S. Murakami, and R. Kanno	Statistical properties of the neoclassical diffusion in a tokamak equilibrium	Plasma Phys. Control. Fusion	43 (2001) 1211-1226	2001-JF1-10
28	2001	N. N. Gorelenkov, S. Bernabei, C. Z. Cheng, G. Y. Fu, K. Hill, S. Kaye, G. J. Kramer, Y. Kusama, K. Shinohara, R. Nazikian, T. Ozeki, and W. Park	Fast Particle Effects on the Internal Kink, Fishbone and Alfvén Modes	Princeton Plasma Physics Laboratory	Report No. PPPL-3512 (2001)	2000-JF1-05
29	2001	D. R. Mikkelsen, H. Shirai, N. Asakura, T. Fujita, T. Fukuda, T. Hatae, S. Ide, A. Isayama, Y. Kamada, Y. Kawano, Y. Koide, O. Naito, Y. Sakamoto, T. Takizuka, and H. Urano	Correlation between core and pedestal temperatures in JT-60U: Experiment and modeling	Princeton Plasma Physics Laboratory	Report No. PPPL-3512 (2001)	2001-JF1-04
30	2002	S. Ohsaki, N. Shatashvili, Z. Yoshida and S. M. Mahajan	Energy transformation mechanism in the Solar atmosphere associated with magnetofluid Coupling: Explosive and eruptive events	Astrophys. J.	570 (2002) 395-407	2000-JF1-09

31	2002	Swadesh M. Mahajan, Komunela I. Nikol'skaya, Nana L. Shatashvili, and Zensho Yoshida	Generation of flows in the solar atmosphere due to magnetofluid coupling	Astrophys. J.	576 (2002) L161-164	2001-JF1-09
32	2002	Y. Todo, H. L. Berk, and B. N. Breizman	Simulation study of beam ion loss due to Alfvén eigenmode bursts	NIFS	Report No. NIFS-749 (2002)	2001-JF2-05
33	2002	G. Rewoldt, K.W. Hill, R. Nazikian, W.M. Tang, H. Shirai, Y. Sakamoto, Y. Kishimoto, S. Ide, and T. Fujita	Radial patterns of instability and transport in JT-60U internal transport barrier discharges	Nucl. Fusion	42-4 (2002) 403-411	2000-JF1-03
34	2002	W. Horton, F. Porcelli, P. Zhu, A. Aydemir, Y. Kishimoto, and T. Tajima	Ignitor physics assessment and confinement projects	Nucl. Fusion	42 (2002) 169-179	2001-JF1-08
35	2002	K. Shinohara, M. Takechi, M. Ishikawa, Y. Kusama, N. N. Gorelenkov, C. Z. Cheng, A. Morioka, N. Oyama, K. Tobita, T. Ozeki, G. J. Kramer, and R. Nazikian	Recent progress of Alfvén eigenmode experiments using N-NB in JT-60U tokamak	Nucl. Fusion	42 (2002) 942–948	2001-JF2-05
36	2002	G. Rewoldt, L.-P. Ku, W.M. Tang, H. Sugama, N. Nakajima, K. Y. Watanabe, S. Murakami, H. Yamada, and W. A. Cooper	Microinstability studies for the Large Helical Device	Nuclear Fusion	42 (2002) 1047-1054	2001-JF1-06
37	2002	A. Ito, Z. Yoshida, T. Tatsuno, S. Ohsaki, and S.M. Mahajan	Kelvin-Helmholtz instability in Beltrami fields	Phys. Plasmas	9-12 (2002) 4856-4862	2001-JF1-09
38	2002	Y. Kishimoto, T. Masaki, and T. Tajima	High energy ions and nuclear fusion in laser-plasma interaction	Phys. Plasmas	9 (2002) 589-601	2001-JF2-04
39	2002	V. I. Berezhiani, S. M. Mahajan, Z. Yoshida, and M. Pekker	Dynamics of self-trapped singular beams in an underdense plasma	Phys. Rev. E	65-4 (2002) 046415	2001-JF1-09
40	2002	Z. Yoshida and S. M. Mahajan	Variational principles and self-organization in two-fluid plasmas	Phys. Rev. Lett.	88-9 (2002) 095001-1-4	2001-JF1-09
41	2002	V. I. Berezhiani, S. M. Mahajan, Z. Yoshida, and M. Ohhashi	Self-trapping of strong electromagnetic beams in relativistic plasmas	PHYSICAL REVIEW E	65 (2002) 047402	2000-JF1-01
42	2003	Oleg Batishchev, Ritoku Horiuchi	Scope of Simulation Science	a special issue of Computer Physics Communications Journal (UK) http://web.mit.edu/ned/ICNSP/abstracts.html	about 75 refereed articles (400 pages)	2003-JF1-05
43	2003	Z. Yoshida, S. Ohsaki, A. Ito, and S. M. Mahajan	Stability of Beltrami flows	J. Math. Phys.	44 (2003) 2168	2003-JF1-10
44	2003	M. Yagi	Report of US-Japan JIFT Workshop on Structures and Self-Organization in Turbulent Plasmas and Fluids	Journal of Plasma and Fusion Research	79 (2003) 1197	2003-JF1-06
45	2003	D. R. Mikkelsen, H. Shirai, H. Urano, T. Takizuka, Y. Kamada, T. Hatae. Y. Koide, N. Asakura, T. Fujita, T. Fukuda, S. Ide, A. Isayama, Y. Kawano, O. Naito, and Y. Sakamoto	Stiff temperature profiles in JT-60U ELMy H-mode plasmas	Nucl. Fusion	43 (2003) 30	2001-JF1-04

46	2003	H. Takenaga, S. Higashijima, N. Oyama, L.G. Bruskin, Y. Koide, S. Ide, H. Shirai, Y. Sakamoto, T. Suzuki, K.W. Hill, G. Rewoldt, G.J. Kramer, R. Nazikian, T. Takizuka, T. Fujita, A. Sakasai, Y. Kamada, H. Kubo, and JT-60 Team	Relationship between particle and heat transport in JT-60U plasmas with internal transport barrier	Nuclear Fusion	43 (2003) 1235-1245	2000-JF1-04
47	2003	H. Sugama, T.-H. Watanabe, and W. Horton	Comparison between kinetic and fluid simulations of slab ion temperature gradient driven turbulence	Phys. Plasmas	10 (2003) 726	2001-JF2-08 2002-JF2-2 2002-JF2-10
48	2003	H. Sugama, T.-H. Watanabe, and W. Horton	Comparison between kinetic and fluid simulations of slab ion temperature gradient driven turbulence	Phys. Plasmas	10 (2003) 726-736	2002-JF1-10
49	2003	Y. Todo, H. L. Berk, and B. N. Breizman	Simulation of intermittent beam ion loss in a Tokamak Fusion Test Reactor experiment	Physics of Plasmas	10-7 (2003) 2888-2902	2000-JF1-09
50	2004	R. Horiuchi, H. Ohtani, and A. Ishizawa	Structure formation and dynamical behavior of kinetic plasmas controlled by magnetic reconnection	Computer Physics Communications	164 (2004) 17-32	2004-JF1-16
51	2004	Steve Jardin, Atsushi Fukuyama	Theory-Based Modeling and Integrated Simulation of Burning Plasma (Ⅱ)	http://w3.pppl.gov/usjapanim		2004-JF1-09
52	2004	Noriyoshi Nakajima, Donald Monticello	Progress of Theoretical Analyses in Three Dimensional Configuration	http://www.center.iae.kyoto-u.ac.jp/kondok/meetings/jift/presentations.html		2004-JF1-01
53	2004	Guoyong Fu, Yasushi Todo	Physics of Energetic Particles	http://www.mfescience.org/TTF2005/		2004-JF1-08
54	2004	Y. Todo, H. L. Berk, and B. N. Breizman	Energetic ion transport due to Alfvén eigenmode bursts	Journal of Plasma and Fusion Research SERIES	6 (2004) 69–73	2004-JF1-12
55	2004	S. Ohsaki and S. M. Mahajan	Hall current and Alfvén wave	Phys. Plasmas	11 (2004) 898	2003-JF1-10
56	2004	E. Hameiri and R. Torasso	Linear stability of static equilibrium states in the Hall-magnetohydrodynamics model	Phys. Plasmas	11 (2004) 4934	2004-JF1-05
57	2004	C. Chiu, W. Horton, and Y. Ohsawa	Large acceleration of electrons by the microstructure of quasi-normal shocks	Phys. Plasmas	submitted for publication	2004-JF1-14
58	2004	S. I. Krasheninnikov, Y. Tomita, R. D. Smirnov, and R. K. Janev	On dust dynamics in tokamak edge plasmas	Physics of Plasmas	11 (2004) 3141 (10p)	2003-JF1-04
59	2004	E. Hameiri	Linear Stability of a Hall-MHD Equilibrium with Discontinuity		to be submitted for publication	2004-JF1-05
60	2005	J. Ramos et al.		Bull. Am. Phys. Soc.	50-8 (2005) UP1-5	2005-JF1-05
61	2005	Atsushi Fukuyama, Steven Jardin	Integrated Modeling of Multi-Scale Physics in Fusion Plasmas	http://pbsi.nucleng.kyoto-u.ac.jp/bpsi/usjws3/index.html		2005-JF1-02
62	2005	Donald Monticello, Noriyoshi Nakajima	Issues in Theoretical Analyses for Three Dimensional Configurations	http://w3.pppl.gov/~shudson/JIFT/2006/JIFT2006.html		2005-JF1-06

63	2005	Ritoku Horiuchi, Oleg Batishchev	New Development of Simulation Science	http://www.tcsc.nifs.ac.jp/icnsp/US-JapanSimulationWorkshop.html.		2005-JF1-03
64	2005	M. S. Chu and K. Ichiguchi	Effect of the Resistive Wall on the Growth Rate of Weakly Unstable External Kink Mode in General 3D Configurations	Nucl. Fusion	45 (2005) 804–813	2004-JF1-06
65	2005	E. Hameiri, A. Ishizawa, and A. Ishida	Waves in the Hall-Magnetohydrodynamics Model	Phys. Plasmas	12-7 (2005) 072109-1-13	2004-JF1-05
66	2005	R. Nazikian, K. Shinohara, G.J. Kramer, E. Valeo, K. Hill, T.S. Hahm, G. Rewoldt, S. Ide, Y. Koide, Y. Oyama, H. Shirai, W. Tang	Measurement of Turbulence Decorrelation during Transport Barrier Formation in a High Temperature Fusion Plasma	Phys. Rev. Lett.	94 (2005) 135002	2004-JF1-04
67	2005	P. H. Diamond, S.-I. Itoh, K. Itoh and T. S. Hahm	Zonal Flows in Plasma—A Review	Plasma Physics and Controlled Fusion	47 (2005) R35-R161	2003-JF1-05
68	2005	Ritoku Horiuchi, Oleg Batishchev	New Development of Simulation Science	special issue of Journal of Plasma Physics (UK)	include about 120 refereed articles	2005-JF1-03
69	2006	Noriyoshi Nakajima, Donald A. Spong	Progress of Extended MHD Models	http://www.dss.nifs.ac.jp/todo/US-Japan2007/		2006-JF1-01
70	2006	H. Miura, N. Nakajima, T. Hayashi, and M. Okamoto	Vortical toroidal and compressible motions in 3D MHD simulations of LHD	J. Plasma Phys	72 (2006) 1095-1099	2005-JF1-10
71	2006	K. Ichiguchi and B. A. Carreras	Multi-Scale Approach to the Solution of Nonlinear MHD Evolution of Heliotron Plasma	Journal of Plasma Physics	72 (2006) 1117-1121	2005-JF1-10
72	2006	S. Murakami et al.	A global simulation study of ICRF heating in the LHD	Nucl. Fusion	46 (2006) S425~S432	2005-JF1-08
73	2007	H. Miura, N. Nakajima, T. Hayashi and M. Okamoto	Nonlinear Evolution of MHD Instability in LHD	Fusion Science and Technology	51 (2007) 8-19	2005-JF1-10
74	2007	F. L. Waelbroeck, J. W. Van Dam, Ritoku Horiuchi	Numerical simulation of complex plasmas	http://workshops.ph.utexas.edu/ssw/index.php		2007-JF1-7
75	2007	Donald B. Batchelor, Atsushi Fukuyama	Integrated Modeling of Multi-Physics in Fusion Plasmas Ⅱ	http://www.cswim.org/meetings/us-japan-2007/		2006-JF1-06
76	2007	D. A. Spong, J. H. Harris, A. S. Ware, S. P. Hirshman and L. A. Berry	Shear Flow Generation in Stellarators–Configurational Variations	Nucl. Fusion	47 (2007) 626-633	2006-JF1-04
77	2007	S. Toda, K. Itoh, A. Fujisawa, S.-I. Itoh, M. Yagi, A. Fukuyama, P.-H. Diamond, and K. Ida	Transport analysis of the effect of zonal flows on electron internal transport barriers in toroidal helical plasmas	Nucl. Fusion	47 (2007) 914-919	2007-JF1-11
78	2007	M. Furukawa and L.-J. Zheng	Alfven resonance effect on the error-field-induced magnetic islands in rotating plasmas	Nucl. Fusion	submitted	2007-JF1-5
79	2007	A. Ito, J.J. Ramos and N. Nakajima	Ellipticity of axisymmetric equilibria with flow and pressure anisotropy in single-fluid and Hall magnetohydrodynamics	Phys. Plasmas	14 (2007) 062502	2005-JF1-05

80	2007	T. Nakamura, K. Mima, H. Sakagami, and T. Johzaki	Electron surface acceleration on a solid capillary target inner wall irradiated with ultra-intense laser pulses	Phys. Plasmas	14 (2007) 053112	2006-JF1-02 2007-JF1-02 2007-JF1-10
81	2007	B. N. Rogers, S. Kobayashi, P. Ricci, W. Dorland, J. Drake, and T. Tatsuno	Gyrokinetic Simulations of Collisionless Magnetic Reconnection	Physics of Plasmas	14 (2007) 092110-092110-10	2006-JF1-03
82	2007	H. Sugama, T.-H. Watanabe, and W. Horton	Collisionless kinetic-fluid model of zonal flows in toroidal plasmas	Physics of Plasmas	14-2 (2007) 022502-1-18	2007-JF2-7
83	2007	T. Nakamura, K. Mima, et al.	Electron surface interaction on a solid capillary inner surface irradiated with ultra-intense laser pulses	Physics of Plasmas	to be published	2006-JF1-02
84	2008	R. Kanno, M. Nunami, S. Satake, H. Takamaru and M. Okamoto	Transport Modeling of Edge Plasma in an m/n=1/1 Magnetic Island	Contributions to Plasma Physics	48 (2008) 106-110	2006-JF1-13
85	2008	Gennady Shvets, and Kunioki Mima	Theory and Simulation on Ultra-Intense Laser Plasmas	http://peaches.ph.utexas.edu/ifs/jift2008-intenselaser.html		2008-JF1-3
86	2008	Alex Arefiev, Hiroaki Ohtani	Progress of Multi-Scale Simulation Models	http://peaches.ph.utexas.edu/ifs/jift2008-simulationmodels.html		2008-JF1-1
87	2008	Y. Todo, G. Y. Fu	Energetic Particle Physics in Toroidal Plasmas	http://www.dss.nifs.ac.jp/todo/US-Japan2008		2008-JF1-9
88	2008	S. M. Mahajan and H. Miura	Linear superposition of nonlinear wave	J. Phys. Plasmas	10 (2008) 1-8	2005-JF1-10
89	2008	G. Kawamura and A. Fukuyama	Refinement of the gyrokinetic equations for edge plasmas with large flow shear	Phys. Plasmas	15 (2008) 042304	2006-JF1-06
90	2008	T. Cho, V. P. Pasthukov, W. Horton, T. Mumakura, M. Hirata, J. Kohagura, N. V. Chudin, and J. Pratt	Active Control of Internal Transport Barrier Formation Due to Off-Axis Electron-Cyclotron Heating in Gamma 10 Experiments	Phys. Plasmas	15 (2008) 056120	2008-JF1-12
91	2008	Y. Todo, N. Nakajima, M. Osakabe, S. Yamamoto, and D. A. Spong	Simulation Study of Energetic Ion Transport due to Alfven Eigenmodes in LHD Plasma	Plasma and Fusion Research	3 (2008) S1074	2006-JF1-04
92	2008	R. Kanno, M. Nunami, S. Satake, H. Takamaru, Y. Tomita, K. Nakajima, M. Okamoto and N. Ohyabu	Monte-Carlo Simulation of Neoclassical Transport in Magnetic Islands and Ergodic Regions	Plasma and Fusion Research	3 (2008) S1060	2006-JF1-13
93	2008	K. Ichiguchi and B. A. Carreras	Mercier Stability Improvement in Nonlinear Development of LHD Plasma	Plasma and Fusion Research	3 (2008) S1033	2007-JF1-09
94	2008	T.-H. Watanabe, Y. Todo, and W. Horton	Benchmark Tests of Fusion Plasma Simulation Codes for Studying Microturbulence and Energetic-Particle Dynamics	Plasma and Fusion Research	3 (2008) 061	2008-JF1-12

95	2009	Y. Todo, S. Murakami, T. Yamamoto, A. Fukuyama, D. A. Spong, S. Yamamoto, M. Osakabe, and N. Nakajima	Numerical Analyses of Energetic Particles in LHD	Fusion Science and Technology	submitted	2008-JF1-9
96	2009	K. Toi, M. Isobe, M. Osakabe, F. Watanabe, K. Ogawa, S. Yamamoto, N. Nakajima, D.A. Spong, K. Ida, T. Ido, T. Ito, S. Morita, K. Nagaoka, K. Narihara, M. Nishiura, S. Ohdachi, S. Sakakibara, A. Shimizu, K. Tanaka, Y. Todo, T. Tokuzawa, A. Weller and LHD Experiment Group	MHD Modes Destabilized by Energetic Ions on LHD	Fusion Science and Technology	submitted	2008-JF1-9
97	2009	H. Ohtani and A. Arefiev	Advanced Simulation Methods in Plasmas	http://www.dss.nifs.ac.jp/ohtani/JIFT2009/		2009-JF-8
98	2009	K. Ichiguchi and B. A Carreras	Multi-Scale MHD Simulation Incorporating Pressure Transport Equation for LHD Plasmas	J. Plasma Fusion Res. SERIES	8 (2009) 1171-1175	2007-JF1-9
99	2009	H. Ohtani, W. Horton, T. Petrosky, and R. Horiuchi	Energy Conversion in Magnetic Reconnection with Chaos Diffusion	J. Plasma Fusion Res. SERIES	8 (2009) 203-207	2008-JF1-12
100	2009	Y. Nagashima, S.-I. Itoh, K. Itoh, A. Fujisawa, S. Inagaki, Y. Kawai, S. Shinohara, M. Fukao, T. Yamada, K. Terasaka, T. Maruta, K. Kamatak, H. Arakawa, M. Yagi,N. Kasuya, G. Tynan, P. H. Diamond, and Y. Takase	Reynolds Stress Measurements for Investigation of Nonlinear Processes of Turbulence in the Large Mirror Device and in the Large Mirror Device-Upgrade	J. Plasma Fusion Res. SERIES	8 (2009) 50-54	2009-JF-2
101	2009	D. A. Spong, Y. Todo, M. Osakabe, L. Berry, B. N. Breizman, D. L. Brower, C. B. Deng, A. Konies, E. D'Azevedo	Energetic particle physics issues for three-dimensional toroidal configurations	Nucl. Fusion	submitted	2006-JF1-04
102	2009	M. Furukawa and L. J. Zheng	Suppression of error-field-induced magnetic islands by Alfvén resonance effect in rotating plasmas	Nuclear Fusion	49 (2009) 075018 (6 pp)	2008-JF1-6
103	2009	T. S. Hahm, Lu Wang, and J. Madsen	Fully electromagnetic nonlinear gyrokinetic equations for tokamak edge turbulence	Phys. Plasmas	16 (2009) 022305	2007-JF1-1
104	2009	M. Furukawa, S. Tokuda, and L. J. Zheng	A numerical matching technique for resistive magnetohydrodynamics modes	Phys. Plasmas	17 (2010) 052502	2008-JF1-6
105	2009	H.B. Cai, K. Mima, W.M. Zhou, T. Jozaki,1 H. Nagatomo, A. Sunahara, R.J. Mason	Enhancing the Number of High-Energy Electrons Deposited to a Compressed Pellet via Double Cones in Fast Ignition	Phys. Rev. Lett.	102 (2009) 245001	2009-JF-7
106	2009	S. Takahashi, H. Kawai, Y. Ohsawa, S. Usami, C. Chiu, and W. Horton	The effect of parallel electric field in shock waves on the acceleration of relativistic ions, electrons, and positrons	Physics of Plasmas	16-11 (2009) 112308-1-10	2009-JF-3
107	2009	A. Arefiev	Generation of fast ions by microclusters	Plasma and Fusion Research	accepted for publication	2009-JF-10
108	2009	T. Johzaki, Y. Sentoku, et al.	Core heating properties in FIREX-I - influence of cone tip	Plasma Phys. Control. Fusion	51 (2009) 014002 (15pp)	2009-JF-5

109	2010	D. A. Spong, B. N. Breizman, D.L. Brower, E. D'Azevedo, C. B. Deng, A. Konies, Y. Todo, and K. Toi	Energetic particle-driven instabilities in general toroidal configurations	Contributions to Plasma Physics	50 (8) (2010) 708-712	2006-JF1-1
110	2010	K. Toi, M. Isobe, M. Osakabe, K. Ogawa, D. Spong, Y. Todo, and LHD Experiment Group	Overview of Studies on Energetic Ion Driven MHD Instabilities in Stellarator/Helical Plasmas and Comparison with Tokamaks	Contributions to Plasma Physics	50 (6-7) (2010) 493-500	2006-JF1-1
111	2010	Paul Bonoli and Atsushi Fukuyama	Integrated Modeling and Simulation in Toroidal Plasmas	http://www.psfc.mit.edu/JIFT09/JIFT09.html		2009-JF-1
112	2010	D. A. Spong, E. D'Azevedo, and Y. Todo	Clustered frequency analysis of shear Alfvén modes in stellarators	Physics of Plasmas	17 (2010) 022106	2006-JF1-1
113	2010	M. Natata, T.-H. Watanabe, H. Sugama, and W. Horton	Formation of coherent vortex streets and transport reduction in electron temperature gradient driven turbulence	Physics of Plasmas	17-4 (2010) 042306-1-13	2008-JF1-12
114	2010	S. R. Hudson and N. Nakajima	Pressure, chaotic magnetic fields and MHD equilibria	Physics of Plasmas	17 (2010) 052511	2009-JF-9
115	2010	K. Saito, K. Ichiguchi, and N. Ohyabu	Interaction between static magnetic islands and interchange modes in a straight heliotron plasma with high resistivity	Phys. Plasmas	17, 6 (2010) 062504-1-14	2007-JF1-9

2. Conference Paper

No	Year	Authors	Title of Paper	Conference Name	Month Date, Year, Place, Country	Year-Category-No.
1	2000	Y. Todo, T.-H. Watanabe, H.-B. Park, and T. Sato	Fokker-Planck Simulation Study of Alfvén Eigenmode Burst	18th IAEA Fusion Energy Conference	October 4-10, 2000, Sorrento, Italy	2000-JF1-09
2	2000	N. N. Gorelenkov, S. Bernabei, C. Z. Cheng, G. Y. Fu, K. Hill, S. Kaye, G. J. Kramer, Y. Kusama, K. Shinohara, R. Nazikian, T. Ozeki, and W. Park	Fast Particle Effects on the Internal Kink, Fishbone and Alfvén Modes	The 18th International Conference on Plasma Physics and Controlled Nuclear Fusion Research	October 4-10, 2000, Sorrento, Italy	2000-JF1-05
3	2001	Y. Todo and T. Sato	Kinetic-magnetohydrodynamic simulation study of fast ions and toroidal Alfvén eigenmode	The 17th Conference	October 18-24, 1998, Yokohama Japan (IAEA, Vienna, 1999)	2000-JF1-05
4	2001	C. Z. Cheng, N. N. Gorelenkov, G. J. Kramer, R. Nazikan, Y. Kusama, K. Shinohara, and T. Ozeki	N-NBI excitation of frequency chirping modes in JT-60U experiments	The 7th IAEA Technical Committee Meeting on Energetic Particles in Magnetic Confinement Systems	October 8-11, 2001, Gothenberg, Sweden	2001-JF2-05
5	2001	K. Shinohara, M. Takechi, M. Ishikawa, Y. Kusama, N. N. Gorelenkov, C. Z. Cheng, A. Morioka, N. Oyama, K. Tobita, T. Ozeki, G. J. Kramer, and R. Nazikian	Recent progress of Alfvén eigenmode experiments using NNB in JT-60U tokamak	The 7th IAEA Technical Committee Meeting on Energetic Particles in Magnetic Confinement Systems	Oct. 8-11, 2001, Gothenberg, Sweden	2001-JF2-05
6	2002	S. M. Mahajan, R. D.Hazeltine, and Z. Yoshida	General Fluid Theories, Variational Principles and Self-Organization	19th IAEA Fusion Energy Conference	October 14-19, 2002, Lyon, France	2001-JF1-09
7	2002	Y. Todo, H. L. Berk, and B. N. Breizman	Simulation study of beam ion loss due to Alfvén eigenmode bursts	19th IAEA Fusion Energy Conference	October 14-19, 2002, Lyon, France	2002-JF2-19

8	2002	H. Naitou, T. Kobayashi, M. Yagi, T. Matsumoto, S. Tokuda, Y. Kishimoto, and J.-N. Leboeuf	Interaction between MHD modes and vortexes	6th Kyushu-Okinawa-Yamaguchi Branch Division Meeting of Japan Society of Plasma Science and Nuclear Fusion Research	December 13, 2002, Saga, Japan	2001-JF2-01
9	2002	Y. Sakamoto, T. Suzuki, S. Ide, Y. Koide, H. Takenaga, Y. Kamada, T. Fujita, T. Fukuda, T. Takizuka, H. Shirai, N. Oyama, Y. Miura, K.W. Hill, G. Rewoldt, and JT-60 Team	Properties of Internal Transport Barrier Formation in JT-60U	The 19th International Atomic Energy Agency's (IAEA) Fusion Energy Conference 2002 (CN-94)	October 14-19, 2002, Lyon, France	2000-JF1-04
10	2002	H. Takenaga, S. Higashijima, N. Oyama, L.G. Bruskin, Y. Koide, S. Ide, H. Shirai, Y. Sakamoto, T. Suzuki, K.W. Hill, G. Rewoldt, G.J. Kramer, R. Nazikian, T. Takizuka, T. Fujita, A. Sakasai, Y. Kamada, H. Kubo, and JT-60 Team	Relationship between particle and heat transport in JT-60U plasmas with internal transport barrier	The 19th International Atomic Energy Agency's (IAEA) Fusion Energy Conference 2002 (CN-94)	October 14-19, 2002, Lyon, France	2000-JF1-04
11	2002	K.W. Hill, D.R. Ernst, D. Mikkelsen, G. Rewoldt, S. Higashijima, N. Asakura, H. Shirai, T. Takizuka, S. Konoshima, Y. Kamada, H. Kubo, and Y. Miura	Study of Integrated High-Performance Regimes with Impurity Injection in JT-60U Discharges	The 19th International Atomic Energy Agency's (IAEA) Fusion Energy Conference 2002 (CN-94)	October 14-19, 2002, Lyon, France	2001-JF1-04
12	2002	H. Yamada, S. Murakami, et al.	Response of Density and Temperature Profiles to Heat Deposition Profile and Its Impact on Global Scaling in LHD	The 19th International Atomic Energy Agency's (IAEA) Fusion Energy Conference 2002 (CN-94)	October 14-19, 2002, Lyon, France	2002-JF2-02 2002-JF2-07
13	2002	M. Yokoyama, K. Itoh, S. Okamura, K. Matsuoka, N. Nakajima, S.-I. Itoh, G.H. Neilson, M.C. Zarnstorff, and G. Rewoldt	Drift Reversal Capability in Helical Systems	The 19th International Atomic Energy Agency's (IAEA) Fusion Energy Conference 2002 (CN-94)	October 14-19, 2002, Lyon, France	2002-JF2-20 2002-JF2-8
14	2003	Ishida, H. Caesar, L. C. Steinhauer, and Y.-K. M. Peng	Improved Formalism for Flowing Two-Fluid Equilibrium and Its Application to ST	The 13th International Toki Conference on Plasma Physics and Controlled Nuclear Fusion	December 9-12, 2003, Toki, Japan	2003-JF1-03
15	2003	S. I. Krasheninnikov, D. D. Ryutov, and G. Yu	Large plasma pressure perturbations and radial convective transport in a tokamak	The 13th International Toki Conference on Plasma Physics and Controlled Nuclear Fusion	December 9-12, 2003, Toki, Japan	2003-JF1-04
16	2003	T.-H. Watanabe, H. Sugama, W. Horton, and H.V. Wong	A non-dissipative closure model for mirror instability in a collisionless plasma	The 2003 International Sherwood Fusion Theory Conference	April 28-30, 2003, Texas, USA	2002-JF1-10
17	2003	S. I. Krasheninnikov	Blobs in edge plasmas	The Meeting on Advances in Nonlinear Fluid and Plasma Dynamics	December 3-4, 2003, Kyushu University, Japan	2003-JF1-04
18	2003	S. I. Krasheninnikov, Y. Tomita, R. D. Smirnov, and R. K. Janev	On dust dynamics in tokamak edge plasmas	The US-Japan JIFT Workshop on Theory-based Modeling and Integrated Simulation of Burning Plasmas	December 15-17, 2003, Kyoto, Japan	2003-JF1-04

19	2003	H. Naitou, J.-N. Leboeuf, H. Nagahara, T. Kobayashi, M. Yagi, T. Matsumoto, S. Tokuda	Vortex Generation and Collisionless Internal Kink Mode in Tokamaks	U.S.-Japan Joint Institute for Fusion Theory Workshop on Structures and Self-Organization in Turbulent Plasmas and Fluids	September 19, 22-23, 2003, San Diego, USA	2003-JF1-08
20	2004	A. Fukuyama et al.	Advanced Transport Modeling of Toroidal Plasmas with Transport Barriers	20th IAEA Fusion Energy Conference	November 1-6, 2004, Vilamoura, Portugal	2004-JF1-09
21	2004	M. Yagi, S. Yoshida, S.-I. Itoh, H. Naitou, H. Nagahara, J.-N. Leboeuf, K. Itoh, T. Matsumoto, S. Tokuda, and M. Azumi	Nonlinear simulation of tearing mode and m=1 internal kink mode based on kinetic RMHD model	The 20th IAEA Fusion Energy Conference	November 1-6, 2004, Vilamoura, Portugal	2003-JF1-08
22	2006	K. Ichiguchi and B. A. Carreras	Multi-Scale Simulation of Heliotron Plasma	Joint Workshop of NIFS Cooperative Programs 2006 for MHD Theory and Related Topics	September 14-15, 2006, Toki, Japan	2006-JF2-08
23	2007	H. Ohtani, R. Horiuchi, and W. Horton	Three dimensional particle simulations of driven magnetic reconnection	2007 International Sherwood Fusion Theory Conference	April 23-25, 2007, Annapolis, USA	2006-JF1-12
24	2007	H. Ohtani, R. Horiuchi, W. Horton, and T. Petrosky	Energy release between fields and particles, and change of velocity distribution in collisionless driven reconnection	2007 US-Japan Workshop on Magnetic Reconnection	March 26-29, 2007, St.Michaels, USA	2006-JF1-12
25	2007	H. Ohtani, R. Horiuchi, and W. Horton	Dynamics of magnetic dissipation region in collisionless driven reconnection in open system	20th International Conference on Numerical Simulation of Plasmas	October 10-12, 2007, Austin, USA	2006-JF1-12
26	2007	J. Pratt and W. Horton	Drift Waves and Stability in the GAMMA-10	49th American Physical Society Division of Plasma Physics Annual Meeting	November 12-16, 2007, Orlando, USA	2007-JF1-4
27	2007	J. Pratt, W. Horton, J-H. Kim, and H. L. Berk	Drift Wave Fluctuation in Tandem Mirrors with Anchor Cells and Sheared Flows	International Sherwood Fusion Theory Conference	April 23–25, 2007, Annapolis, USA	2007-JF1-4
28	2007	R. Kanno, M. Nunami, S. Satake, H. Takamaru and M. Okamoto	Transport Modeling of Edge Plasma in an m/n=1/1 Magnetic Island	The 11th International Workshop on Plasma Edge Theory in Fusion Devices	23-25 May 2007, Takayama, Japan	2006-JF1-13
29	2007	R. Kanno, M. Nunami, S. Satake, H. Takamaru, Y. Tomita, K. Nakajima, M. Okamoto and N. Ohyabu	Monte-Carlo Simulation of Neoclassical Transport in Magnetic Islands and Ergodic Regions	The Joint Conference of 17th International Toki Conference (ITC) on Physics of Flows and Turbulence in Plasmas and 16th International Stellarator/Heliotron Workshop (ISHW) 2007	15-19 October 2007, Toki, Japan	2006-JF1-13
30	2007	W. Horton, J.-H. Kim, E. Asp, T. Hoang, T.-H. Watanabe, and H. Sugama	Drift Wave Turbulence	Turbulent Transport in Fusion Plasmas, First ITER International Summer School	July 16-20, 2007,Aix-en-Provence, France	2007-JF1-1
31	2007	Atsushi Ito, Jesus. J. Ramos, and Noriyoshi Nakajima	High-beta axisymmetric equilibria with flow in reduced single-fluid and two-fluid models	Workshop of NIFS Cooperative Programs 2007 ‘Progress of MHD Theory and Related Topics’	1-2 November, 2007, Toki, Japan	2005-JF1-05
32	2007	Noriyoshi Nakajima, Satoru Sakakibara, Kiyomasa Watanabe, Stuart Hudson, and Chris Hegna	Analysis of MHD stability in high-beta plasmas in LHD	Workshop of NIFS Cooperative Programs 2007 ‘Progress of MHD Theory and Related Topics’	1-2 November, 2007, Toki, Japan	2005-JF1-06

33	2007	K. Ichiguchi and B. A Carreras	Mercier Stability Improvement in Nonlinear Development of Heliotron Plasma	Workshop of NIFS Cooperative Programs 2007 'Progress of MHD Theory and Related Topics'	1-2 November, 2007, Toki, Japan	2007-JF1-09
34	2008	M. Furukawa, S. Tokuda, and L.-J. Zheng	Tearing mode stability analysis via a new numerical matching technique for resistive MHD	50th Annual Meeting of the Division of Plasma Physics, American Physical Society	November 17-21, 2008, Dallas, USA	2008-JF1-6
35	2008	H. Ohtani, W. Horton. T. Petrosky, and R. Horiuchi	Energy Conversion in Magnetic Reconnection with Chaos Diffusion	2008 International Congress on Plasma Physics	September 8-12, 2008, Fukuoka, Japan	2006-JF1-12
36	2008	H. Ohtani, R. Horiuchi, W. Horton, and T. Petrosky	Energy release in Magnetic Reconnection with Chaos Diffusion	2008 International Sherwood Fusion Theory Conference	March 30 - April 2, 2008, Boulder, USA	2006-JF1-12
37	2008	A. H. Glasser	Preconditioning and Scalability of Implicit Extended MHD Plasma Simulation by FEETI-DP Domain Substructuring	20th International Conference on Numerical Simulation of Plasmas	October 10-12, 2008, Austin, USA	2007-JF1-6
38	2008	Y. Todo, M. Osakabe, et al	Simulation Study of Interaction between Energetic Ions and Alfven Eigenmodes in LHD	22nd IAEA Fusion Energy Conference	October 13-18, 2008, Geneva, Switzerland	2008-JF1-9
39	2008	M. Furukawa and L.-J. Zheng	Suppression of error-field-induced magnetic islands by Alfvén resonance e ffect in rotating plasmas	22th IAEA Fusion Energy Conference	Oct. 13-18, 2008, Geneva, Swizerland	2008-JF1-6
40	2008	T. Johzaki, Y. Sentoku, H. Sakagami, H. Nagatomo, K. Mima, and Y. Nakao	Core Heating Properties in FIREX-I – Influence of Cone Tip	35th European Physical Society Plasma Physics Conference	June 09-13, 2008, Crete, Greece	2007-JF1-10
41	2008	H. Ohtani, W. Horton. T. Petrosky, and R. Horiuchi	Role of Chaotic Orbits of Meandering Particles in Magnetic Reconnection	50th Annual Meeting of the Division of Plasma Physics, American Physical Society	November 17-21, 2008, Dallas, USA	2008-JF1-12
42	2008	K. Uzawa, T. H. Watanabe, H. Sugama, N. Nakajima, and W. Horton	Zonal Flows from Parametric Decays in ITG Turbulence and the Internal Gravity Wave Paradigm	50th Annual Meeting of the Division of Plasma Physics, American Physical Society	November 17-21, 2008, Dallas, USA	2008-JF1-12
43	2008	M. Nakata, T. H. Watanabe, and W. Horton	Gyrokinetic Analysis of Vortex Structures and Distribution Functions in Slab ETG Turbulence	50th Annual Meeting of the Division of Plasma Physics, American Physical Society	November 17-21, 2008, Dallas, USA	2008-JF1-12
44	2008	W. Horton and H. Miura	Dust Devil Dynamics	50th Annual Meeting of the Division of Plasma Physics, American Physical Society	November 17-21, 2008, Dallas, USA	2008-JF1-12
45	2010	L. Zheng and M. Furukawa	Current-interchange Tearing Modes: Conversion from Interchange-type Modes to Tearing Modes	IAEA Fusion Energy Conference	11-16 October, 2010, Daejeon, Korea	2009-JF-11
46	2010	S. Murakami, K. Itoh, L. Zheng, J. W. Van Dam, and A. Fukuyama	Simulation Study of Toroidal Flow Generation by the ICRF Minority Heating	IAEA Fusion Energy Conference	11-16 October, 2010, Daejeon, Korea	2009-JF-11
47	2010	W. Horton, O. Yamagishi, and A. Sen	Electron temperature gradient drift mode in the Columbia Linear Mirror	The International Sherwood Fusion Theory Conference	19-21 April, 2010, Seattle, Washington, USA	2009-JF-6
48	2010	O. Yamagishi, W. Horton, F. L. Waelbroeck, P. J. Morrison, and C. Correa	Numerical study of zonal flow generation with the Hasegawa-Wakatani model and comparison with linear predictions	U.S. Transport Task Force Workshop	13-16 April, 2010, Annapolis, Maryland, Spain	2009-JF-6

CHAPTER 5 JUPITER-II

Task 1-1A Flibe Handling/Tritium Chemistry

No	Year	Authors	Title of Paper	Journal	(Year) Page (Start) -Page(End) or Identification No.
1	2001	Sagara, A., Yamanishi H., Uda T., Motojima, O., Kunigi, T., Matsumoto, Y., Wu, Y., Matsui, H., Takahasi, T., Yamamoto, T., Toda, S., Mitarai, O., Satake, S., Terai, T., Tanaka, S., Fukada, S., Nishikawa, M., Shimizu, A., Yoshida, N.	Studies on Flibe Blanket Designs in Helical Reactor FFHR	Fusion Technology	39 (2001) 753-757
2	2001	Terai, T., Suzuki, A., Tanaka, S.	Tritium Release from Li2BeF4 Molten Salt Breeder under Neutron Irradiation at Elevated Temperature	Fusion Technology	39 (2001) 768-772
3	2001	Terai, T., Nishimura, H., Yamaguchi, K., Yamawaki, M., Suzuki, A., Muroga, T., Sagara, A. and Motojima, O.	Compatibility of Structural Materials with Li2BeF4 Molten Salt Breeder	Fusion Technology	39 (2001) 784-788
4	2001	Nishimura, H., Suzuki, A., Terai, T., Yamawaki, M., Tanaka, S., Sagara A., and Motojima, O	Chemical Behavior of Li2BeF4 Molten Salt as a Liquid Tritium Breeder	Fusion Engineering and Design	58-59 (2001) 667-672
5	2002	Petti, D.A., Anderl, R.A., Smolik, G.R., Sze, D.-K., Terai T. and Tanaka, S.	JUPITER-II Flibe Tritium Chemistry and Safety Experimental Program	Fusion Science and Technology	41 (2002) 807-811
6	2002	Fukada, S., Nishikawa, M., Sagara A. and Terai, T.	Mass-Transport Properties to Estimate Rates of Tritium Recovery from FLIBE Blanket	Fusion Science and Technology	41 (2002) 1054-1058
7	2002	Fukada, S. Anderl, R.A., Hatano, Y., Schuetz, S.T., Pawelko, R.J., Petti, D.A., Smolik, G.R., Terai, T., Nishikawa, M., Tanaka S. and Sagara, A.	Initial Studies of Tritium Behavior in Flibe and Flibe-facing Material	Fusion Engineering and Design	61-62 (2002) 783-788
8	2002	Nishimura, H., Terai, T., Yamawaki, M., Tanaka, S., Sagara A. and Motojima, O.	Compatibility of Ferritic Steels with Li2BeF4 Molten Salt Breeder	Journal of Nuclear materials	307-311 (2002) 1355-1359
9	2003	Fukada, S., Anderl, R.A., Pawelko, R.J., Smolik, G.R., Schultz, S.T., O' Brien, J.E., Nishimura, H., Hatano, Y., Terai, T., Petti, D.A., Sze, D.-K. and Tanaka, S.	FLIBE-D2 Permeation Experiment and Analysis	Fusion Engineering and Technology	44 (2003) 410-414
10	2004	Smolik, G., Pawelko, R., Morimoto, Y., Okuno, K., Anderl, R., Petti, D.A. and Terai, T.	Mobilization Measurements from Flibe under Argon and Air Flow	Journal of Nuclear Materials	329-333 (2004) 1322-1326
11	2004	Anderl, R.A., Fukada, S., Smolik, G.R., Pawelko, R.J., Schuetz, S.T., Sharpe, J.P., Merrill, B.J., Petti, D.A., Nishimura, H., Terai T. and Tanaka, S.	Deuterium/tritium Behavior in Flibe and Flibe-facing Materials	Journal of Nuclear Materials	329-333 (2004) 1327-1331
12	2006	Fukada, S., Morisaki, A., Sagara A. and Terai, T.	Control of Tritium in FFHR-2 Self-cooled Flibe Blanket	Fusion Engineering and Design	81 (2006) 477-483
13	2006	Fukada, S., Morisaki, A.	Hydrogen permeability through a mixed molten salt of LiF, NaF and KF (Flinak) as a heat-transfer fluid	Journal of Nuclear Materials	358 (2006) 235-242
14	2006	Simpson, M.F., Smolik, G.R., Sharpe, J.P., Anderl, R.A., Petti, D.A., Hatano, Y., Hara, M., Oya, Y., Fukada, S., Tanaka, S., Terai T., and Sze, D.-K	Quantitative Measurement of Beryllium-controlled Redox of Hydrogen Fluoride in Molten Flibe	Fusion Engineering and Design	81 (2006) 541-547

15	2006	Hara, M., Hatano, Y., Simpson, M.F., Smolik, G.R., Sharpe, J.P., Oya, Y., Okuno, K., Nishikawa, M., Terai, T., Tanaka, S., Anderl, R.A., Petti D.A. and Sze, D.-K	Interactions between Molten Flibe and Metallic Be	Fusion Engineering and Design	81 (2006) 561-566
16	2006	Klix, A., Suzuki A. and Terai, T.	Study of Tritium Migration in Liquid Li2BeF4 with Ab initio Molecular Dynamics	Fusion Engineering and Design	81 (2006) 713-717
17	2006	Kimura, A., Kasada, R., Kohyama, A., Konishi, S., Enoeda, M., Akiba, M., Jitsukawa, S., Ukai, S., Terai T. and Sagara, A.	Ferritic Steel-blanket Systems Integration R&D-Compatibility Assessment	Fusion Engineering and Design	81 (2006) 909-916
18	2006	Sagara, A., Imagawa, S., Tanaka, T., Muroga, T., Kubota, Y., Dolan, T., Hashizume, H., Kunugi, T., Fukada, S., Shimizu, A., Terai T. and Mitarai, O.	Carbon Tiles as Spectral-shifter for Long-life Liquid Blanket in LHD-type Reactor FFHR	Fusion Engineering and Design	81 (2006) 1299-1304
19	2006	Petti, D.A., Smolik, G.R., Simpson, M.F., Sharpe, J.P., Anderl, R.A., Fukada, S., Hatano, Y., Hara, M., Oya, Y., Terai, T., Sze, D.-K. and Tanaka, S.	JUPITER-II Molten Salt Flibe Research: An Update on Tritium, Mobilization and Redox Chemistry Experiments	Fusion Engineering and Design	81 (2006) 1439-1449
20	2007	Fukada, S., Simpson, M.F., Anderl, R.A., Sharpe, J.P., Katayama, K., Smolik, G.R., Oya, Y., Terai, T., Okuno, K., Hara, M., Petti, D.A., Tanaka, S., Sze, D.-K. and Sagara, A.	Reaction Rate of Beryllium with Fluorine Ion for Flibe Redox Control	Journal of Nuclear Materials	367-370 (2007) 1190-1196
21	2007	Calderoni, P., Sharpe, J.P., Hara M. and Oya, Y.	Measurement of tritium permeation in flibe	Fusion Engineering and Design	367-370, Part 2 (2007) 1190-1196

Task 1-1B Thermofluid Characteristics of Flibe Simulant

22	2001	Chiba, S., Toda, S., Yuki, K. and Sagara, A.	Heat Transfer Enhancement for a Molten Salt FLiBe Channel	Fusion Technology	39 (2001) 779-783
23	2001	Sagara, A., Yamanishi, H., Uda, T., Motojima, O., Mitarai, O., Kunugi, T., Matsumoto, Y., Satake, S., Wu, Y., Terai, T., Tanaka, S., Matsui, H., Takahashi, S., Yamamoto, T., Toda, S., Fukada, S., Nishikawa, M., Shimizu, A. and Yoshida, N.	Studies in Flibe Blanket Designs in Helical Reactor FFHR	Fusion Technology	39 (2001) 753-757
24	2001	Kunugi, T., Satake, S. and Sagara, A.	Direct Numerical Simulation of Turbulent Free-Surface High Prandtl Number Fluid Flows in Fusion Reactors	Nuclear Instruments and Methods in Physics Research A	464 (2001) 165-171
25	2001/ 2002	Smolentsev, S., Abdou, M. A., Kunugi ,T., Morley, N. B., Satake, S. and Ying, A.	Modeling of Liquid Walls in Apex Study	International Journal of Applied Electro-Magnetics and Mechanics	13 (2001/2002) 373-379
26	2002	Satake, S., Kunugi, T. and Smolentsev, S.	Advances in Direct Numerical Simulation for MHD Modeling of Free Surface Flows	Fusion Engineering Design	61-62 (2002) 95-102
27	2002	Freeze, B., Dagher, M., Sketchley, T., Morley, N. B., Smolentsev, S. and Abdou, M. A.	FLIHY experimental facilities for studying open channel turbulent flows and heat transfer	Fusion Engineering Design	63-64 (2002) 391-395
28	2002	Smolentsev, S., Freeze, B., Morley, N. B. and Abdou, M. A.	Experimental study of turbulent supercritical open channel water flow as applied to the CLiFF concept	Fusion Engineering Design	63-64 (2002) 397-403
29	2002	Toda, S., Chiba, S., Yuki, K., Omae, M. and Sagara, S.	Experimental research on molten salt thermofluid technology using a high-temperature molten salt loop applied for a fusion reactor flibe blanket	Fusion Engineering Design	63-64 (2002) 405-409.
30	2002	Kunugi, T. and Satake, S.	Approaches of Fusion Science to Global Warming from the Perspective of Thermofluid Research	Fusion Engineering Design	63-64 (2002) 665-672

31	2002	Smolentsev, S., Abdou, M. A., Morley, N. B., Ying, A. and Kunugi, T.	Application of the "K-epsilon" model to open channel flows in a magnetic field	International Journal of Engineering Science	40 (2002) 693-711
32	2002	Freeze, B., Smolentsev, S., Morley, N. B. and Abdou, M. A.	Characterization of the Effect of Froude Number on Surface Waves and Heat Transfer in Inclined Turbulent Open Channel Water Flows	International Journal of Heat and Mass Transfer	46 (2002) 3765-3775
33	2002	Satake, S., Kunugi, T. and Smolentsev, S.	DNS of Turbulent Pipe Flow in a Transverse Magnetic Field	Journal of Turbulence	3 (2002) 020 (http://jot.iop.org/)
34	2002	Satake, S., Kunugi, T. and Smolentsev, S.	Direct numerical simulation of MHD turbulent free surface flow	Transaction JSME	68 (2002) 755-760
35	2004	Smolentsev, S., Morley, N. B., Freeze, B., Miraghaie, R., Nave, J. C., Banerjee, S., Ying, A. and Abdou, M. A.	Thermofluid Modeling and Experiments for Free Surface Flows of Low-Conductivity Fluid in Fusion Systems	Fusion Engineering Design,	72 (2004) 63-81
36	2005	Chiba, S., Omae, M., Yuki, K., Hashizume, H., Toda, S. and Sagara, A.	Experimental research on heat transfer enhancement for high Prandtl-number fluid	Fusion Science and Technology	47 (2005) 569-573
37	2005	Morley, N. B., Malang, S. and Kirillov, I.	Thermofluid Magnetohydrodynamic Issues for Liquid Breeders	Fusion Science and Technology	47 (2005) 488-501
38	2005	Okumura, M., Yuki, K., Hashizume, H. and Sagara, A.	Evaluation of Flow Structure in Packed-Bed Tube by Visualization Experiment	Fusion Science and Technology	47 (2005) 1089-1093
39	2005	Sagara, A., Tanaka, T., Muroga, T., Hashizume, H., Kunugi, T., Fukada, S. and Shimizu, A.	Innovative liquid breeder blanket design activities in Japan	Fusion Science and Technology	47 (2005) 524-529
40	2005	Smolentsev, S., Miraghaie, R. and Abdou, M. A.	MHD Effects on Heat Transfer in a Molten Salt Blanket	Fusion Science and Technology	47 (2005) 559-563
41	2005	Smolentsev, S.,and Miraghaie, R.	Study of a Free Surface in Open-Channel Water Flows in the Regime from weak to strong Turbulence	International Journal of Multiphase Flow	31 (2005) 921-939
42	2005	Abdou, M. A., Morley, N. B., Ying, A., Smolentsev, S. and Calderoni, P.	Overview of fusion blanket R&D in the US over the last decade	Nuclear Engineering and Technology	37 (2005) 401-422
43	2005/ 2006	Li, F-Ch., Kunugi, T. and Serizawa, A.	MHD effect on flow structures and heat transfer characteristics of liquid metal-gas annular flow in a vertical pipe	International Journal of Heat and Mass Transfer	48 (2005/2006) 2571-2581
44	2006	Morley, N. B., Abdou, M. A., Anderson, M., Calderoni, P., Kurtz, R. J., Nygren, R., Raffray, R., Sawan, M., Sharpe, P., Smolentsev, S., Willms, S. and Ying, A.	Overview of Fusion Nuclear Technology in the US	Fusion Engineering Design	81 (2006) 33-43
45	2006	Satake, S., Kunugi, T., Naito, N. and Sagara, A.	Direct numerical simulation of MHD flow with electrically conducting wall	Fusion Engineering Design	81 (2006) 367-374
46	2006	Chiba, S., Yuki, K., Hashizume, H., Toda, S. and Sagara, A.	Numerical research on heat transfer enhancement for high Prandtl-number fluid	Fusion Engineering Design	81 (2006) 513-517
47	2006	Satake, M., Yuki, K., Chiba, S. and Hashizume, H.	Numerical analysis of MHD flow structure behind a square rod	Fusion Engineering Design	81 (2006) 525-532
48	2006	Takeuchi, J., Satake, S., Miraghaie, R., Yuki, K., Yokomine, T., Kunugi, T., Morley, N. B. and Abdou M. A.	Study of heat transfer enhancement / suppression for molten salt flows in a large diameter circular pipe: Part one – Benchmarking,	Fusion Engineering Design	81 (2006) 601-606
49	2006	Satake, S., Kunugi. T., Takase, K. and Ose, Y.	Direct numerical simulation of turbulent channel flow under a uniform magnetic field for large-scale structures at high Reynolds number	Physics of Fluids	18 (2006) 125106

50	2007	Nakaharai, H., Takeuchi, J., Yokomine, T., Kunugi, T., Satake, S., Morley, N. B. and Abdou, M. A	The influence of a magnetic field on turbulent heat transfer of high Prandtl number fluid	Experimental Thermal and Fluid Science	32 (2007) 23-28
51	2007	Takeuchi, J., Satake, S., Kunugi, T., Yokomine, T., Morley, N. B., and Abdou, M. A.	Development of PIV technique under magnetic fields and measurement of turbulent pipe flow of FLIBE simulant fluid	Fusion Science and Technology	52 (2007) 860-864
52	2007	Nakaharai, H., Takami, S., Yokomine, T., Ebara, S., Shimizu, A.	Numerical study of heat transfer characteristics in a tube with regularly spaced twisted tape	Fusion Science and Technology	52 (2007) 855-859
53	2007	Yokomine, T., Takeuchi, J., Nakaharai, H., Satake, S., Kunugi, T., Morley, N. B., Abdou, M. A.	Experimental investigation of turbulent heat transfer of high Prandtl number fluid flow under strong magnetic field	Fusion Science and Technology	52 (2007) 625-629
54	2007	Satoh, T., Yuki, K., Chiba, S., Hashizume, H. and Sagara, S.	Heat Transfer Performance for High Prandtl and High Temperature Molten Salt Flow in Sphere-Packed Pipes	Fusion Science and Technology	52 (2007) 618-624
55	2008	Seto, N., Yuki, K., Hashizume, H., Sagara, A.	Heat transfer and pressure drop correlations of sphere-packed pipes for a wide range of Re and Pr	Fusion Engineering and Design	83, 7-9 (2008) 1102-1107
56	2008	Takeuchi, J., Satake, S., Kunugi, T., Yokomine, T., Morley, N. B.and Abdou, M.A.	Experimental study on MHD effects on turbulent flow of FLIBE stimulant fluid in a circular pipe	Fusion Engineering and Design	83, 7-9 (2008) 1082-1086
57	2008	Y. Yamamoto, T. Kunugi, S. Satake, S. Smolentsev	DNS and k-epsilon model simulation of MHD turbulent channel flows with heat transfer	Fusion Engineering and Design	83, 7-9 (2008) 1309-1312

Task 1-2A MHD coating for V/Li systems

58	2002	Fujiwara, M., Natesan, K., Satou, M., Hasegawa, A., and Abe, K.	Effects of doping elements on oxidation properties of V-Cr-Ti type alloys in several environments	Journal of Nuclear Materials	307-311 (2002) 601-604
59	2002	Pint, B.A., DeVan, J.H. and DiStefano, J.R.	Temperature Limits on Compatibility of Insulating Ceramics in Lithium	Journal of Nuclear Materials	307-311 (2002) 1344-50
60	2002	Suzuki, A., Koch, F., Maier, H., Nishimura, H., and Muroga, T.	Fabrication of ceramics coatings on NIFS-HEAT by arc-source plasma-assisted deposition method for fusion blanket application	Journal of Plasma Fusion Research SERIES	5 (2002) 551-555
61	2002	Sakurai, T., Yoneoka, T., Tanaka, S., Suzuki, A., Muroga, T.	Control of nitrogen concentration in liquid lithium by hot trapping	Fusion Engineering and Design	61-62 (2002) 763-768
62	2002	Smith, D.L., Konys, J., Muroga T. and Evitkhin, V.	Development of coating for fusion power applications	Journal of Nuclear Materials	307-311 (2002) 1314-1322
63	2002	Sakurai, T. Yoneoka, T., Tanaka, S., Suzuki, A. and Muroga, T.	Control of the nitrogen concentration in liquid lithium by the hot trap method	Journal of Nuclear Materials	307-311 (2002) 1380-1384
64	2003	Pint, B.A., DiStefano J.R. and Tortorelli, P.F.	High Temperature Compatibility Issues for Fusion Reactor Structural Materials	Fusion Science and Technology	44 (2003) 433-40
65	2003	Suzuki, A., Muroga, T., Pint, B.A., Yoneoka, T., Tanaka, S.	Corrosion behaviour of AlN for self-cooled Li/V blanket application	Fusion Engineering and Design	69 (2003) 397-401
66	2004	Pint, B.A., Tortorelli, P.F., Jankowski, A.,J. Hayes, J., Muroga, T., Suzuki,A., Yeliseyeva. O.I., and Chernov, V.M.	Recent progress in the development of electrically insulating coatings for a liquid lithium blanket	Journal of Nuclear Materials	329-333 (2004) 119-124
67	2004	Tanaka, T., Suzuki, A., Muroga, T., Sato, F., Iida T. and Nishitani T.	Radiation induced conductivity of ceramic coating materials under 14 MeV neutron irradiation	Journal of Nuclear Materials	329-333 (2004) 1434-1437
68	2004	Yao, Z., Suzuki, A., Muroga T. and Katahira, K.	Chemical formation of erbium oxide layer on V–4Cr–4Ti during exposure to liquid lithium doped with erbium	Journal of Nuclear Materials	329-333（2004）1414-1418
69	2005	Pint, B.A., More, K.L., Meyer, H.M. and DiStefano, J.R.	Recent Progress Addressing Compatibility Issues Relevant to Fusion Environments	Fusion Science and Technology	47 (2005) 851-855
70	2005	Suzuki, A., Muroga, T., Yoneoka, T., Tanaka, S.	Compatibility of compound oxides with liquid lithium for fusion reactor blanket application	Journal of Physics and Chemistry of Solids	66 (2005) 690-693

71	2005	Tanaka, T., Shikama, T., Narui, M., Tsuchiya, B., Suzuki A. and Muroga T.	Evaluation of insulating property of ceramic materials for V/Li blanket system under fission reactor irradiation	Fusion Engineering and Design	75-79 (2005) 933-937
72	2005	Sawada, A., Suzuki, A., Maier, H., Koch, F., Terai T. and Muroga T.	Fabrication of yttrium oxide and erbium oxide coatings by PVD methods	Fusion Engineering and Design	75-79 (2005) 737-740
73	2005	Yao, Z., Suzuki, A., Muroga, T., Katahira, K.	In situ formation and chemical stability of Er2O3 coating on V-4Cr-4Ti in liquid lithium	Fusion Engineering and Design	75-79 (2005) 1015-1019
74	2006	Nagasaka, T., Muroga, T., Li, M., Hoelzer, D.T., Zinkle, S.J., Grossbeck, M.L., and Matsui, H.	Tensile property of low activation vanadium alloy after liquid lithium exposure	Fusion Engineering and Design	81 (2006) 307-313
75	2006	Jankowski, A. F., Saw, C. K., Ferreira, J. L., Harper, J. S., Hayes J. P. and Pint, B. A.	Morphology, Microstructure and Residual Stress in EB-PVD Erbia Coatings	Journal of Materials Science	42 (2006) 5722-5727
76	2006	Pint, B. A., Moser, J. L. and Tortorelli, P. F.	Liquid Metal Compatibility Issues for Test Blanket Modules	Fusion Engineering and Design	81 (2006) 901-908
77	2006	Yao, Z., Suzuki, A., Muroga T. and Nagasaka T.	Structural stability and self-healing capability of Er2O3 in situ coating on V–4Cr–4Ti in liquid lithium	Fusion Engineering and Design	81 (2006) 2887-2892
78	2006	Tanaka, T., Nagayasu, R., Sato, F., Muroga, T., Ikeda, T. and Iida, T.	Comparison of electrical properties of ceramic insulators under gamma ray and ion irradiation	Fusion Engineering and Design	81(2006) 1027-1031
79	2006	Yao, Z., Suzuki, A., Muroga, T., Yeliseyeva O. and Nagasaka, T.	The in situ growth of Er2O3 coatings on V–4Cr–4Ti in liquid lithium	Fusion Engineering and Design	81(2006) 951-956
80	2007	Muroga, L., Chen, J.M., Chernov, V.M., Fukumoto, K., Hoelzer, D.T., Kurtz, R.J., Nagasaka, T., Pint, B.A., Satou, M., Suzuki A., and Watanabe, H.	Review of advances in development of vanadium alloys and MHD insulator coatings	Journal of Nuclear Materials	367-370 (2007) 780-787
81	2007	Li, M, Nagasaka, T, Hoelzer, DT, Grossbeck, ML, Zinkle, SJ, Muroga, T, Fukumoto, K, Matsui, H and Narui, M	Biaxial thermal creep of two heats of V-4Cr-4Ti at 700 and 800 °C in a liquid lithium environment	Journal of Nuclear Materials	367-370 (2007) 788-793
82	2007	Pint, B. A., Moser, J. L., Jankowski, A. and Hayes, J.	Compatibility of Multi-Layer, Electrically Insulating Coatings For the Vanadium-Lithium Blanket	Journal of Nuclear Materials	367-370 (2007) 1165-1169
83	2007	Nagura, M., Kondoh, M., Suzuki, A., Muroga T., and Terai, T.	Experimental Study on Corrosion of Ceramic materials in National Convection Lithium Loop	Fusion Science and Technology	52 (2007) 625-629
84	2007	Tanaka, T., Nagayasu, R., Sawada, A., Ikeda, T., Sato, F., Suzuki, A., Muroga T. and Iida T.	Electrical insulating property of ceramic coating materials in radiation and high-temperature environment	Journal of Nuclear Materials	367-370 (2007) 1155-1159
85	2009	Pint, B. A., Pawel, S. J., Howell, M., Moser, J. L., Garner, G. W., Santella, M. L., Tortorelli, P. F., Wiffen, F. W. and DiStefano, J. R.	Initial Characterization of V-4Cr-4Ti and MHD Coatings Exposed to Flowing Li,	Journal of Nuclear Materials	386-388, 30 (2009) 712-715

Task 1-2B Vanadium Alloy Capsule Irradiation

86	2002	Nagasaka, T., Heo, N. J., Muroga T., and Imamura, M.	Examination of fabrication process parameters for improvement of low-activation vanadium alloys	Fusion Engineering and Design	61-62 (2002) 757-762
87	2002	Heo, N. J., Nagasaka, T. ,Muroga, T., Nishimura, A., Shinozaki K., and Takeshita, N.	Metallurgical and mechanical properties of laser weldment for low activation V-4Cr-4Ti alloy	Fusion Engineering and Design	61-62 (2002) 749-755
88	2002	Nishimura, A., Nagasaka T., and Muroga, T.	Fracture toughness of high-purity V-4Cr-4Ti alloy (NIFS-HEAT-2) at room temperature	Journal of Nuclear Materials	307-311 (2002) 571-575
89	2002	Watanabe, H., Suda, M., Muroga, T., and Yoshida, N.	Oxide formation of a purified V-4Cr-4Ti alloy during heat treatment and ion irradiation	Journal of Nuclear Materials	307-311 (2002) 408-412
90	2002	Grossbeck, M. L., King, J. F., Nagasaka T., and David, S. A.	Gas tungsten arc welding of vanadium alloys with impurity control	Journal of Nuclear Materials	307-311 (2002) 1590-1594

91	2002	Heo, N. J., Nagasaka, T., Muroga, T., and Matsui, H.	Effect of impurity levels on precipitation behavior in the low-activation V-4Cr-4Ti alloys	Journal of Nuclear Materials	307-311 (2002) 620-624
92	2002	Chuto, T., Satou, M., Hasegawa, A., Abe, K., Nagasaka T., and Muroga, T.	Fabrication using a levitation melting method of V-4Cr-4Ti-Si-Al-Y alloys and their mechanical properties	Journal of Nuclear Materials	307-311 (2002) 555-559
93	2002	Nagasaka, T., Muroga, T., Grossbeck, M. L., and Yamamoto, T.	Effects of post-weld heat treatment conditions on hardness, microstructures and impact properties of vanadium alloys	Journal of Nuclear Materials	307-311 (2002) 1595-1599
94	2002	Nagasaka, T., Muroga, T.,, Wu, W.C., Xu, Z.Y., and Imamura, M.	Low Activation Characteristics of Several Heats of V-4Cr-4Ti Ingot	Journal of Plasma and Fusion Research SERIES	5 (2002) 545-550
95	2002	Gelles, DS	Microstructural examination of irradiated and unirradiated V-4Cr-4Ti pressurized creep tubes	Journal of Nuclear Materials	307-311 (2002) 393-397
96	2002	Toloczko, MB, Kurtz, RJ, Hasegawa, A, and Abe, K	Shear punch tests performed using a new low compliance test fixture	Journal of Nuclear Materials	307-311 (2002) 1619-1623
97	2002	Hoelzer, DT and Rowcliffe, AF	Investigating solute interactions in V-4Cr-4Ti based on tensile deformation behavior of vanadium	Journal of Nuclear Materials	307-311 (2002) 596-600
98	2002	Odette, GR, He, MY, Donahue, EG, Spatig, P, and Yamamoto, T.	Modeling the multiscale mechanics of flow localization-ductility loss in irradiation damaged bcc alloys	Journal of Nuclear Materials	307-311 (2002) 171-178
99	2002	Lucas, GE, Odette, GR, Sokolov, M, Spatig, P, Yamamoto, T, Jung, P	Recent progress in small specimen test technology	Journal of Nuclear Materials	307-311 (2002) 1600-1608
100	2002	Odette, GR, He, M, Gragg, D, Klingensmith, D, Lucas, GE	Some recent innovations in small specimen testing	Journal of Nuclear Materials	307-311 (2002) 1643-1648
101	2002	Zinkle, SJ, Hashimoto, N, Hoelzer, DT, Qualls, AL, Muroga, T, and Singh, BN	Effect of periodic temperature variations on the microstructure of neutron-irradiated metals	Journal of Nuclear Materials	307-311 (2002) 192-196
102	2003	Nagasaka, T., Muroga, T., and Iikubo, T.	Development of tubing technique for high-purity low activation vanadium alloys	Fusion Science and Technology	44 (2003) 465-469
103	2003	Heo, N., Nagasaka, T., Muroga, T., Nishimura, A., Shinozaki, K., Watanabe, H.	Mechanical properties of laser weldment of V-4Cr-4Ti alloy	Fusion Science and Technology	44 (2003) 470-474
104	2004	Fukumoto, K., Matsui, H., Narui, M., Nagasaka, T., Muroga, T.	Manufacturing pressurized creep tubes from highly purified V-4Cr-4Ti alloys, NIFS-Heat2	Journal of Nuclear Materials	335 (2004) 103-107
105	2004	Koyama, M., Fukumoto, K., Matsui, H.	Effects of purity on high temperature mechanicalproperties of vanadium alloys	Journal of Nuclear Materials	329-333 (2004) 442-446
106	2004	Fukumoto, K., Matsui, H., Muroga, T., Zinkle, S. J., Hoelzer, D. T., Snead, L. L.	Varying temperature effects on mechanical properties of vanadium alloys during neutron irradiation	Journal of Nuclear Materials	329-333 (2004) 472-476
107	2004	Sugiyama, M., Fukumoto, K., Matsui, H.	Dislocation channel formation process in V－Cr－Ti alloys irradiated below 300˚C	Journal of Nuclear Materials	329-333 (2004) 467-471
108	2004	Chuto, T., Satou, M., Hasegawa, A., Abe, K., Muroga T., and Yamamoto, N.	Effects of small amount of additional elements on control of interstitial impurities and mechanical properties of V-4Cr-4Ti-Si-Al-Y	Journal of Nuclear Materials	326 (2004) 1-8
109	2004	Chuto. T., Satou, M., Hasegawa, A., Abe, K., Muroga, T., and Yamamoto, N.	Changes in mechanical properties of high-purity V-4Cr-4Ti-Si, Al, Y alloys after neutron irradiation at relatively low temperatures	ASTM Special Technical Publications STP	1447 (2004) 693-701
110	2004	Kurtz, R.J, Abe, K., Chernov, V.M., Hoelzer, D.T., Matsui, H., Muroga, T., and Odette, G.R.	Recent progress on development of vanadium alloys for fusion	Journal of Nuclear Materials	329-333 (2004) 47-55
111	2004	Watanabe, H., Nagamine M., Yamasaki, K., Yoshida, N., Nagasaka, T., Muroga, T., Shinozaki, K	Effects of Ion Irradiation on Yag Laser Welded V-4Cr-4Ti Alloy	Journal of Plasma Fusion Res	80, No.10 (2004) 889-894
112	2005	Muroga, T., Nagasaka, T., Nishimura A., and Chen, J.M.	Improvement of Vanadium Alloys by Precipitate Control for Structural Component of Fusion Reactors	Materials Science Forum	475-479 (2005) 1449-1454

113	2005	Muroga, T.	Vanadium Alloys for Fusion Blanket Applications	Materials Transactions	46 (2005) 405-411
114	2005	Nagasaka, T. Muroga, T., Watanabe, H., Yamasaki, K., Heo, N-J., Shinozaki K., and Narui M.	Recovery of hardness, impact properties and microstructure of neutron-irradiated weld joint of a fusion candidate vanadium alloys	Materials Transactions	46 (2005) 498-502
115	2005	Nagasaka, T., Muroga, T., Noda, N., Kawamura M., and Ise, H.	Tungsten Coating on Low Activation Vanadium Alloy by Plasma Spray Process	Fusion Science and Technology	47 (2005) 876-880
116	2005	Lee, CY, Donahue, EG, and Odette, GR, “,” Advances in Fracture and Strength, Pts 1-4, Key Engineering Materials	Verification of mechanical properties of a V-4CR-4TI alloy using finite element method	Key Engineering Materials	297 - 300 (2005) 1013-1018
117	2005	Watanabe, H., Nagamine, M., Yamasaki, A., Yoshida, N., Nagasaka, T., Muroga, T.	The microstructure of laser welded V-4Cr-4Ti alloy after ion irradiation	Materials Science Forum Volumes	475-479 (2005) 1491-1496
118	2005	Fukumoto, K., Takahashi, S., Kurtz, R.J., Smith, D.L., and Matsui, H.	Microstructural examination of V-(Fe or Cr)-Ti alloys after thermal-creep or irradiation-creep tests	Journal of Nuclear Materials	341 (2005) 83-89
119	2005	Fukumoto, K., Takahashi, K., Anma, Y., Matsui, H.	Effect of Impurities on Microstructural Evolution and Deformation Process of Ion-Irradiated V-Cr-Ti alloys	Materials Transactions	46 (2005) 503-510
120	2005	Kurishita, H., Kuwabara, T., Hasegawa, M., Kobayashi, S., and Nakai, K.	Microstructural control to improve the resistance to radiation embrittlement in vanadium	Journal of Nuclear Materials	343 (2005) 318-32
121	2006	Nagasaka, T., Muroga, T., Li, M., Hoelzer, D.T., Zinkle, S.J., Grossbeck, M.L., and Matsui, H.	Tensile property of low activation vanadium alloy after liquid lithium exposure	Fusion Engineering and Design	81 (2006) 307-313
122	2006	Nagasaka, T. Muroga, T., Fukumoto, K., Watanabe, H., Grossbeck, M.L., and Chen, J.M.	Development of fabrication technology for low activation vanadium alloys as fusion blanket structural materials	Nucl. Fusion	46 No 5 (2006) 618-625
123	2007	Muroga, L., Chen, J.M., Chernov, V.M., Fukumoto, K., Hoelzer, D.T., Kurtz, R.J., Nagasaka, T., Pint, B.A., Satou, M., Suzuki A., and Watanabe, H.	Review of advances in development of vanadium alloys and MHD insulator coatings	Journal of Nuclear Materials	367-370(2007) 780-787
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126	2007	Fukumoto, K., Sugiyama, M., Matsui, H.	Features of dislocation channeling in neutron-irradiated V–(Fe, Cr)–Ti alloy	Journal of Nuclear Materials	367-370 (2007) 829-833
127	2007	Watanabe, H., Yamasaki, K., Higashizima, A., Yoshida, N., Nagasaka, T., Muroga, T.	The microstructure of laser welded V-4Cr-4Ti alloy after neutron irradiation	Journal of Nuclear Materials	367-370 (2007) 794-799
128	2007	Rowcliffe, A.F., Hoelzer, D.T., Kurtz, R.J., and Young, C.M.	Oxidation behavior of a V-4Cr-4Ti alloy during the commercial processing of thin-wall tubing	Journal of Nuclear Materials	367-370 (2007) 839-843
129	2007	Gelles, D.S., Toloczko, M.B., and Kurtz, R.J.	Thermal creep mechanisms in V-4Cr-4Ti pressurized tube specimens	Journal of Nuclear Materials	367-370 (2007) 869-875
130	2009	Li, M., Hoelzer, D.T., Grossbeck M.L., Rowcliffe, A.F., Zinkle, S.J., and Kurtz, R.J.	Irradiation creep of the US Heat 832665 of V-4Cr-4Ti	Journal of Nuclear Materials	386-388 (2009) 618-621
131	2009	Muroga, T., Nagasaka, T., Li, Y., and Chen, J.M.	Microstructure of Creep-deformed V-4Cr-4Ti Strengthened by Precipitation and Cold Rolling	Journal of Nuclear Materials	386-388 (2009) 606-609
132	2009	Watanabe, H., Higashizima. A., Yoshida, N., Nagasaka. T., Muroga, T.	The Microstructure of Laser Welded Y Doped V-4Cr-4Ti Alloys after Ion Irradiation	Journal of Nuclear Materials	386-388 (2009) 598-601

133	2008	Watanabe, H., Yamasaki, M., Higashizima. A., Yoshida, N., Nagasaka, T., Muroga, T., Shinozaki, K.	The Effects of Postwelding Heat Treatment on Microstructural Evolution of Yag Laser Welded V-4Cr-4Ti Alloy	Journal of plasma and fusion research	84(1) (2008) 46-50

Task 2-1 SiC/SiC Fundamentals and Material Processing

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135	2005	Katoh, Y., Nozawa, T., Snead, L.L., , J. Am. Ceram. Soc.	Mechanical properties of thin pyrolitic carbon interphase SiC-Matrix composites reinforced with near-stoichiometric SiC fibers	Journal of the American Ceramic Society	88 (2005) 3088-3095
136	2005	Katoh Y., Snead, L.L., Nozawa, T., Hinoki, T., Kohyama, A., Igawa, N., Taguchi, T.	Mechanical properties of chemically vapor-infiltrated silicon carbide structural composites with thin carbon interphases for fusion and advanced fission applications	Mater. Trans.	46 (2005) 527-535
137	2005	Nozawa, T., Katoh, Y., Kohyama, A	Evaluation of tensile properties of SiC/SiC composites with miniaturized specimens	Mater. Trans	46 (2005) 543-551
138	2005	Igawa, N., Taguchi, T., Nozawa, T., Snead, L.L., Hinoki, T., McLaughl, J.C., Katoh, Y., Jitsukawa, S., Kohyama	Fabrication of SiC fiber reinforced SiC composite by chemical vapor infiltration for excellent mechanical properties	Journal of Physics and Chemistry of Solids	66 (2005) 551-554
139	2005	Nozawa, T., Katoh, Y., Snead, L.L., Hinoki, T., Kohyama, A.	Tensile and thermal properties of chemically vapor-infiltrated silicon carbide composites with various high-modulus fiber reinforcements	Ceram. Eng. and Sci. Proc.	26 (2005) 311-318
140	2005	Katoh, Y., Nozawa, T., Kotani, M., Ozawa, K., Kohyama, A	Microstructures and flexural properties of high temperature-pyrolyzed PIP-SiC/SiC composites	Key Eng. Mater.	287 (2005) 346-351
141	2004	Taguchi, T., Nozawa, T., Igawa, N., Katoh, Y., Jitsukawa, S., Kohyama, A., Hinoki, T., Snead, L.L.	Fabrication of advanced SiC fiber/F-CVI SiC matrix composites with SiC/C multi-layer interphase	J. Nucl. Mater.	329-33 (2004) 572-576
142	2004	Nozawa, T., Ozawa, K., Katoh, Y., Kohyama, A.	Effect of heat treatment on microstructure and mechanical properties of stoichiometric SiC/SiC composites	Mater. Trans	45 (2004) 307-310
143	2004	Katoh, Y., Lowden, R.A., Yang, W., Nozawa, T., Hinoki, T., Kohyama, A.	Fast Fracture Properties of Thin Interphase Silicon Carbide Composites, in: M. Singh, R.J. Kerans, E. Lara-Curzio, R. Naslain (Eds.), High Temperature Ceramic Matrix Composites 5	The American Ceramic Society, Westerville, OH	(2004) 169-174
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145	2004	S.J. Son, K.H. Park, Y. Katoh and A. Kohyama	Interfacial reactions and mechanical properties of W –SiC in-situ joints for plasma facing components	Journal of Nuclear Materials	329-333, Part 2 (2004) 1549-1552
146	2003	Nozawa, T., Katoh, Y., Kohyama, A., Lara-Curzi E.	Specimen Size Effect on the Tensile and Shear Properties of the High-Crystalline and High-Dense SiC/SiC Composites	Ceram. Eng. and Sci. Proc.	24 (2003) 415-420
147	2003	Y. Katoh, A. Kohyama, T. Hinoki and L.L. Snead	Progress in SiC-Based Ceramic Composites for Fusion Applications	Fusion Science and Technology	44 (2003) 155-162
148	2003	W. Yang, A. Kohyama, Y.T. Katoh, H. Araki, J.N. Yu and T. Noda	Effect of Carbon and Silicon Carbide/Carbon Interlayers on the Mechanical Behavior of Tyranno-SA-Fiber-Reinforced Silicon Carbide-Matrix Composites	Journal of the American Ceramic Society	86, 5 (2003) 851-856
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150	2003	T. Hino, T. Jinushi, Y. Hirohata, M. Hashiba, Y. Yamauchi, Y. Katoh and A. Kohyama	Helium Gas Permeability of SiC/SiC Composite Developed for Blanket Component	Fusion Science and Technology	43 (2003) 184-190

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153	2002	Nozawa, T., Katoh ,Y., Kohyama, A., Lara-Curzi, E.	Advances in Ceramic Matrix Composites VIII: Ceramic Transactions	The American Ceramic Society, Westerville, OH	139 (2002) 127-138
154	2002	Nozawa, T., Hinoki, T., Katoh, Y., Kohyama, A., Lara-Curzi, E.(Eds.)	Specimen Size Effects on the Tensile Properties of 2D/3D SiC/SiC Composites	ASTM International, West Conshohocken, PA	2002
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157	2002	Y. Hirohata, T. Jinushi, Y. Yamauchi, M. Hashiba, T. Hino, Y. Katoh and A. Kohyama	Gas permeability of SiC/SiC composites as fusion reactor material	Fusion Engineering and Design	61-62 (2002) 699-704
158	2002	Y. Katoh, S.M. Dong and A. Kohyama	Thermo-mechanical properties and microstructure of silicon carbide composites fabricated by nano-infiltrated transient eutectoid process	Fusion Engineering and Design	61-62 (2002) 723-731
159	2002	J.S. Park, Y. Katoh, A. Kohyama, S.P. Lee and H.K. Yoon	Evaluation of fracture toughness of ceramic matrix composites using small specimens	Fusion Engineering and Design	61-62 (2002) 733-738
160	2002	W. Yang, H. Araki, T. Noda, Q. Hu, H. Suzuki, Y. Katoh and A. Kohyama	Effects of Interlayers on InterfacialShear Strength and Flexural Properties of Tyranno-SA Fiber-Reinforced CVI-SiC/SiC Composites	Ceramic Transactions	144 (2002) 273-280
161	2002	J.S. Park, Y. Katoh, A. Kohyama and H.K. Yoon	Fracture Resistance Evaluation of Ceramic Matrix Composities	Ceramic Transactions	144 (2002) 263-272
162	2002	T. Nozawa, K. Hironaka, Y. Katoh, A. Kohyama, T. Taguchi, S. Jitsukawa and L.L. Snead	Tensile Strength of Chemical Vapor Infiltrated Adavanced SiC Fiber Composites at Elevated Temperatures	Ceramic Transactions	144 (2002) 245-252
163	2002	Y. Katoh, S.M. Dong and A. Kohyama	A Novel Processing Technique of Silicon Carbide-Based Ceramic Composites for High Temparature Applications	Ceramic Transactions	144 (2002) 77-86
164	2002	T. Taguchi, N. Igawa, S. Jitsukawa, T. Nozawa, Y. Katoh, A. Kohyama, L.L. Snead and J.C. McLaughlin	Opimizing the Fabrication process for excellent mechanical properties in Stoichiometric SiC Fiber / FCVI SiC Matrix Composites	Ceramic Transactions	144 (2002) 69-76
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166	2002	J.S. Park, Y. Katoh and A. Kohyama	Preliminary Study of Influence of Test Specimen Size on the Fracture Behaviour of 2D Woven Ceramic Matrix Composies	26th Annual Conference on Composites, Advanced Ceramics, Materials, and Structures: A: Ceramic Engineering and Science Proceedings	23, 3 (2002) 469-475
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168	2002	Y. Katoh, A. Kohyama, S.M. Dong, T. Hinoki and J.J. Kai	Microstructure and Properties of Liquid Phase Sintered SiC/SiC Composites	26th Annual Conference on Composites, Advanced Ceramics, Materials, and Structures: A: Ceramic Engineering and Science Proceedings	23, 3 (2002) 362-370

Task 2-2 SiC System Thermomechanics

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170	2004	G. R. Longhurst, L. L. Snead, A. Abou-Sena	The Status of Beryllium Research for Fusion in the United States	Proceedings of the 6th IEA International Workshop on Beryllium Technology for Fusion, Miyazaki, Japan, March 2004	
171	2005	An, Z., Ying, A., Abdou, M.	Experimental and numerical study of ceramic breeder pebble bed thermal deformation behavior	Fusion Science & TechnologyFusion Science & Technology	47 (4) (May 2005) 1101 - 1105
172	2005	Abou-Sena, A., Ying, A., Abdou, M.	Effective thermal conductivity of lithium ceramic pebble beds for fusion blankets: a review	Fusion Science & Technology	47 (4) (May 2005) 1094 - 1100
173	2005	Z. An, A. Ying, M. Abdou	Experimental and numerical study on the thermomechanical properties of ceramic pebble bed structure	Proc. 2005 Joint ASME/ASCE/SES Conference on Mechanics and Materials (McMat2005), Baton Rouge, LA (06/01/2005)	
174	2005	Z. An, A. Ying and M. Abdou	Thermo-mechanical analysis of ITER test unit cell under pulse operation	Proceedings of 21st IEEE/NPSS Symposium on Fusion Engineering 2005, Oct. 2005	
175	2006	Ali Abou-Sena, Alice Ying, Mohamed Abdou	Experimental Measurements of the Effective Thermal Conductivity of a Lithium Titanate (Li2TiO3) Pebbles-Packed Beds	Journal of Materials Processing Technology	181 (January 2006) 206-212
176	2006	Calderoni, P., Ying, A., Sketchley, T., Abdou, M.	Experimental Study of the Interaction of Ceramic Breeder Pebble Beds with Structural Materials under Thermo-Mechanical Loads	Fusion Engineering & Design	81 (1-7) (February 2006) 607 - 612
177		An, Z., Ying, A., Abdou, M.	Numerical characterization of thermo-mechanical performance of breeder pebble beds	Proceedings of the 12th International Conference on Fusion Reactor Materials (ICFRM-12), to be published in Journal of Nuclear Materials (2006)	

Task 2-3 SiC Capsule Irradiation

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179	2002	Nozawa, T., Hinoki, T., Katoh, Y., Kohyama, A.	Effects of fibers and fabrication processes on mechanical properties of neutron irradiated SiC/SiC composites	Journal of Nuclear Materials	307 (2002) 1173-1177
180	2002	Hinoki, T., Katoh, Y., Kohyama, A.	Effect of fiber properties on neutron irradiated SiC/SiC composites	Mater. Trans	43 (2002) 617-621
181	2002	H. Kishimoto, Y. Katoh and A. Kohyama	Microstructural stability of SiC and SiC/SiC composites under high temperature irradiation environment	Journal of Nuclear Materials	307-311, Part 2 (2002) 1130-1134
182	2002	K.H. Park, Y. Katoh, H. Kishimoto and A. Kohyama	Evaluation of dual-ion irradiated β-SiC by means of indentation methods	Journal of Nuclear Materials	307-311, Part 2 (2002) 1187-1190
183	2002	Y. Katoh, H. Kishimoto and A. Kohyama	The influences of irradiation temperature and helium production on the dimensional stability of silicon carbide	Journal of Nuclear Materials	307-311, Part 2 (2002) 1221-1226
184	2002	Y. Katoh, H. Kishimoto and A. Kohyama	Low Temperature Swelling in Beta-SiC Associated with Point Defect Accumulation	Materials Transactions	43 (2002) 612-616
185	2002	S. Nogamia, A. Hasegawa, L. L. Snead	Indentation fracture toughness of neutron irradiated silicon carbide	Journal of Nuclear Materials	307-311, Part 2 (2002) 1163-1167
186	2002	A. Hasegawa , S. Nogami, T. Aizawa, K. Katou and K. Abe	Mechanical property change and swelling behavior of SiC fiber after light-ion irradiation	Journal of Nuclear Materials	307-311, Part 2 (2002) 1152-1156
187	2002	S. Nogami , S. Ohtsuka, M. B. Toloczko, A. Hasegawa and K. Abe	Analysis of possible deformation mechanisms in helium–ion irradiated SiC	Journal of Nuclear Materials	307-311, Part 2 (2002) 1178-1182
188	2003	Y. Katoh, M. Ando and A. Kohyama	Radiation and helium effects on microstructures, nano-indentation properties and deformation behavior in ferrous alloys	Journal of Nuclear Materials	323, Issues 2-3, (2003) 251-262

189	2003	K.H. Park, S. Kondo, Y. Katoh and A. Kohyama	Mechanical Properties of -SiC After Si- and Dual Si + He-Ion Irradiation at Various Temperatures	Fusion Science and Technology	44 (2003) 455-459
190	2003	S. Kondo, K.H. Park, Y. Katoh and A. Kohyama	High Temperature Ion-Irradiation Effects on Microstructural Evolution inβ -SiC	Fusion Science and Technology	44 (2003) 181-185
191	2003	A.Hasegawa, S.Nogami, S.Miwa, K.Abe, T.Taguchi, N.Igawa	Synergistic Effect of Displacement Damage, Helium and Hydrogen of Silicon Carbide Composite	Fusion Science and Technology	44 (1) (2003) 175-180
192	2004	Nogami, S., Hasegawa, Snead, L.L., Jones, R.H. Abe, K.	Effect of He pre-implantation and neutron irradiation on mechanical properties of SiC/SiC composite	Journal of Nuclear Materials	329–333 (2004) 577–581
193	2004	Nozawa, T., Hinoki, T., Snead, L.L., Katoh, Y., Kohyama, A.	Neutron irradiation effects on high-crystallinity and near-stoichiometry SiC fibers and their composites	Journal of Nuclear Materials	329-33 (2004) 544-548
194	2004	Nogami, S., Miwa, M., Hasegawa, A., Abe, K.	Mechanical and Structural Property Change of Monolithic SiC and Advanced SiC/SiC Composites due to Low Temperature He+-ion Irradiation and Post-irradiation High Temperature Annealing	American Society for Testing and Materials (ASTM) STP 1447	1447 (2004) 655-669
195	2004	Hasegawa, A., Miwa, S., Nogami, S., Taniguchi, A., Taguchi, T., Abe,K.	Study of hydrogen effects on microstructural development of SiC base materials under simultaneous irradiation with He- and Si-ion irradiation conditions	Journal of Nuclear Materials	329-333 (2004) 582-586
196	2005	Miwa, S., Hasegawa, A., Taguchi,T., Igawa, N., Abe, K.	Cavity Formation in a SiC/SiC Composites under Simutaneous Irradiation of Hydrogen, Helium and Silicon Ions	Materials Transactions	46(3) (2005) 536-542
197	2005	Nozawa, T., Ozawa, K., Kondo, S., Hinoki, T., Katoh, Y., Snead, L.L., Kohyama, A., Tensile	Flexural, and Shear Properties of Neutron Irradiated SiC/SiC Composites with Different Fiber-Matrix Interfaces	J. ASTM Int.	2 (2005) 12884-12881-12813
198	2005	Katoh, Y., Snead, L.L.	Bend stress relaxation creep of CVD silicon carbide	Ceram. Eng. and Sci. Proc.	26 (2005) 265-272
199	2005	Katoh, Y., Snead, L.L.	Mechanical Properties of Cubic Silicon Carbide after Neutron Irradiation at Elevated Temperatures	J. ASTM Int. 2	(2005) 12377-12371-12313
200	2005	Kondo, S., Katoh, Y., Kishimoto, H., Hinoki, T., Kohyama, A.	Swelling and Recovery Behavior in Silicon Carbide Irradiated at High Temperature	Proceedings of 2005 International Congress on Advances in Nuclear Power Plants (ICAPP-05),2005	2782-2787
201	2005	T. Hinoki and A. Kohyama	Current status of SiC/SiC composites for nuclear applications	Annales de chimie science des mat ériaux	30[6] (2005) 659-671
202	2005	A. Kohyama	Current Status of Fusion Reactor Structural Materials R&D	Materials Transactions	46[3] (2005) 384-393
203	2005	A. Kohyama, K. Abe, A. Kimura, T. Muroga and S. Jitsukawa	Recent Accomplishments and Future Prospects of Materials R&D in Japan	Fusion Science and Technology	47[4] (2005) 836-843
204	2005	K. Ozawa, S. Kondo, T. Hinoki, K. Jimbo and A. Kohyama	Cavity Swelling Behavior in SiC/SiC Under Charged Particle Irradiation	Fusion Science and Technology	47[4] (2005) 871-75
205	2005	H. Kishimoto, K. Ozawa, S. Kondo and A. Kohyama	Effects of Dual-Ion Irradiation on the Swelling of SiC/SiC Composites	Materials Transactions	46 [8] (2005) 1923-1927
206	2005	H. Kishimoto, T. Hinoki, K. Ozawa, K.-H. Park, S. Kondo and A. Kohyama	Dimension stability analysis of nite sic/sic composite using ion bombardments for the investigation of reliability as fusion materials	Ceramic Engineering and Science Proceedings	26[8] (2005) 215-222
207	2006	Katoh, Y., Nozawa, T., Snead, L.L., Hinoki, T., Kohyama, A.	Property tailorability for advanced CVI silicon carbide composites for fusion	Fusion Eng. and Design	81 (2006) 937-944
208	2006	Katoh, Y., Hashimoto, N., Kondo, S., Snead, L.L., Kohyama, A.	Microstructural Development in Cubic Silicon Carbide during Irradiation at Elevated Temperatures	Journal of Nuclear Materials	351 (2006) 228-240
209	2006	Ozawa, K., Hinoki, T., Nozawa, T., Katoh, Y., Maki, Y., Kondo, S., Ikeda, S., Kohyama, A.	Evaluation of Fiber/Matrix Interfacial Strength of Neutron Irradiated SiC/SiC Composites Using Hysteresis Loop Analysis of Tensile Test	Mater. Trans.	47 (2006) 207-210
210	2006	Katoh, Y., Snead, L.L., Nozawa, T., Windes, W.E., Morley N.B.	Advanced Radiation-Resistant Ceramic Composites	Advances in Science and Technology	45 (2006) 1915-1924
211	2006	Y. Katoh, N. Hashimoto, S. Kondo, L.L. Snead and A. Kohyama	Microstructural development in cubic silicon carbide during irradiation at elevated temperatures	Journal of Nuclear Materials	351, Issues 1-3 (2006) 228-240

212	2006	K. Ozawa, T. Nozawa, T. Hinoki and A. Kohyama	The effects of irradiation-induced swelling of constituents on mechanical properties of advanced SiC/siC composites	Ceramic Engineering and Science Proceedings	27 (5) (2006) 157-167
213	2009	Nogami, S., Murayama, T., Nagata, Y., Hasegawa A.	Compatibility between SiC and Li Ceramics for Solid Breeding Blanket System	Journal of Nuclear Materials	386-388 (2009) 628-630
214	2008	Nogami, S., Otake, N., Hasegawa, A., Katoh, Y., Yoshikawa, A., Satou, M., Oya, Y., Okuno, K.	Oxidation behavior of SiC/SiC composites for helium cooled solid breeder	Fusion Engineering and Design	83, Issues 10-12 (2008) 1490-1494
215	2007	Nozawa, T., Katoh, Y., Snead, L.L.	The Effect of Neutron Irradiation on Interfacial Shear Properties of Multilayered Interphase SiC/SiC Composite	Journal of Nuclear Materials	3670-370 (2007) 685-691
216	2007	Katoh, Y., Nozawa, T., Snead, L.L., Hinoki, T.	Effect of Neutron Irradiation on Tensile Properties of Unidirectional Silicon Carbide Composites	Journal of Nuclear Materials	367-370 (2007) 774-779
217	2007	Katoh, Y., Snead, L.L., Hinoki, T., Kondo, S., Kohyama, A	Irradiation Creep of Chemically Vapor Deposited Silicon Carbide as Estimated by Bend Stress Relaxation Method	Journal of Nuclear Materials	367-370 (2007) 758-763
218	2007	Ozawa, K., Nozawa, T., Katoh, Y., Hinoki, T., Kohyama, A.	Mechanical Properties and Microstructure of Advanced SiC/SiC composites after Neutron Irradiation	Journal of Nuclear Materials	367-370 (2007) 713-718
219	2007	Katoh, Y., Snead, L.L., Henager, C.H., Hasegawa, A., Kohyama, A., Riccardi, B., Hegema, J.B.J.	Current status and critical issues for development of SiC composites for fusion applications	Journal of Nuclear Materials	367-370 (2007) 659-671
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221	2007	Nozawa, T., Katoh, Y., Snead, L.L.	The Effects of Neutron Irradiation on the Interfacial Shear Strength of SiC/SiC Composites	Journal of Nuclear Materials	367-370, Part 1 (2007) 685-691

Task 3-1 Design-based Integration Modeling

222	2002	Fukada, S., Nishikawa, M., Sagara, A., Terai, T.	Mass-Transport Properties to Estimate Rates of Tritium Recovery from Flibe Blanket	Fusion Science & Technology	41 (2002) 1054-1058
223	2002	Hashizume, H., Usui, Y., Kitajima, S., Hida, T., Sagara, A.	Numerical analysis of MHD flow in remountable first wall	Fusion Engineering and Design	61-62 (2002) 251-254
224	2002	Toda, S., Chiba, S., Yuki, K., Omae, M., Sagara, A.	Experimantal research on molten salt thermofluid technology using a high-temperature molten salt loop applied for a fusion reactor Flibe blanket	Fusion Engineering and Design	63-64 (2002) 405-409
225	2003	Kunugi, T., Matsumoto, Y., Sagara, A.	A new cooling concept of free surface flow balanced with surface tension for FFHR	Fusion Engineering and Design	65 (2003) 381-385
226	2004	Hashizume, H., Usui, Y., Kitajima, S., Sagara, A.	New concept of the first wall to reduce MHD pressure drop	International Journal of Applied Electromagnetics and Mechanics	19, No.1-4 (2004) 591-595
227	2005	Sagara, A., Imagawa, S., Mitarai, O., Dolan, T., Tanaka, T., Kubota, Y., Yamazaki, K., Watanabe, K.Y., Mizuguchi, N., Muroga, T., Noda, N., Kaneko, O., Yamada, H., Ohyabu, N., Uda, T., Komori, A., Sudo, S., and Motojima, O.	Improved structure and long-life blanket concepts for heliotron reactors	Nuclear Fusion	45 (2005) 258-263
228	2005	Sagara, A., Tanaka, T., Muroga, T., Hashizume, H., Kunugi, T., Fukada, S., Shimizu, A.	Innovative Liquid Breeder Blanket Design Activities in Japan	Fusion Science and Technology	47 (2005) 524-529
229	2005	Okumura, M., Yuki, K., Hashizume, H., Sagara, A.	Evaluation of Flow Structure in Packed-Bed Tube by Visualization Experiment	Fusion Science and Technology	47 (2005) 1089-1093
230	2005	Chiba, S., Omae, M., Yuki, K., Hashizume, H., Toda, S., Sagara, A.	Experimental Research on Heat Transfer Enhancement for High Prandtl-Number Fluid Experimental Research on Heat Transfer Enhancement for High Prandtl-Number Fluid	Fusion Science and Technology	47, No.4 (2005) 569-573
231	2005	Tanaka, T., Muroga, T., Sagara, A.	Tritium Self-Sufficiency and Neutron Shielding Performance of Self-Cooled Liquid Blanket System for Helical Reactor	Fusion Science and Technology	47 (2005) 530-534
232	2005	Fukada, S., Anderl, R.A., Sagara, A., Nishikawa, M.	Diffusion Coefficient of Tritium Through Molten Salt Flibe and Rate of Tritium Leak from Fusion Reactor System	Fusion Science and Technology	48 (2005) 666-669

233	2006	Satake, S., Kunugi, T., Naito, N., Sagara, A.	Direct numerical simulation of MHD flow with electrically conducting wall	Fusion Engineering and Design	81(2006) 367-374
234	2006	Fukada, S., Morisaki, A., Sagara, A., Terai, T.	Control of tritium in FFHR-2 self-cooled Flibe blanket	Fusion Engineering and Design	81 (2006) 477–483
235	2006	Chiba, S, Yuki, K., Hashizume, H., Toda, S., Sagara, A.	Numerical research on heat transfer enhancement for high Prandtl-number fluid	Fusion Engineering and Design	81 (2006) 513-517
236	2006	Muroga, T., Tanaka, T., Sagara, A.	Blanket neutronics of Li/vanadium-alloy and Flibe/vanadium-alloy systems for FFHR	Fusion Engineering and Design	81 (2006) 1203-1209
237	2006	Sagara, A., Imagawa, S., Tanaka, T., Muroga, T., Kubota, Y., Dolan, T., Hashizume, H., Kunugi, T., Fukada, S., Shimizu, A., Terai, T., Mitarai, O.	Carbon tiles as spectral-shifter for long-life liquid blanket in LHD-type reactor FFHR	Fusion Engineering and Design	81 (2006) 1299–1304
238	2006	Sagara, A., Mitarai, O., Imagawa, S., Morisaki, T., Tanaka, T., Mizuguchi, N., Dolan, T., Miyazawa, J., Takahata, K., Chikaraishi, H., Yamada, S., Seo, K., Sakamoto, R., Masuzaki, S., Muroga, T., Yamada, H., Fukada, S., Hashizume, H., Yamazaki, K., Mito, T., Kaneko, O., Mutoh, T., Ohyabu, N., Noda, N., Komori, A., Sudo, S., Motojima, O., and FFHR design group	Conceptual design activities and key issues on LHD-type reactor FFHR	Fusion Engineering and Design	81 (2006) 2703–2712
239	2006	Tanaka, T., Sagara, A., Muroga, T., Youssef, M.Z.	Development of three-dimensional neutronics calculation system for design studies on helical reactor FFHR	Fusion Engineering and Design	81 (2006) 2761–2766
240	2008	Tanaka, T., Sagara, A., Muroga, T., Youssef, M.Z.	Neutronics Investigation of Advanced Self-Cooled Liquid Blanket Systems in Helical Reactor	Nuclear Fusion	48, No. 3 (2008) 035005
241	2007	Muroga, T., Tanaka, T., Li, Z., Sagara, A., and Sze, D.K.	Tritium control for Flibe/V-alloy blanket system	Fusion Science & Technology	52 (2007) 682-686
242	2007	Satoh, T., Yuki, K., Chiba, S., Hashizume, H., Sagara, A.	Heat Transfer Performance for High Prandtl and High Temperature Molten Salt Flow in Sphere-Packed Pipes	Fusion Science & Technology	52 (2007) 618-624
243	2007	Fukada, S., Katayama, K., Terai, T., Sagara, A.	Recovery of Tritium from Flibe Blanket in Fusion Reactor	Fusion Science & Technology	52 (2007) 677-681

Task 3-2 Materials Modeling

244	2001	Morishita, K., Wirth, B.D., Diaz de la Rubia, T., Kimura, A.	Effects of Helium on Radiation Damage Processes in Iron	Proc. Fourth Pacific Rim Int. Conf. on Advanced Materials and Processing (PRICM4), (The Japan Institute of Metals, 2001)	1383-1386
245	2001	Morishita, K., Sugano, R., Iwakiri, H., Yoshida, N., Kimura, A.	Thermal helium desorption from α-Iron	Proc. Fourth Pacific Rim Int. Conf. on Advanced Materials and Processing (PRICM4), (The Japan Institute of Metals, 2001)	1395-1398
246	2002	Sugano, R., Morishita, K., Iwakiri, H., Yoshida, N.	Effects of dislocation on thermal helium desorption from iron and ferritic steel	Journal of Nuclear Materials	307-311 (2002) 941-945
247	2002	Iwakiri, H., Morishita, K., Yoshida, N.	Effects of helium bombardment on the deuterium behavior in tungsten	Journal of Nuclear Materials	307-311 (2002) 135-138
248	2003	Morishita, K., Sugano, R., Wirth B.D., Diaz de la Rubia, T.	Thermal stability of helium-vacancy clusters in iron	Nuclear Instruments and Methods in Physics Research Section B	202 (2003) 76-81
249	2003	Morishita, K., Sugano, R., Wirth, B.D.	MD and KMC modeling of the formation and migration of He-V clusters in Fe	Journal of Nuclear Materials	323 (2003) 243-250
250	2003	Morishita, K., Sugano, R., Wirth, B.D.	Thermal stability of helium-vacancy clusters and bubble formation	Fusion Science Technology	44 (2) (2003) 441-445
251	2003	Sugano, R., Morishita, K., Kimura, A	Helium accumulation behavior in iron based model alloys	Fusion Science Technology	44 (2) (2003) 446-449
252	2004	Sugano, R., Morishita, K., Kimura, A., Iwakiri, H., Yoshida, N.	Microstructural evolution in Fe and Fe-Cr model alloys after He+ ion irradiations	Journal of Nuclear Materials	329-333 (2004) 942-946

253	2004	Morishita, K., Sugano, R.	Atomistic Modeling of Helium Bubble Formation in Fe during Irradiation	Conference proceedings of Second International Conference on Multiscale Materials Modeling (MMM-II), UCLA, Los Angeles, CA, USA, 2004	525-527
254	2004	Satou, M., Komatsu, N., Sawada, T., Abe, K.	Calculation of electronic structure at bonding interface between vanadium and oxide ceramics for insulator coating applications	Journal of Nuclear Materials	329-333 (2004) 1571-1574
255	2004	Satou, M., Abe, K., Kioussis, N., Ghoniem, N.	Ideal Interfacial Strength Between Vanadium and Oxide Ceramics	Second International Conference on Multiscale Materials Modeling Proceedings (2004)	135-137
256	2005	Okita, T., Wolfer, W.G., Garner, F.A., Sekimura, N.	Effects of titanium additions to austenitic ternary alloys on microstructural evolution and void swelling	Philosophical Magazine	85 No.18/21 (2005) 2033
257	2006	Morishita, K., Sugano, R.	Mechanism map for nucleation and growth of helium bubbles in metals	Journal of Nuclear Materials	353 (2006) 52-65
258	2007	Morishita, K., Sugano, R.	Modeling of Helium Bubble Migration in bcc Fe	Nuclear Instruments and Methods in Physics Research Section B	255 (2007) 52-56
259	2007	Watanabe, Y., Iwakiri, H., Yoshida, N., Morishita, K., Kohyama, A.	Formation of interstitial loops in tungsten under helium ion irradiation: Rate theory modeling and experiment	Nuclear Instruments and Methods in Physics Research Section B	255 (2007) 32-36
260	2007	Morishita, K.	Atomistic evaluation of the point defect capture efficiency of He-V clusters in α-Fe	Nuclear Instruments and Methods in Physics Research Section B	255 (2007) 41-46
261	2007	Morishita, K.	Nucleation path of helium bubbles in metals during irradiation	Philosophical Magazine	87 (2007) 1139-1158
262	2009	Morishita, K., Watanabe, Y., Kohyama, A., Heinisch, H.L., Gao, F.	Nucleation and growth of vacancy clusters in β-SiC during irradiation	Journal of Nuclear Materials	386-388 (2009) 30-32
263	2007	Okita, T., Sato, T., Sekimura, N., Iwai, T., Garner, F.A.	The Synergistic Influence of Temperature and Displacement Rate on Microstructural Evolution of Ion-Irradiated Model Austenitic Alloy Fe-15Cr-16Ni	Journal of Nuclear Materials	367-370, Part 2 (2007) 930-934
264	2007	Hu, Q., Sharafat, S., Ghoniem, N.	Modeling Space-Time Dependent Helium Bubble Evolution in Tungsten Armor Under IFE Conditions	Fusion Science & Technology	52 [3] (2007) 574-578

CHAPTER 5 TITAN

1. Journal Paper

Task 1-1 Tritium and mass transfer in first wall

No	Year	Authors	Title of Paper	Journal	Vol. (Year) Page (Start) -Page(End) or Identification No.
1	2007	D. Nishijima, R. P. Doerner, M. J. Baldwin, E. M. Hollmann, and R. P. Seraydarian, Y. Ueda	Spectroscopic determination of the singly ionized helium density in low electron temperature plasmas mixed with helium in a linear divertor plasma simulator	Phys. Plasmas	14 (2007) 103509
2	2007	S. Kajita, S. Takamura, N. Ohno, T. Nishimoto	Alleviation of Damaged Tungsten Having Helium Holes/Bubbles by Use of Transient Heat Load	Plasma Fusion Res.	2 (2007) 9-10
3	2007	N. Ohno, S. Kajita, D. Nishijima, S. Takamura	Surface Modification at Tungsten and Tungsten coated Graphite due to Low Energy and High Fluence Plasma and Laser Pulse Irradiation	J. Nucl. Mater.	363-365 (2007) 1153-1159
4	2007	S. Kajita,S. Takamura, N. Ohno,D. Nishijima,H. Iwakiri, N. Yoshida	Sub-ms Laser Pulse Irradiation on Tungsten Target Damaged by Exposure to Helium Plasma	Nucl. Fusion	47 (2007) 1358-1366
5	2007	S.Kajita, N.Ohno, S.Takamura, W.Sakaguchi, D.Nishijima	Plasma-assisted Laser Ablaion of Tungsten: Reduction in Ablation Power Threshold Due to Bursting of Holes/Bubbles	Applied Phys. Let.	91 (2007) 261501
6	2008	M.J. Baldwin and R.P. Doerner	Helium induced nanoscopic morphology	Nucl. Fusion	48 (2008) 035001
7	2009	S.Kajita, N.Ohno, W.Sakaguchi, M.Takagi	Visualized blow-off from helium irradiated tungsten in response to ELM-like heat load	Plasma Fusion Res.	4 (2009) 4
8	2009	S.Kajita, S.Takamura, N.Ohno	Prompt ignition of a unipolar arc on helium irradiated tungsten	Nucl. Fusion	49 (2009) 032002
9	2009	W.Sakaguchi, S.Kajita, N.Ohno, M.Takagi	In situ reflectivity of tungsten mirrors under helium plasma exposure	J. Nucl. Mater.	390-391 (2009) 179-182
10	2009	S.Kajita, W.Sakaguchi, N.Ohno	Formation and mitigation of fiberform nanostructured tungsten by helium and sub-ms laser pulse irradiations	Plasma Devices and Operations	17 (2009) 165-173
11	2009	Shin Kajita, Shuichi Takamura and Noriyasu Ohno	Prompt ignition of a unipolar arc on helium irradiated tungsten	Nucl. Fusion	49 (2009) 032002
12	2009	Shin Kajita, Wataru Sakaguchi, Noriyasu Ohno, Naoaki Yoshida, Tsubasa Saeki	Formation process of tungsten nanostructure by the exposure to helium plasma under fusion relevant plasma conditions	Nucl. Fusion	49 (2009) 095005
13	2009	N.Ohno, M.Yoshimi, M.Tokitani, S.Takamura, K.Tokunaga, N.Yoshida	Spherical cauliflower-like caron dust formed by interaction between deuterium plasma and graphite target and its internal structure	J. Nucl. Mater.	390-391 (2009) 61-64
14	2009	K R Umstadter, R Doerner and G Tynan	Effect of bulk temperature on erosion of tungsten plasma-facing components subject to simultaneous deuterium plasma and heat pulses	Phys. Scr.	T138 (2009) 014047
15	2009	K.R. Umstadter, R. Doerner, G. Tynan	Enhanced erosion of tungsten plasma-facing components subject to simultaneous heat pulses and deuterium plasma	J. Nucl. Mater.	386–388 (2009) 751–755
16	2009	M. Miyamoto, D. Nishijima, Y. Ueda, R.P. Doerner	Observations of suppressed retention and blistering for tungsten exposed to deuterium–helium mixture plasmas	Nucl. Fusion	49 (2009) 065035
17	2009	M.J. Baldwin, R.P. Doerner, D. Nishijima, K. Tokunaga, Y. Ueda	The effects of high fluence mixed-species (deuterium, helium, beryllium)	J. Nucl. Mater.	390–391 (2009) 886–890
18	2010	K.Tokunaga, M.J. Baldwin, R.P. Doerner, D. Nishijima, H. Kurishita, T. Fujiwara, K. Araki, Y. Miyamoto, N. Ohno and Y. Ueda	Nanoscale surface morphology of tungsten induced by Be-seeded D-He plasma exposure	J. Nucl. Mater.	to be published

Task 1-2 Tritium behavior in blanket systems

19	2008	S. Fukada, Y. Edao, Y. Maeda, T. Norimatsu	Tritium recovery system for Li-Pb of Inertial Fusion Reactor	Fusion Eng. Des.	83 (2008) 747-751
20	2008	J. P. Sharpe, N.B. Morley, T. Terai, T. Kunugi, T. Yokomine, K. Messadek, S. Smolentsev, S. Konishi, S. Fukada	US/Japan TITAN collaboration activities on tritium and MHD flow control for lead-lithium eutectic blankets	TOFE-18	Sep-08
21	2008	P. Calderoni, P. Sharpe, S. Konishi, K. Noborio, T. Kamei, T. Terai	Measurement of hydrogen and deuterium solubility in the eutectic lead-lithium alloy Name of Conference	SOFT-25	Sep-08
22	2008	Y. Maeda, S. Fukada, Y. Edao	Solubility, diffusivity and isotopic exchange rate of hydrogen isotopes in Li-Pb	Fusion Sci. Tech.	54 (2008) 131-134
23	2009	Y. Edao, S. Fukada, H. Noguchi, Y. Maeda, K. Katayama	Isotope effects of hydrogen isotope absorption and diffusion in $Li_{0.17}Pb_{0.83}$ eutectic alloy	Fusion Sci. Tech.	56 (2009) 831-835
24	2009	D. Masuyama, T. Oda, S. Fukada, S. Tanaka	Chemical state and diffusion behavior of hydrogen isotopes in liquid lithium-lead	Chem. Phys. Let.	483 (2009) 214-218
25	2009	S. Fukada, Y. Edao, T. Norimatsu	Design of tritium recovery system for laser fusion reactor	Annual Report of NIFS	(2009) 496
26	2010	Y. Edao, H. Noguchi, S. Fukada	Experiment of hydrogen isotopes permeating through Li-Pb with diffusion, dissolution and isotopic exchange	J. Nucl. Mater.	submitted
27	2010	S. Fukada, Y. Edao	Unresolved issues on tritium mass transfer in Li-Pb liquid blankets	J. Nucl. Mater.	submitted
28	2010	S. Fukada, Y. Edao, A. Sagara	Effects of simultaneous transfer of heat and tritium through Li-Pb or Flibe blanket	Fusion Eng. Des.	In press
29	2010	Y. Edao, H. Noguchi, S. Fukada	Isotopic exchange rate between hydrogen and deuterium in the process of permeating through $Li_{0.17}Pb_{0.83}$	Fusion Eng. Des.	In press
30	2010	R. Nadaoka, K. Uriu, Y. Yamamoto, and S. Konishi	Difffusion and Solution of Hydrogen Isotopes in Lithium-Lead Blanket	Proc. Of the 23rd SOFE	SP4A-4 (2010)
31	2010	S. Konishi and Y.Wu	LiPb blankets for TBM and DEMO	Fusion Eng. Des.	submitted

Task 1-3 Flow control and thermofluid modeling

32	2007	J. Takeuchi, S. Satake, T. Kunugi, T. Yokomine, N. Morley, M. Abdou	Development Of PIV Technique Under Magnetic Fields And Measurement Of Turbulent Pipe Flow Of Flibe Simulant Fluid	Fusion Sci. Tech.	52 (2007) 860-864
33	2007	T. Yokomine, J. Takeuchi, H. Nakaharai, S. Satake, T. Kunugi, N. Morley, M. Abdou	Experimental Investigation Of Turbulent Heat Transfer Of High Prandtl Number Fluid Flow Under Strong Magnetic Field	Fusion Sci. Tech.	52 (2007) 625-629
34	2007	H. Nakaharai, J. Takeuchi, T. Yokomine, T. Kunugi, S. Satake, N. Morley, M. Abdou	The influence of a magnetic field on turbulent heat transfer of high Prandtl number fluid	Experimental Thermal and Fluid Science	32 (2007) 23–28
35	2007	S. Smolentsev, R. Moreau	One-Equation Model for Quasi-Two-Dimensional Turbulent Magnetohydrodynamic Flows	Phys. Fluids	19 (2007) 078101
36	2007	A. Beltrán, S. Cuevas, S. Smolentsev	Instabilities in the Flow past Localized Magnetic Fields	J. Phys.: Conference Series	64 (2007) 012009
37	2008	J. Takeuchi, S. Satake, N.Morley, T. Kunugi, T. Yokomine, M.Abdou	Experimental study of MHD effects on turbulent flow of Flibe simulant fluid in a circular pipe	Fusion Eng. Des.	83 (2008) 1082–1086
38	2008	Y. Yamamoto, T. Kunugi, S. Satake, S. Smolentsev	DNS and k–ε model simulation of MHD turbulent channel flows with heat transfer	Fusion Eng. Des.	83 (2008) 1309-1312
39	2008	K. Yuki, M. Okumura, H. Hashizume, S. Toda, N. Morley, A. Sagara	Flow visualization and heat transfer characteristics for sphere-packed pipes	J. Thermophys. Heat Transfer	22(4) (2008) 638-648

40	2008	S. Satake, N. Yoshida, T. Kunugi, K. Takase, Y. Ose, T. Kano	DNS of turbulent heat transfer under a uniform magnetic field at high Reynolds number	Fusion Eng. Des.	83 (2008) 1092-1096
41	2008	S. Smolentsev, N.B. Morley, C. Wong and M. Abdou	MHD and heat transfer considerations for the US DCLL blanket for DEMO and ITER TBM	Fusion Eng. Des.	83 (2008) 1788-1791
42	2008	S. Smolentsev, R. Moreau, M. Abdou	Characterization of Key Magnetohydrodynamic Phenomena in PbLi Flows for the US DCLL Blanket	Fusion Eng. Des.	83 (2008) 771-783
43	2008	N. Morley, Y. Katoh, S. Malang, B.A. Pint, A.R. Raffray, S. Sharafat, S. Smolentsev, G.E. Youngblood	Recent Research and Development for the Dual-Coolant Blanket Concept in the US	Fusion Eng. Des.	83 (2008) 920-927
44	2008	N. Morley, M.-J. Ni, R. Munipalli, P. Huang, M. Abdou	MHD simulations of liquid metal flow through a toroidally-oriented manifold	Fusion Eng. Des.	83 (2008) 1335-1339
45	2009	Y.Ueki, M.Hirabayashi, T.Kunugi, T. Yokomine and K. Ara	Acoustic Properties of Pb-17Li Alloy for Ultrasonic Doppler Velocimetry	Fusion Sci. Tech.	56 (2009) 846-850
46	2009	N.Morley, A.Medina, M.Abdou	Meaurement of Specific Electrical Contact Resistance Between SiC and Lead-Lithium Eutectic Alloy	Fusion Sci. Tech.	56 (2009) 195-200
47	2009	S.Smolentsev, S. Malang	Double-Layer Flow Channel Insert for Electric and Thermal Insulation in the Dual-Coolant Lead-Lithium Blanket	Fusion Sci. Tech.	56 (2009) 201-205
48	2009	N.Vetcha, S. Smolentsev, M.Abdou	Theoretical Study of Mixed Convection in Poloidal Flows of DCLL Blanket	Fusion Sci. Tech.	56 (2009) 851-855
49	2009	K. Messadek, M.Abdou	Experimental study of the MHD flow in a prototypic inlet manifold section of the DCLL blanket	Magnetohydrodynamics	45 (2009) 233-238
50	2009	R. Moreau, S. Smolentsev, S. Cuevas	Flow in an Insulating Rectangular Duct at the Entry of a Magnet	Magnetohydrodynamics	45 (2009) 181-192
51	2010	S. Smolentsev, S. Cuevas, A. Beltrán	Induced Electric Current-Based Formulation in Computations of Low Magnetic Reynolds Number Magnetohydrodynamic Flows	J. Comput. Phys	229 (2010) 1558-1572
52	2010	S. Smolentsev, Z.Xu, Ch.Pan, M.Abdou	Numerical and Experimental Studies of MHD flow in a Rectangular Duct with a Non-Conducting Flow Insert	Magnetohydrodynamics	46 (2010) 99-111
53	2010	Y.Ueki, T.Kunugi, M. Kondo, A.Sagara, N.Morley, M.Abdou	Consideration of Alumina Coating Fabricated by Sol-gel Method for PbLi Flow	Zero-Carbon Energy Kyoto 2009 (Springer Book)	(2010) 373-379
54	2010	Y.Ueki, T.Kunugi, N.Morley, M.Abdou	Consideration of Alumina Coating Fabricated by Sol-gel Process as MHD Coating against Liquid Pb-17Li	Fusion Eng. Des.	2010 in press
55	2010	S. Smolentsev, R. Moreau, L. B ühler, C. Mistrangelo	MHD Thermofluid Issues of Liquid-Metal Blankets: Phenomena and Advances	Fusion Eng. Des.	2010 in press
56	2010	S. Smolentsev, C. Wong, S. Malang, M. Dagher, M. Abdou	MHD Considerations for the DCLL Inboard Blanket and Access Ducts	Fusion Eng. Des.	In press
57	2010	C.P.C. Wong, M. Abdou, M. Dagher, Y. Katoh, R.J. Kurtz, S. Malang, E.P. Marriott, B.J. Merrill, K. Messadek, N.B. Morley, M.E. Sawan, S. Sharafat, S. Smolentsev, D.K. Sze, S. Willms, A. Ying, M.Z. Youssef	An Overview of the US DCLL ITER-TBM Program	Fusion Eng. Des.	In press

Task2-1 Irradiation-tritium synergism

58	2008	Y. Oya, P. Calderoni, M. Shimada, Y. Hatano, R. Kolasinski, P. Sharpe, K. Okuno	Deuterium Retention and Desorption Behaviors in Tungsten Exposed to TPE	SOFT-25	Sep. 15-19, 2008, Rostock, Germany
59	2009	Y. Hatano, M. Hara, Y. Oya, P. Calderoni, P. Sharpe, M. Shimada, Y. Katoh, T. Yamamoto	Tungsten Related Activities in Japan-US Joint Research Project TITAN Task 2-1	ICFRM-14	Sep. 6-11, 2009, Sapporo, Japan
60	2009	Y. Oya, Y. Inagaki, S. Suzuki, H. Ishikawa, Y. Kikuchi, A. Yoshikawa, T. Iwakiri, N. Ashikawa, A. Sagara, N. Yoshida, K. Okuno	Behavior of hydrogen isotope retention in carbon implanted tungsten	J. Nucl. Mater.	390-391 (2009) 622-625
61	2009	Y. Oya, S. Suzuki, W. Wang, R. Kurata, M. Kobayashi, N. Ashikawa, A. Sagara, N. Yoshida, K. Okuno	Correlation between deuterium retention and microstructure change for tungsten under triple ion implantation	Phys. Scr.	T138 (2009) 014051
62	2009	M. Kobayashi, S. Suzuki, W. Wang, R. Kurata, K. Kida, N. Ashikawa, A. Sagara, N. Yoshida, Y. Oya, K. Okuno	Trapping behaviour of deuterium ions implanted into tungsten simultaneously with carbon ions	Phys. Scr.	T138 (2009) 014050
63	2010	R. D. Kolasinski, M. Shimada, T. Otsuka, J. M. Shea, T. R. Allen, P. Calderoni, J. P. Sharpe, and R. A. Causey	Hydrogen isotope retention, surface profile and depth profile of polycrystalline tungsten exposed to high flux deuterium plasma	Phys. Scr.	(2009) 014042

Task2-2 Joining and coating integrity

64	2007	N. Baluc, D. S. Gelles, S. Jitsukawa, A. Kimura, R. L. Klueh, G. R. Odette, B. van der Schaaf and Jinnan Yu	Status of Reduced Activation Ferritic/martensitic Steel Development	J. Nucl. Mater	367-370 (2007) 33-41
65	2007	A. Kimura, R. Kasada, A. Kohyama, H. Tanigawa, T. Hirose, K. Shiba, S. Jitsukawa, S. Ohtsuka, S. Ukai, M.A. Sokolov, et al.	Recent Progress in US-Japan Collaborative Research on Ferritic Steels R&D	J. Nucl. Mater	367-370 (2007) 60-67
66	2007	J.S. Lee, C.H. Jang, I.S. Kim and A. Kimura	Embrittlement and Hardening during Thermal Aging of High Cr Oxide Dispersion Strengthened Alloys	J. Nucl. Mater	367-370 (2007) 229-233
67	2007	H.S. Cho, R. Kasada and A. Kimura	Effects of Neutron Irradiation on the Tensile Properties of High-Cr Oxide Dispersion Strengthened Ferritic Steels	J. Nucl. Mater	367-370 (2007) 239-243
68	2007	C.P.C. Wong, V. Chernov, A. Kimura, Y. Katoh, N. Morley, T. Muroga, K.W. Song, Y.C. Wu and M. Zmitko	ITER-Test Blanket Module Functional Materials	J. Nucl. Mater	367-370 (2007) 1287-1292
69	2007	K. Yutani, H. Kishimoto, R. Kasada and A. Kimura	Evaluation of Helium effects on Swelling Behavior of Oxide Dispersion Strengthened Ferritic Steels under Ion Irradiation	J. Nucl. Mater	367-370 (2007) 423-427
70	2007	M.A. Sokolov, A. Kimura, H. Tanigawa and S. Jitsukawa	Fracture Toughness Characterization of JLF-1 Steel after Irradiation in HFIR to 5 dpa	J. Nucl. Mater	367-370 (2007) 644-647
71	2007	S.Ukai and S. Ohtsuka	Nano-mesoscopic Structural Control in 9Cr-ODS Ferritic/martensitic Steels	Energy Mater.	2(1) (2007) 26-35
72	2007	E.M.Tabakin, S.V.Kuzmin, Yu.V.Ivanovich, S.Ukai, et al.	Investigation of Y2O3 Distribution in Welding Joints of Thin Claddings from Dispersion-hardened Steel	Atomic Energy	102(6) (2007) 430

73	2007	S.Yamashita, N.Akasaka, S.Ukai, et al.	Microstructural Development of a Heavily Neutron-irradiated ODS Ferritic Steel (MA957) at Elevated Temperature	J. Nucl. Mater.	367-370 (2007) 202
74	2008	Y. Katoh, T. Hinoki, H.C. Jung, J.S. Park, S. Konishi, M. Ferraris	DEVELOPMENT AND EVALUATION OF SILICON CARBIDE JOINTS FOR APPLICATIONS IN RADIATION ENVIRONMENT	Fusion Materials Semi-Annual Progress Reports	DOE/ER-0313/44 (2008) 26-32
75	2009	C. Chun Fu, A. Kimura, M. Samaras, M. Serrano de Caro, R E. Stoller	Materials for Future Fusion and Fission Technologies	Materials Research Society Symposium Proceedings	December 2-4, 2008, Boston, Massachusetts, USA
76	2009	C. Park, K. Noborio, R. Kasada, Y. Yamamoto, G. Nam, S. Konishi	Compatibility of materials for advanced blanket with liquid LiPb	23rd Symposium on Fusion Engineering	May31-June 5, 2009, San Diego,California, USA
77	2009	N. Okuda, R. Kasada, A. Kimura	Statistical evaluation of anisotropic fracture behavior of ODS ferritic steels by using small push tests	J. Nucl. Mater.	386-388 (2009) 974-978
78	2009	A.Hasegawa, M. Ejiri, S. Nogami, M. Ishiga, R. Kasada, A. Kimura, K. Abe,S. Jitsukawa	Effects of helium on ductile-brittle transition behavior ofreduced-activation ferritic steels after high-concentration heliumimplantation at high temperatureJournal of Nuclear Materials	J. Nucl. Mater.	386-388 (2009) 241-244
79	2009	H.Kishimoto, R. Kasada, O. Hashitomi, A. Kimura	Stability of Y–Ti complex oxides in Fe–16Cr–0.1Ti ODS ferritic steel beforeand after heavy-ion irradiationJournal of Nuclear Materials	J. Nucl. Mater.	386-388 (2009) 533-536H
80	2009	T. Nagasaka, R. Kasada, A. Kimura, Y. Ueda, T. Muroga	Thermophysical properties and microstructure of plasma-sprayed tungsten coating on low activation materials	Fusion Sci. Tech.	56 (2009) 1053-1057
81	2009	H. Watanabe, A. Higashijima, N. Yoshida, T. Nagasaka and T. Muroga	The microstructure of laser welded Y doped V–4Cr–4Ti alloys after ion irradiation	J. Nucl. Mater.	386-388 (2009) 598-601
82	2009	N. Hara, S. Nogami, T. Nagasaka, A. Hasegawa, H. Tanigawa, T. Muroga	Mechanical Property Changes and Irradiation Hardening Due to Dissimilar Metal Welding with Reduced Activation Ferritic/Martensitic Steel and 316L Stainless Steel	Fusion Sci. Tech.	56 (2009) 318-322
83	2010	Naoko Oono, Sanghoon Noh, Noriyuki Iwata, Takuya Nagasaka, Ryuta Kasada, Akihiko Kimura	Metallurgical analysis of ODS steel/Tungsten joints	J. Nucl. Mater.	submitted
84	2010	R. Kasada, S.G. Lee, J. Isselin, J.H. Lee, T. Omura, A. Kimura, T. Okuda, M. Inoue, S. Ukai, S. Ohnuki, T. Fujisawa, F. Abe	Anisotropy in Tensile and Ductile-Brittle Transition Behavior of ODS Ferritic Steels	J. Nucl. Mater.	submitted
85	2010	M. Nono, T. Nakajima, M. Iwama, R. Kasada, A. Kimura	SCC Behavior of SUS316L in The High Temperature Pressurized Water Environment	J. Nucl. Mater.	submitted
86	2010	Sanghoon Noh, R. Kasada，A. Kimura, Seung Hwan C. Park, S. Hirano	Microstructure and Mechanical Properties of Friction Stir Processed ODS ferritic steels	J. Nucl. Mater.	submitted
87	2010	K. Yabuuchi, H. Yano, R. Kasada, A. Kimura	Dose dependence of irradiaiton hardening of binary ferritic alloys irradiated with Fe3+ ions	J. Nucl. Mater.	submitted
88	2010	J. ISSELIN, R. Kasada, A. Kimura, T. Okuda, M. Inoue, S. Ukai, S. Ohnuki, T. Fujiwara, T. F. Abe	Evaluation of Fracture Behavior of Recrystallized and Aged High-Cr ODS Ferritic Steels	J. Nucl. Mater.	submitted
89	2010	H. Noto, S. Ukai, S. Hayashi and A. Kimura	Transient Liquid-Phase (TLP) Bonding of ODS Martensitic Steels	J. Nucl. Mater.	to be published

90	2010	Y. Sugino, S. Ukai and S. Hayashi	Directional Recrystallization of ODS Alloys by Means of Zone Annealing	J. Nucl. Mater.	to be published
91	2010	M. Yamamoto, S. Ukai, S. Hayashi, T. Kaito and S. Ohtsuka	Reverse Phase Transformation from Ferrite to Austenite in 9CrODS Ferritic Steels	J. Nucl. Mater.	to be published
92	2010	S.Ukai, M. Yamamoto, N. Chikata, S. Hayashi, T. Kaito, S. Ohtsuka, T. Azuma and S. Ohsaki	Ultra High-Strength of AUSFOMed 9CrODS Ferritic Steels	J. Nucl. Mater.	to be published
93	2010	M. Ferraris, M. Salvo, V. Casalegno, Y. Katoh, A. Kohyama, T. Hinoki	Joining of SiC-based materials for nuclear energy applications	J. Nucl. Mater.	submitted
94	2010	Charles H. Henager, Jr.	Low-Activation Joining of SiC/SiC Composites for Fusion Applications	J. Nucl. Mater.	submitted
95	2010	Hun-Chea Jung, Tatsuya Hinoki, Yutai Katoh, Akira Kohyama	Development of the testing method of shear stress for NITE-SiC joining material	J. Nucl. Mater.	submitted
96	2010	M. Ferraris, A. Ventrella, M. Salvo, H. Shaohua, V. Casalegno, S. Rizzo, Y. Katoh, H. Jung, T. Hinoki, A. Kohyama	Joining of SiC and SiC/SiC for nuclear applications	Ceramic Engineering & Science Proceedings	submitted
97	2010	N. Hashimoto, H. Tanigawa, H. Kinoshita, and S. Ohnuki	Multiple-beam Irradiation Effects in Electron-Beam-Welded F82H Joint	J. Nucl. Mater.	submitted
98	2010	H Seto, N. Hashimoto, H. Kinoshita, and S. Ohnuki	Effects of multi-beam irradiation on defect formation in Fe-Cr alloys	J. Nucl. Mater.	submitted
99	2010	T. Nagasaka, T. Muroga, H. Watanabe, R. Kasada, N. Iwata, A. Kimura	Mechanical property of V-4Cr-4Ti alloy after first wall coating with tungsten	J. Nucl. Mater.	submitted
100	2010	N. Hashimoto, H. Seto, N. Yamaguchi, H. Kinoshita, and S. Ohnuki	Multiple-beam Irradiation Effects in Ferritic steels and EB-Welded F82H Joint	Materials Research Society 2010 Spring Meeting	Apr. 5-9, 2010, San Francisco, USA

Task2-3 Dynamic deformation

101	2008	Y. Katoh, K. Ozawa, L.L. Snead, Y.B.Choi, T. Hinoki, A. Hasegawa	MECHANICAL CHARACTERIZATION OF SILICON CARBIDE COMPOSITES FOR HFIR-18J EXPERIMENT IN UNIRRADIATED CONDITION	Fusion Materials Semi-Annual Progress Reports	DOE/ER-0313/45 (2008) 21-34
102	2008	Y. Katoh, Y.B.Choi, T. Hinoki	TITAN TASK 2-3 SILICON CARBIDE BEND STRESS RELAXATION CREEP EXPERIMENT	Fusion Materials Semi-Annual Progress Reports	DOE/ER-0313/45 (2008) 140-145
103	2009	Shuhei Nogami, Akira Hasegawa, Takahide Murayama, Nobuyuki Otake, Manabu Satou, Katsunori Abe	Compatibility between SiC and Li ceramics for solid breeding blanket system	J. Nucl. Mater.	386-388 (2009) 218-221
104	2009	T. Nozawa, T. Hinoki, A. Hasegawa, A. Kohyama, Y. Katoh, L.L. Snead, C.H. Henager, J.B.J. Hegeman	Recent advances and issues in development of silicon carbide composites for fusion applications	J. Nucl. Mater.	386 (2009) 622-627
105	2009	K. Shimoda,J.S. Park, T. Hinoki, A. Kohyama	Microstructural optimization of high-temperature SiC/SiC composites by NITE process	J. Nucl. Mater.	386 (2009) 634-638
106	2009	K. Shimoda,A. Kohyama, T. Hinoki	High mechanical performance SiC/SiC composites by NITE process with tailoring of appropriate fabrication temperature to fiber volume fraction	COMPOSITES SCIENCE AND TECHNOLOGY	69[10] (2009) 1623-1628
107	2008	K. Shimoda,J.S. Park, T. Hinoki, A. Kohyama	Influence of pyrolytic carbon interface thickness on microstructure and mechanical properties of SiC/SiC composites by NITE process	COMPOSITES SCIENCE AND TECHNOLOGY	68[1] (2008) 98-105

108	2010	K. Abe, S. Nogami, A. Hasegawa, T. Hinoki, T. Nozawa	Study on Stress Relaxation Behavior of Silicon Carbide by BSR method	J. Nucl. Mater.	submitted
109	2010	Y. B. Choi, T. Hinoki, K. Ozawa, Y. Katoh	Tansthickness Tensile Properties of NITE SiC/SiC Composite Irradiated at High Temperature	J. Nucl. Mater.	submitted
110	2010	Yutai Katoh, Tatsuya Hinoki, Kazumi Ozawa, Yong-Bum Choi, Akira Hasegawa, Lance L. Snead	Properties of Advanced SiC Fiber Composites Irradiated at High Temperatures: Results from US/Japan HFIR-18J Experiment	J. Nucl. Mater.	submitted

Common Task MFE/IFE system integration modeling

111	2010	Akio Sagara, Yuri Igitkhanov, Farrokh Najmabadi	Review of stellarator/heliotron design issues towards MFE DEMO	Fusion Eng. Des.	In press.
112	2010	S. Fukada, Y. Edao, A. Sagara	Effects of simultaneous transfer of heat and tritium through Li–Pb or Flibe blanket	J. Nucl. Mater.	In press.

2. Conference Paper

Task 1-1 Tritium and mass transfer in first wall

No	Year	Authors	Title of Paper	Conference Name	Month Date, Year, Place, Country
1	2010	K.Tokunaga, M.J. Baldwin, D. Nishijima, R.P. Doerner, S. Nagata, B.Tsuchiya,H. Kurishita, T. Fujiwara, K.Araki, Y. Miyamoto, N. Ohno and Y. Ueda	Properties of re-deposited layer formed by Be seeded D-He mixture plasma tungsten interactions	PSI-19	May 24-28,2010, San Diego,USA
2	2010	T. Otsuka, M. Shimada, R. Kolasinski, et al.	Application of tritium imaging plate technique to examine tritium behaviors on the surface and in the bulk of plasma exposed materials	PSI-19	May. 24-28, 2010, San Diego, USA
3	2010	T. Otsuka, M. Shimada, T. Tanabe, et al.	Behavior of tritium near surface region of metals exposed to tritium plasma	Tritium-9	Oct. 24-29, 2010, Nara, Japan
4	2010	Noriyasu Ohno, Shin Kajita, Yuki Hirahata, Masato Yamagiwa, Makoto Takagi	Influence of Crystallographic Orientation on Helium Bubble and Fuzz Structure Formation in Tungsten	PSI-19	May 24-28, 2010, San Diego, U.S.A.
5	2010	Y. Kikuchi, D. Nishijima, M. Nakatsuka, K. Ando, T. Higashi, N. Fukumoto, M. Nagata, R.P. Doerner, Y. Ueda	Experimental Study of Plasma-Material Interaction Under ELM-like Heat Loads	PSI-19	May 24-28, 2010, San Diego, U.S.A.
6	2010	M. Miyamoto, D. Nishijima, M.J. Baldwin, R.P. Doerner, Y. Ueda, Y. Yasunaga, N. Yoshida, and K. Ono	Microscopic Damage of Tungsten Exposed to Duetrium-Helium Mixture Plasma in PISCES and Its Impacts on Retention Property	PSI-19	May 24-28, 2010, San Diego, U.S.A.

Task 1-2 Tritium behaviorin blanket systems

7	2010	Y. Edao, H. Noguchi, H. Okitsu, S. Fukada	Permeation behavior of two-component hydrogen isotopes in lithium-lead eutectic alloy	Tritium-9	Oct. 24-29, 2010, Nara, Japan
8	2010	S. Konishi , T. Shibata, K. Noborio, and Y. Yamamoto	Strategy for environmentally and socially attractive fusion tritium system	Tritium-9	Oct. 24-29, 2010, Nara, Japan
9	2010	S. Konishi , M.Ichinose, and Y. Yamamoto	Fusion-Biomass Hybrid Concept and its Implication in Fusion Development	23rd IAEA Fusion Energy Conference	10-16 October 2010 Daejon, Republic of Korea

Task 1-3 Flow control and thermofluid modeling

10	2010	Y.Ueki, K.Nagai, T.Kunugi et al.	Contact Angle Measurement of Molten Lead-Lithium on Silicon Carbide Surfaces	SOFT-26	Sep. 28- Oct. 1, 2010, Porto, Portugal

Task2-1 Irradiation-tritium synergism

11	2010	M. Shimada, Y. Hatano, P. Calderoni, T. Oda, Y. Oya, M. Sokolov, K. Zhang, R. Kolasinski, J. P. Sharpe	Deuterium Retention in Neutron-Irradiated Tungsten and Molybdenum Exposed to High Flux Plasma in TPE	PSI-19	May 24-28, 2010, San Diego, USA
12	2010	T. Oda, M. Shimada, K. Zhang, P. Calderoni, Y. Oya, M. Sokolov, R. Kolasinski, J. P. Sharpe, Y. Hatano	Behavior of Hydrogen Isotopes Loaded into Neutron-Irradiated Tungsten by TPE Plasma Exposure	Tritium-9	Oct. 24-29, 2010, Nara, Japan
13	2010	Masashi Shimada, Y. Hatano, P. Calderoni, T. Oda, Y. Oya, M. Sokolov, K. Zhang, R. Kolasinski, and J. P. Sharpe	First Results from Deuterium Retention in Neutron-Irradiated Tungsten	10th International Workshop on Hydrogen Isotopes in Fusion Reactor Materials	May 31- June 2, 2010 Pleasanton, California, USA

Task2-2 Joining and coating integrity

14	2010	R. Kasada, H. Takahashi, H. Kishimoto, K. Yutani, A. Kimura	Superior Radiation Resistance of ODS Ferritic Steels	PRICM7	August 1-6, 2010, Cairns, Australia
15	2010	K. Yabuuchi, M. Saito, R. Kasada, A. Kimura	Neutron Irradiation Hardening of Fe-based Binary Alloys	PRICM7	August 1-6, 2010, Cairns, Australia
16	2010	Y.Takayama, R.Kasada, K.Yabuuchi, A.Kimura, D.Hamaguchi, M.Ando, H.Tanigawa	Evaluation of irradiation hardening of Fe-ion irradiated F82H by nano-indentation techniques	PRICM7	August 1-6, 2010, Cairns, Australia
17	2010	Sanghoon Noh, R. Kasada, N. Oono, T. Nagasaka, A. Kimura	Joining of ODS steels and Tungsten for Fusion Applications	PRICM7	August 1-6, 2010, Cairns, Australia

CHAPTER 6 Doublet III

1. Journal Paper

No	Year	Authors	Title of Paper	Journal	Vol. (Year) Page (Start) - Page(End) or Identification No.
1	2001	H. Takenaga, et al.	Comparison of particle confinement in the high confinement mode plasmas with the edge localized mode of the Japan Atomic Energy Research Institute Tokamak-60 Upgrade and DIII-D tokamak	Phys. Plasmas	8 (2001) 1607-1611
2	2001	L.L. Lao, et al.	Dependence of Edge Stability on Plasma Shape and Local Pressure Gradients in the DIII-D and JT-60U Tokamaks	Nucl. Fusion	41 (2001) 295-300
3	2001	H. Takenaga, et al.	Study of particle pumping characteristics for different pumping geometries in JT-60U and DIII-D divertors	Nucl. Fusion	41 (2001) 1777-1767
4	2001	Y. Kamada, et al.	Extended JT-60U plasma regimes for high integrated performance	Nucl. Fusion	41 (2001) 1311-1325
5	2002	C.C. Petty, et al.	Analysis of current drive using MSE polarimetry without equilibrium reconstruction	Nucl. Fusion	42 (2002) 1124-1133
6	2003	G.D. Porter, et al.	Simulation on of the effect of plasma flows in DIII-D, JET, and JT-60U	J. Nucl. Mater.	313-316 (2003) 1085-1088
7	2003	A. Loarte, et al.	Characteristics of type I ELM energy and particle losses in existing devices and their extrapolation to ITER	Plasma Phys. Controll. Fusion	45 (2003) 1549-1569
8	2003	P. Gohil, et al.	Increased understanding of the dynamics and transport in ITB plasmas from multi-machine comparisons	Nucl. Fusion	43 (2003) 708-715
9	2003	T. Fujita, et al.	Overview of JT-60U results leading to high integrated performance in reactor-relevant regimes	Nucl. Fusion	43 (2003) 1527-1539
10	2005	N. Oyama, et al.	Energy loss for grassy ELMs and effects of plasma rotation on the ELM characteristics in JT-60U	Nucl. Fusion	45 (2005) 871-881
11	2005	S. Ide, et al.	Overview of JT-60U progress towards steady-state advanced tokamak	Nucl. Fusion	45 (2005) S48-S62
12	2006	R.J. La Haye, et al.	Cross-macine bench-marking for ITER of neoclassical tearing mode stabilization by electron cyclotron current drive	Nucl. Fusion	46 (2006) 451-461
13	2006	T. Fujita, et al.	Steady state operation research in JT-60U with extended pulse length	Nucl. Fusion	46 (2006) S3-S12
14	2006	N. Oyama, et al.	Pedestal conditions for small ELM regimes in tokamaks	Plasma Phys. Control. Fusion	48 (2006) A171-A181
15	2007	R. Prater, et al.	Stabilization and prevention of the 2/1 neoclassical tearing mode for improved performance in DIII-D	Nucl. Fusion	47 (2007) 371-377
16	2007	D.C. McDonald, et al.	Recent progress on the development and analysis of the ITPA global H-mode confinement database	Nucl. Fusion	47 (2007) 147-174
17	2007	J.D. Callen, et al.	Experimental tests of paleoclassical transport	Nucl. Fusion	47 (2007) 1449-1457
18	2007	C.F. Maggi, et al.	Characteristics of the H-mode pedestal in improved confinement scenarios in ASDEX Upgrade, DIII-D, JET and JT-60U	Nucl. Fusion	47 (2007) 535-551
19	2007	K. Kamiya, et al.	Edge localized modes; Recent experimental findings and related issues	Plasma Phys. Controll. Fusion	49 (2007) s43-s62
20	2007	N. Aiba, et al.	Numerical Method for the Stability Analysis of Ideal MHD Modes with a Wide Range of Toroidal Mode Numbers in Tokamaks	Plasma Fusion Res.	2 (2007) 010_1-010_8
21	2007	A. Kojima, et al.	Numerical Simulation of a High-Brightness Lithium Ion Gun for a Zeeman Polarimetry on JT-60U	Plasma Fusion Res.	2 (2007) S1104_1-S1104_4

22	2007	A.M. Garofalo, et al.	Stability and control of resistive wall modes in high beta, low rotation DIII-D plasmas	Nucl. Fusion	47 (2007) 1121-1130
23	2007	H. Reimerdes, et al.	Reduced Critical Rotation for Resistive-Wall Mode Stabilization in a Near-Axisymmetric Configuration	Phys. Rev. Lett.	98 (2007) 055001_1-055004
24	2007	M. Takechi, et al.	Identification of a Low Plasma-Rotation Threshold for Stabilization of the Resistive-Wall Mode	Phys. Rev. Lett.	98 (2007) 055002_1-055004
25	2007	J.E. Rice, et al.	Inter-machine comparison of intrinsic toroidal rotation in tokamaks	Nucl. Fusion	47 (2007) 1618-1624
26	2007	H. Takenaga, et al.	Overview of JT-60U results for the development of a steady-state advanced tokamak scenario	Nucl. Fusion	47 (2007) S563-S578
27	2008	A. Kojima, et al.	Development of a high-brightness and low-divergence lithium neutral beam for a Zeeman polarimetry on JT-60U	Rev. Sci. Instrum.	79 (2008) 093502_1-093502_5
28	2008	A. Kirk, et al.	Comparison of the spatial and temporal structure of type-I ELMs	J. Phys.: Conf. Ser.	123 (2008) 012011_1-012011_10
29	2009	R.J. La Haye, et al.	Prospects for stabilization of neoclassical tearing modes by electron cyclotron current drive in ITER	Nucl. Fusion	49 (2009) 045005_1-045005_8
30	2009	M. Murakami, et al.	Off-axis neutral beam current drive for advanced scenario development in DIII-D	Nucl. Fusion	49 (2009) 065031_1-065031_8
31	2009	J.M. Park, et al.	Validation of on- and off-axis neutral beam current drive against experiment in DIII-D	Phys. Plasmas	16 (2009) 092508_1-092508_8
32	2009	P.B. Snyder, et al.	Pedestal stability comparison and ITER pedestal prediction	Nucl. Fusion	49 (2009) 085035_1-085035_8
33	2009	N. Oyama, et al.	Overview of JT-60U results towards the establishment of advanced tokamak operation	Nucl. Fusion	49 (2009) 104007_1-104007_16
34	2010	K. Kamiya, et al.	Zeeman polarimetry measurement for edge current density determination using Li-beam probe on JT-60U	Rev. Sci. Instrum.	81 (2010) 033502_1-033502_8

2. Conference Paper

No	Year	Authors	Title of Paper	Conference Name	Month Date, Year, Place, Country
1	2002	T. Oikawa, et al.	Comparison of large and small ELM regimes in JT-60U and DIII-D	American Physical Society, 44th Annual Meeting of the Division of Plasma Physics	Nov. 11-15, 2002, Orlando, Florida
2	2004	N. Oyama, et al.	Energy loss for grassy ELMs and effects of plasma rotation on the ELM characteristics in JT-60U	20th IAEA Fusion Energy Conference (FEC2004)	Nov.1-6, 2004, Vilamoura, Portugal
3	2006	R.J. La Haye, et al.	Evaluating electron cyclotron current drive stabilization of neoclassical tearing modes in ITER- Implications of Experiments in ASDEX-U, DIII-D, JET, and JT-60U	21st IAEA Fusion Energy Conference (FEC 2006)	Oct.16-21, 2006, Chengdu, China
4	2006	D.C. McDonald, et al.	Multi-machine dimensionless transport experiments	21st IAEA Fusion Energy Conference (FEC 2006)	Oct.16-21, 2006, Chengdu, China
5	2006	R. Prater, et al.	Prevention of the 2/1 neoclassical tearing mode in DIII-D	21st IAEA Fusion Energy Conference (FEC 2006)	Oct.16-21, 2006, Chengdu, China
6	2006	J.E. Rice, et al.	Inter-machine comparison of intrinsic toroidal rotation	21st IAEA Fusion Energy Conference (FEC 2006)	Oct.16-21, 2006, Chengdu, China
7	2008	R.J. La Haye, et al.	Prospects for stabilization of neoclassical tearing modes by electron cyclotron current drive in ITER	22nd IAEA Fusion Energy Conference (FEC 2008)	Oct.13-18, 2008, Geneva, Switzerland
8	2008	G. Viad, et al.	Particle simulation of energetic particle driven Alfv\'en modes	22nd IAEA Fusion Energy Conference (FEC 2008)	Oct.13-18, 2008, Geneva, Switzerland
9	2008	M. Murakami, et al.	Off-axis neutral beam current drive for advanced scenario development in DIII-D	22nd IAEA Fusion Energy Conference (FEC 2008)	Oct.13-18, 2008, Geneva, Switzerland

CHAPTER 7 HFIR

1. Journal Paper

No	Year	Authors	Title of Paper	Journal	Vol. (Year) Page (Start) - Page(End) or Identification No.
1	2000	N. Hashimoto, et al.	Microstructure of austenitic stainless steels irradiated at 400°C in the ORR and the HFIR spectral tailoring experiment	J. Nucl. Mater.	280 (2000) 186-195
2	2000	E. Wakai, et al.	Tensile properties and damage microstructures in ORR/HFIR-irradiated austenitic stainless steels	J. Nucl. Mater.	283-287 (2000) 435-439
3	2000	E. Wakai, et al.	Effect of helium production on swelling of F82H irradiated in HFIR	J. Nucl. Mater.	283-287 (2000) 799-805
4	2000	R. L. Klueh, et al.	Embrittlement of reduced-activation ferritic/martensitic steels irradiated in HFIR at 300°C and 400°C	J. Nucl. Mater.	283-287 (2000) 478-482
5	2000	Y. Miwa, et al.	Swelling of F82H irradiated at 673 K up to 51 dpa in HFIR	J. Nucl. Mater.	283-287 (2000) 334-338
6	2000	Y. Miwa, et al.	Microstructures in Ti–Al intermetallic compounds irradiated at 673 K in HFIR	J. Nucl. Mater.	283-287 (2000) 273-277
7	2000	K. Shiba, et al.	Tensile behavior of F82H with and without spectral tailoring	J. Nucl. Mater.	283-287 (2000) 358-361
8	2000	L.L. Snead, et al.	In situ thermal conductivity measurement of ceramics in a fast neutron environment	J. Nucl. Mater.	283-287 (2000) 545-550
9	2000	K. Shiba, et al.	Low-temperature irradiation effects on tensile and Charpy properties of low-activation ferritic steels	J. Nucl. Mater.	283-287 (2000) 474-477
10	2002	E. Wakai, et al.	Swelling of cold-worked austenitic stainless steels irradiated in HFIR under spectrally tailored conditions	J. Nucl. Mater.	307-311 (2002) 352-356
11	2002	E. Wakai, et al.	Microstructural study of irradiated isotopically tailored F82H steel	J. Nucl. Mater.	307-311 (2002) 203-211
12	2002	D. S. Gelles, et al.	Recent results for the ferritics isotopic tailoring (FIST) experiment	J. Nucl. Mater.	307-311 (2002) 212-216
13	2002	N. Hashimoto, et al.	Pros and cons of nickel- and boron-doping to study helium effects in ferritic/martensitic steels	J. Nucl. Mater.	307-311 (2002) 222-228
14	2002	S. Jitsukawa, et al.	Development of an extensive database of mechanical and physical properties for reduced-activation martensitic steel F82H	J. Nucl. Mater.	307-311 (2002) 179-186
15	2002	R.L. Klueh, et al.	Ferritic/martensitic steels – overview of recent results	J. Nucl. Mater.	307-311 (2002) 455-465
16	2002	E. Wakai, et al.	Effect of triple ion beams in ferritic/martensitic steel on swelling behavior	J. Nucl. Mater.	307-311 (2002) 278-282

17	2002	Y. Miwa, et al.	Irradiation-assisted SCC susceptibility of HIPed 316LN-IG stainless steel irradiated at 473 K to 1 dpa	J. Nucl. Mater.	307-311 (2002) 347-351
18	2002	M. Ando, et al.	Evaluation of hardening behaviour of ion irradiated reduced activation ferritic/martensitic steels by an ultra-micro-indentation technique	J. Nucl. Mater.	307-311 (2002) 260-265
19	2002	G. E. Lucas, et al.	Recent progress in small specimen test technology	J. Nucl. Mater.	307-311 (2002) 1600-1608
20	2002	T. Sawai, et al.	Swelling behavior of TIG-welded F82H IEA heat	J. Nucl. Mater.	307-311 (2002) 312-316
21	2002	G. R. Odette, et al.	Some recent innovations in small specimen testing	J. Nucl. Mater.	307-311 (2002) 1643-1648
22	2003	E. Wakai, et al.	Swelling behavior of F82H steel irradiated by triple/dual ion beams	J. Nucl. Mater.	318 (2003) 267-273
23	2004	H. Tanigawa, et al.	Microstructure property analysis of HFIR-irradiated reduced-activation ferritic/martensitic steels	J. Nucl. Mater.	329-333 (2004) 283-288
24	2004	T. Taguchi, et al.	Post irradiation plastic properties of F82H derived from the instrumented tensile tests	J. Nucl. Mater.	335 (2004) 457-461
25	2004	S. Jitsukawa, et al.	Recent results of the reduced activation ferritic/martensitic steel development	J. Nucl. Mater.	329-333 (2004) 39-46
26	2004	K. Shiba, et al.	Reduced activation martensitic steels as a structural material for ITER test blanket	J. Nucl. Mater.	329-333 (2004) 243-247
27	2004	T. Nozawa, et al.	Neutron irradiation effects on high-crystallinity and near-stoichiometry SiC fibers and their composites	J. Nucl. Mater.	329-333 (2004) 544-548
28	2004	T. Tsukada, et al.	Effects of water and irradiation temperatures on IASCC susceptibility of type 316 stainless steel	J. Nucl. Mater.	329-333 (2004) 657-662
29	2004	M. Ando, et al.	Synergistic effect of displacement damage and helium atoms on radiation hardening in F82H at TIARA facility	J. Nucl. Mater.	329-333 (2004) 1137-1141
30	2005	N. Okubo, et al.	Heat treatment effects on microstructures and DBTT of F82H steel doped with boron and nitrogen	Mater. Trans.	46 (2005) 193-195
31	2005	E. Wakai, et al.	Effects of helium production and heat treatment on neutron irradiation hardening of F82H steels irradiated with neutrons	Mater. Trans.	46 (2005) 481-486
32	2005	N. Okubo, et al.	Tempering treatment effect on mechanical properties of F82H steel doped with boron and nitrogen	Mater. Trans.	46 (2005) 1779-1782
33	2005	E. Wakai, et al.	Radiation hardening and -embrittlement due to He production in F82H steel irradiated at 250 °C in JMTR	J. Nucl. Mater.	343 (2005) 285-296
34	2006	E. Wakai, et al.	Mechanical properties of small size specimens of F82H steel	Fusion Eng. Des.	81 (2006) 1077-1084

35	2006	R.L. Klueh, et al.	Mechanical properties of neutron-irradiated nickel-containing martensitic steels: II. Review and analysis of helium-effects studies	J. Nucl. Mater.	357 (2006) 169-182
36	2006	R.L. Klueh, et al.	Mechanical properties of neutron-irradiated nickel-containing martensitic steels: I. Experimental study	J. Nucl. Mater.	357 (2006) 156-168
37	2006	T. Sawai, et al.	Microstructural evolution of SINQ irradiated austenitic stainless steels	J. Nucl. Mater.	356 (2006) 118-121
38	2006	E. Wakai, et al.	Effect of gas atoms and displacement damage on mechanical properties and microstructures of F82H	J. Nucl. Mater.	356 (2006) 95-104
39	2007	M.A. Sokolov, et al.	Fracture toughness and Charpy impact properties of several RAFMS before and after irradiation in HFIR	J. Nucl. Mater.	367-370 (2007) 68-73
40	2007	M.A. Sokolov, et al.	Fracture toughness characterization of JLF-1 steel after irradiation in HFIR to 5 dpa	J. Nucl. Mater.	367-370 (2007) 644-647
41	2007	E. Wakai, et al.	Effect of heat treatments on tensile properties of F82H steel irradiated by neutrons	J. Nucl. Mater.	367-370 (2007) 74-80
42	2007	M. Ando, et al.	Creep behavior of reduced activation ferritic/martensitic steels irradiated at 573 and 773 K up to 5 dpa	J. Nucl. Mater.	367-370 (2007) 122-126
43	2007	N. Okubo, et al.	Effects of heat treatment and irradiation on mechanical properties in F82H steel doped with boron and nitrogen	J. Nucl. Mater.	367-370 (2007) 107-111
44	2007	H. Tanigawa, et al.	Radiation induced phase instability of precipitates in reduced-activation ferritic/martensitic steels	J. Nucl. Mater.	367-370 (2007) 132-136
45	2007	T. Yamamoto, et al.	The transport and fate of helium in nanostructured ferritic alloys at fusion relevant He/dpa ratios and dpa rates	J. Nucl. Mater.	367-370 (2007) 399-410
46	2007	G.E. Lucas, et al.	The role of small specimen test technology in fusion materials development	J. Nucl. Mater.	367-370 (2007) 1549-1556
47	2007	R.L. Klueh, et al.	Mechanical properties of irradiated 9Cr–2WVTa steel with and without nickel	J. Nucl. Mater.	367-370 (2007) 102-106
48	2007	A. Kimura, et al.	Recent progress in US–Japan collaborative research on ferritic steels R&D	J. Nucl. Mater.	367-370 (2007) 60-67
49	2007	R.J. Kurtz, et al.	The transport and fate of helium in martensitic steels at fusion relevant He/dpa ratios and dpa rates	J. Nucl. Mater.	367-370 (2007) 417-422
50	2007	T. Nozawa, et al.	The effects of neutron irradiation on shear properties of monolayered PyC and multilayered PyC/SiC interfaces of SiC/SiC composites	J. Nucl. Mater.	367-370 (2007) 685-691
51	2007	Y. Miwa, et al.	SCC behavior of solid-HIPed and irradiated type 316LN-IG stainless steel in oxygenated or hydrogenated water at 423–603 K	J. Nucl. Mater.	367-370 (2007) 1175-1179
52	2007	H. Tanigawa, et al.	Irradiation effects on precipitation and its impact on the mechanical properties of reduced-activation ferritic/martensitic steels	J. Nucl. Mater.	367-370 (2007) 42-47

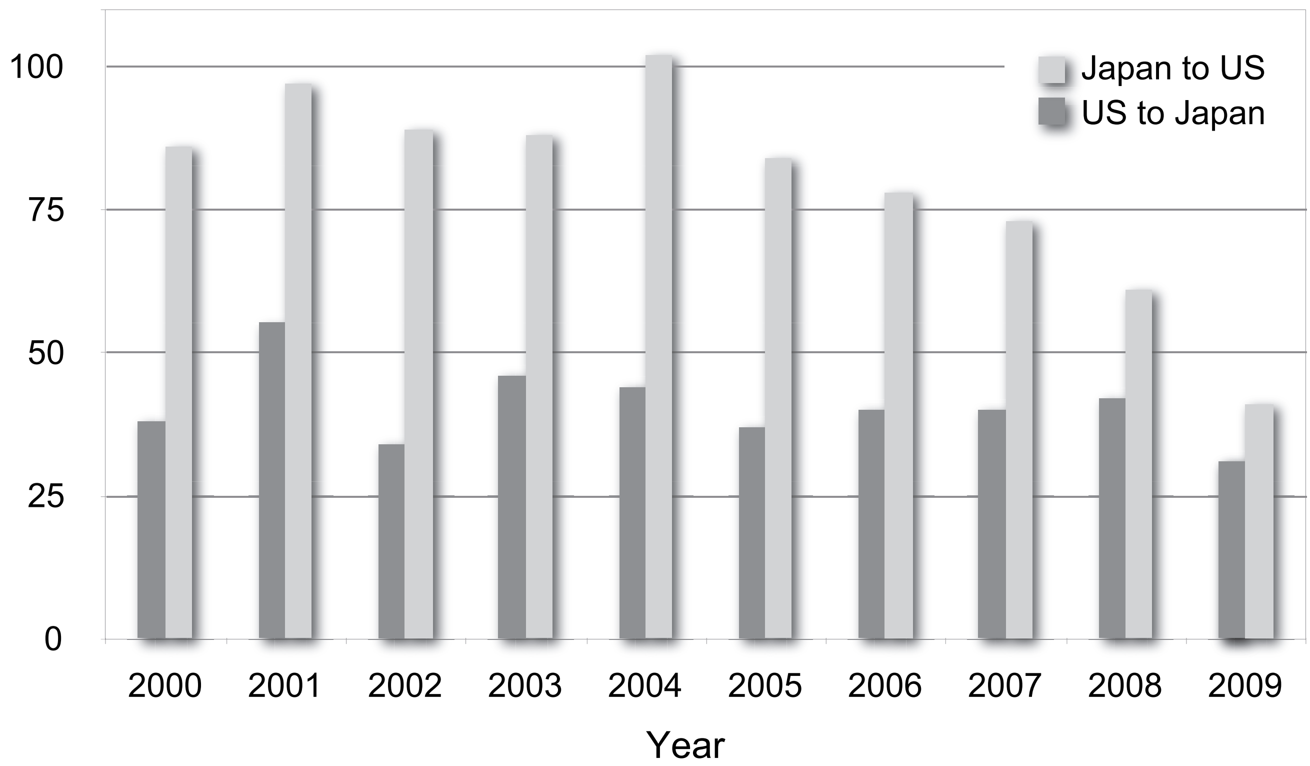
53	2008	H. Tanigawa, et al.	Technical issues of reduced activation ferritic/martensitic steels for fabrication of ITER test blanket modules	Fusion Eng. Des.	83 (2008) 1471-1476
54	2008	R.L. Klueh, et al.	Mechanical properties of unirradiated and irradiated reduced-activation martensitic steels with and without nickel compared to properties of commercial steels	J. Nucl. Mater.	374 (2008) 220-228
55	2008	R.L. Klueh, et al.	Embrittlement of irradiated ferritic/martensitic steels in the absence of irradiation hardening	J. Nucl. Mater.	377 (2008) 427-437
56	2008	R.L. Klueh	Reduced-activation steels: Future development for improved creep strength	J. Nucl. Mater.	378 (2008) 159-166
57	2009	S. Jitsukawa, et al.	Irradiation effects on reduced activation ferritic/martensitic steels – tensile, impact, fatigue properties and moldeling	Nucl. Fusion	49 (2009) 115006
58	2009	Y. Miwa, et al.	Stress corrosion cracking susceptibility of a reduced-activation martensitic steel F82H	J. Nucl. Mater.	386-388 (2009) 703-707
59	2009	T. Yamamoto, et al.	Helium effects on microstructural evolution in tempered martensitic steels: In situ helium implanter studies in HFIR	J. Nucl. Mater.	386-388 (2009) 338-341
60	2009	M. Ando, et al.	Effect of two-steps heat treatments on irradiation hardening in F82H irradiated at 573 K	J. Nucl. Mater.	386-388 (2009) 315-318
61	2009	T. Nozawa, et al.	The effect of neutron irradiation on the fiber/matrix interphase of silicon carbide composites	J. Nucl. Mater.	384 (2009) 195-211
62	2009	R.L. Klueh, et al.	Embrittlement of irradiated F82H in the absence of irradiation hardening	J. Nucl. Mater.	386-388 (2009) 191-194
63	2009	J. Nagakawa, et al.	Creep behavior of the F82H steel under irradiation with 17 MeV protons at 300 °C	J. Nucl. Mater.	386-388 (2009) 264-267
64	2009	R.J. Kurtz, et al.	Recent progress toward development of reduced activation ferritic/martensitic steels for fusion structural applications	J. Nucl. Mater.	386-388 (2009) 411-417
65	2010	E. Wakai, et al.	Reduction method of DBTT shift due to irradiation for reduced-activation ferritic/martensitic steels	J. Nucl. Mater.	398 (2010) 64-67

Appendix B

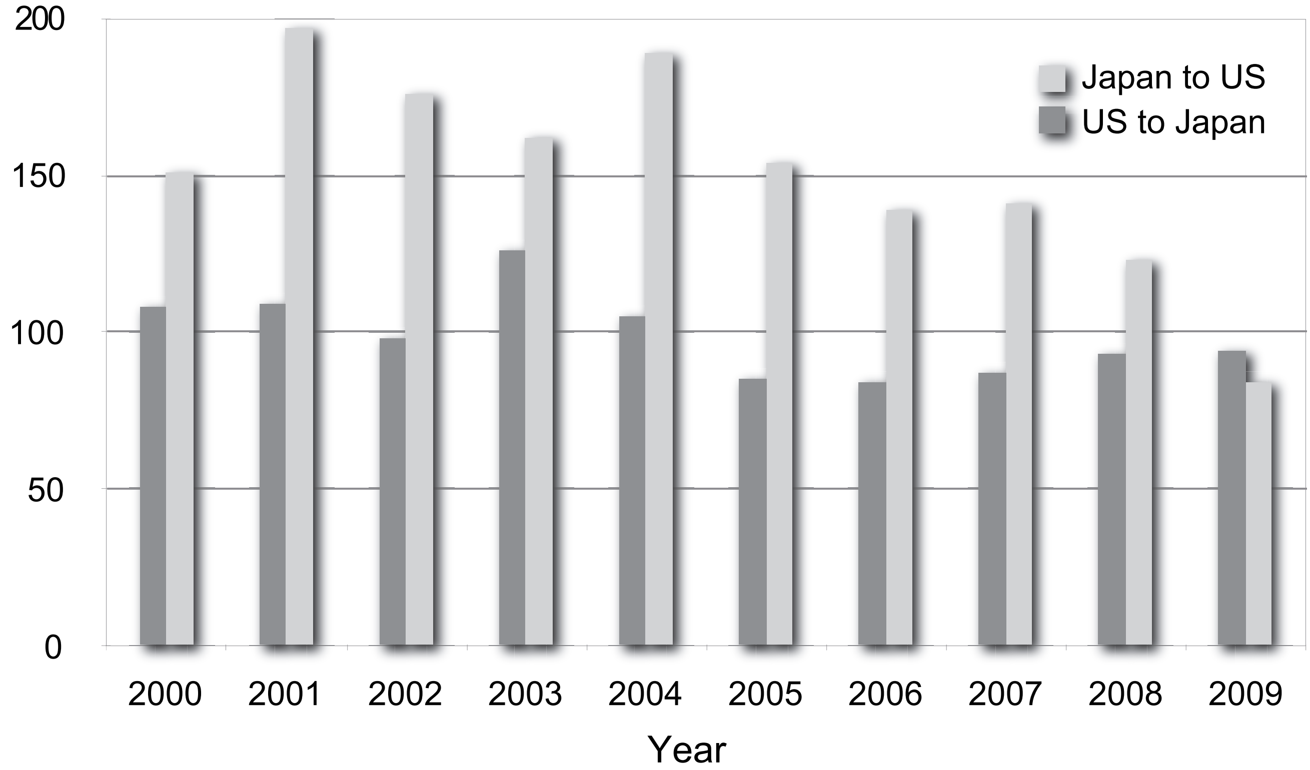
Statistics and Related Documents

B.1 Workshop & Personnel

Number of Workshops



Number of Personnel Exchanges



B.2 Table of Safety Trips

5th: FuY 1995 (Japan -> US)

Visited Sites:	
University of Texas at Austin (TEXAS)	July 21,1995
Pacific Northwest Laboratory at Richland (PNL)	July 24
University of Wisconsin at Madison (WISC)	July 26
Massachusetts Institute of Technology (MIT)	July 28
Princeton Plasma Physics Laboratory (PPPL)	July 31
Japanese Participants :	
Hideo Okada,	Japan Atomic Energy Research Institute (7/21-7/31)
Hiromi Hirabayashi,	National Institute for Fusion Science (7/24-7/31)
Masatsugu Shimizu,	Japan Atomic Energy Research Institute (7/21-7/31)
Teruo Tamano,	University of Tsukuba (7/21-7/31)
Hiroaki Kurishita,	Tohoku University (7/24)

6th: FuY 1996 (US -> Japan)

Visited Sites:	
National Institute for Fusion Science (NIFS), Toki	June 19,1996
National Institute for Fusion Science (NIFS), Nagoya	June 20
Nagoya University	June 20
Kyoto University	June 21
Kyushu University	June 24
University of Tokyo	June 25
University of Tsukuba	June 26
Japan Atomic Energy Research Institute (JAERI)	June 27
US Participants :	
Richard L. Savercool,	General Atomics
Joseph A. Smith,	Princeton Plasma Physics Laboratory

7th: FuY 1997 (Japan -> US)

Visited Sites:	
Oak Ridge National Laboratory (ORNL)	July 9, 1997
General Atomics (GA)	July 11
University of California at San Diego (UCSD)	July 12
University of California at Los Angels (UCLA)	July 14
Lawrence Livermore National Laboratory (LLNL)	July 16
University of California at Davis, Livermore (UCD)	July 18
Japanese Participants :	
Keisuke Hasegawa,	Japan Atomic Energy Research Institute
Masatsugu Shimizu,	Japan Atomic Energy Research Institute
Yoichi Sakuma,	National Institute for Fusion Science

8th: FuY 1999 (US -> Japan)

Visited Sites:	
Japan Atomic Energy Research Institute (JAERI)	November 1, 1999
University of Tsukuba	November 2
Tohoku University	November 4
University of Tokyo	November 5
National Institute for Fusion Science (NIFS)	November 8
Nagoya University	November 9
Kyushu University	November 10
Osaka University	November 11
Kyoto University	November 12
Toyama University	November 15
US Participants :	
Richard L. Savercool,	General Atomics
Lee. Cadwallader,	Idaho National Engineering & Environmental Laboratory

9th: FuY 2001 (Japan -> US)

Visited Sites:	
Massachusetts Institute of Technology (MIT)	March 18, 2002
Princeton Plasma Physics Laboratory (PPPL)	March 19
University of California at San Diego (UCSD)	March 20
General Atomics (GA)	March 20
Lawrence Berkeley National Laboratory (LBNL)	March 21
Lawrence Livermore National Laboratory (LLNL)	March 21
Japanese Participants :	
Yuichi Takase,	University of Tokyo
Naoyuki Miya,	Japan Atomic Energy Research Institute
Kozo Matsushita,	Japan Atomic Energy Research Institute
Tatsuhiko Uda,	National Institute for Fusion Science
Ken'ichi Takagi,	National Institute for Fusion Science
Isao Ohtake,	National Institute for Fusion Science

10th: FuY 2003 (US -> Japan)

Visited Sites:	
Tohoku University	February 16, 2004
National Institute for Fusion Science (NIFS)	February 18
Nagoya University	February 19
University of Tokyo	February 20
Japan Atomic Energy Research Institute (JAERI)	February 23
University of Tsukuba	February 24
Kyoto University	February 25
Osaka University	February 26
Kyushu University	February 25
US Participants :	
Richard L. Savercool,	General Atomics (2/14-2/28)
Mathew Fulton,	Massachusetts Institute of Technology (2/14-2/19)
Michael Viola,	Princeton Plasma Physics Laboratory (2/14-2/19)
Lee. Cadwallader,	Idaho National Engineering & Environmental Laboratory (2/19-2/28)

11th: FuY 2005 (Japan -> US)

Visited Sites:	
Princeton Plasma Physics Laboratory (PPPL)	February 22, 2006
Laboratory for Laser Energetics of Univ. Rochester	February 23
Oak Ridge National Laboratory (ORNL)	February 24
General Atomics (GA)	February 27
University of California at San Diego (UCSD)	February 27
Japanese Participants :	
Hiromi Hayashi,	National Institute for Fusion Science
Nobuyuki Hosogane,	Japan Atomic Energy Agency
Akira Kohyama,	Kyoto University
Takayoshi Norimatsu,	Osaka University
Yuichi Takase,	University of Tokyo
Tatsuhiko Uda,	National Institute for Fusion Science

12th: FuY 2007 (US -> Japan)

Visited Sites:	
University of Tokyo	March 10, 2008
University of Tsukuba	March 11
Tohoku University	March 12
Kyoto University, Yoshida	March 13
Kyoto University, Uji	March 14
Kyushu University	March 17
Osaka University	March 18
National Institute for Fusion Science (NIFS)	March 19
Japan Atomic Energy Research Institute (JAERI)	March 21
US Participants :	
Richard L. Savercool,	General Atomics
Keith Rule,	Princeton Plasma Physics Laboratory
Lee. Cadwallader,	Idaho National Engineering & Environmental Laboratory

13th : FuY 2009 (Japan -> US)

Visited Sites:	
General Atomics (GA)	February 22, 2010
Massachusetts Institute of Technology (MIT)	February 23
Princeton Plasma Physics Laboratory (PPPL)	February 24
University of Wisconsin at Madison (WISC)	February 25
Japanese Participants :	
Kiyohiko Nishimura,	National Institute for Fusion Science
Yuichi Takase,	University of Tokyo
Tetsuo Seki,	National Institute for Fusion Science
Atsuhiko M. Sukegawa,	Japan Atomic Energy Agency