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Annual Report of Fusion Research and Development Directorate of JAEA for FY2008 and FY2009

Fusion Research and Development Directorate

March 2011

Japan Atomic Energy Agency

日本原子力研究開発機構

JAEA-Review

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Japan Atomic Energy Agency
Naka-shi, Ibaraki-ken

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This annual report provides an overview of major results and progress on research and development (R&D) activities at Fusion Research and Development Directorate of Japan Atomic Energy Agency (JAEA) for FY2008 (from April 1, 2008 to March 31, 2009) and FY2009 (from April 1, 2009 to March 31, 2010), including those performed in collaboration with other research establishments of JAEA, research institutes, and universities.

Concerning the ITER project, JAEA was nominated as the domestic agency by the Japanese government after the ITER Agreement took effect, and has fulfilled the obligations. In the development of superconducting conductors, JAEA constructed a technical platform for the fabrication of superconducting conductors for toroidal field (TF) coils ahead of other countries. JAEA immediately started and completed the construction of a plant to fabricate superconducting conductors, and started their fabrication ahead of other countries. In the development of gyrotron high-frequency heating equipment, since only the JAEA satisfies the ITER's procurement specifications among supplier countries, the ITER Organization requested JAEA to conduct confidence tests, and achieved results such as data acquisition that could contribute to the development of the ITER's operational scenario. For the development of neutral beam injectors, advantages of the multi-stage acceleration system developed by JAEA was recognized as a result of comparative experiments with single-stage acceleration systems developed in Europe for the particle acceleration system, and was adopted in the ITER's technical specifications.

For the Broader Approach (BA) activities, JAEA was designated as the implementing agency by the Japanese government after the BA Agreement took effect, and has fulfilled the obligations and promoted three projects in the BA activities steadily through domestic cooperation and coordination with Europe. Concerning activities related to the International Fusion Energy Research Center, preliminary technological development on R&D issues related to each of low-activation structural materials, SiC/SiC composite materials, tritium technologies, advanced tritium breeder, and advanced neutron multiplier to create DEMO reactors was conducted. In addition, review of conceptual design of DEMO reactors through cooperation with universities and domestic research institutes, and that of selection of the models of super computers to be installed in the Fusion Computer Simulation Center were promoted. In engineering demonstration/design activities for the International Fusion Materials Irradiation Facility (IFMIF), the development of lithium test loop was promoted under cooperation with JAEA's Oarai Research and Development Center which has technologies for liquid metals, and the local construction was started. Besides, design of accelerators was promoted and fabrication of prototypes was started. Concerning activities related to Satellite Tokamak (JT-60SA), integrated design of JT-60SA was completed in Japan and Europe incorporating domestic opinions, and fabrication of superconducting conductors for poloidal field coils was started and procurement activities were promoted in the facilities for fabricating superconducting conductors constructed in Naka Fusion Institute. At the same time, the operation of JT-60 was completed in August 2008 aiming for the establishment of JT-60SA, and preparations for dismantling toward full-scale dismantling and removal are being promoted according to schedule. In addition, the development of the Rokkasho BA site, which will be the center of the BA activities, was also advanced according to schedule, and construction of the DEMO R&D Building, the Computer Simulation & Remote Experiment Building, and the IFMIF/EVEDA Accelerator Building, and the central substation was completed as originally planned in March 2010.

For research and development on fusion plasma, research on the realization of steady-state and high-beta plasma was promoted, which resulted in success in the world's first sustainment of plasma with a high normalized beta value 3.0, which exceeded the conventional limit (free-boundary ideal stability limit), for approximately 5 seconds. JAEA also joined inter-machine experiments.

Editor: N.Isei

For research and development on fusion engineering, research and development to construct a technical platform for DEMO reactors was conducted. In the development of breeding blankets, a full-scale mock-up was fabricated and performance demonstration tests were conducted to clarify the fundamental requirements for the ITER Test Blanket Module. In addition, a blanket mock container was fabricated, and neutron irradiation under the same environment as that for actual nuclear fusion reactor blankets was performed at the Fusion Neutronics Source (FNS) facility, where the world's first test to recover tritium generated inside was conducted, demonstrating the achievement of nearly 100% tritium recovery rate for the first time in the world. In research and development on fusion structural materials, the neutron irradiation test of reduced activation ferritic/martensitic steel in HFIR collaboration was continued and irradiation up to 35 dpa was achieved and fundamental data related to corrosion resistance have been accumulated.

Keywords; Fusion Plasma, Fusion Technology, JT-60, JT-60SA, ITER, Broader Approach, IFMIF/EVEDA
International Fusion Energy Research Center, DEMO Reactor

核融合研究開発部門　英文年報（平成 20 年度&平成 21 年度）

日本原子力研究開発機構
核融合研究開発部門

（2011 年 1 月 19 日　受理）

日本原子力研究開発機構（原子力機構）、核融合研究開発部門における平成 20 年度及び平成 21 年度の研究開発（R&D）活動の主な成果と進捗について、原子力機構内の他の研究開発部門および原子力機構外の研究機関並びに大学との協力により実施されたものも含めて、報告する。

国際熱核融合実験炉(ITER)計画については、ITER 協定の発効後は、原子力機構は国より国内機関に指名され、その責務を遂行してきた。超伝導導体の開発では、世界に先駆けてトロイダル磁場（ＴＦ）コイル用超伝導導体の製作技術基盤を構築し、いち早く超伝導導体製作工場の建設に着手し、これを完成させ、世界に先駆けて超伝導導体の製作を開始した。ジャイロトロン高周波加熱装置の開発では、調達極の中で唯一 ITER の調達仕様を満たしていることから ITER 機構より要請を受け､信頼性確認試験を実施し ITER 運転シナリオの策定に貢献するデータの取得等の成果を上げた。中性粒子入射加熱装置の開発では、粒子の加速方式に関して欧州一段加速方式との比較実験の結果、機構の開発した多段加速方式の優位性が認められ、ITER の技術仕様に採用された。

幅広いアプローチ(BA)活動については、BA 協定の発効後は、原子力機構は国より実施機関に指定され、その責務を遂行し、BA 活動の 3 つの事業を国内連携しつつ欧州と協調して順調に進めた。国際核融合エネルギー研究センターに関する活動では、原型炉へ向けて、低放射化構造材料、SiC/SiC 複合材、トリチウム技術、先進増殖材及び先進中性子増倍材に関するそれぞれの R&D 課題について予備的な技術開発を実施したほか、大学や国内研究機関とも連携した原型炉概念設計の検討､核融合計算機シミュレーションセンターに設置するスーパーコンピューターの機種選定検討等を進めている。国際核融合炉材料照射施設の工学実証・工学設計活動では､液体金属に係る技術を有する原子力機構の大洗研究開発センターと連携協力してリチウム試験ループの開発を進めて現地工事を開始したほか、加速器の設計を進めプロトタイプの製作を開始している。サテライトトカマク（JT-60SA）に関する活動では、国内意見を集約しながら日欧で JT-60SA の統合設計を完成させ、那珂核融合研究所内に建設した超伝導導体製作設備でのポロイダル磁場コイル用超伝導導体の製作開始等､調達活動を進めている。一方で JT-60SA の設置に向け、JT-60 の運転を平成 20 年 8 月に完遂させ、その本格的解体・撤去に向けて解体準備作業を順調に進めている。また、BA 活動の拠点となる六ヶ所 BA サイトの整備についても計画通りに進め、原型炉 R&D 棟、計算機・遠隔実験棟、IFMIF/EVEDA 開発試験棟、中央変電所の建設を平成 22 年 3 月に当初予定通り竣工させた。

炉心プラズマの研究開発については、定常高ベータ化の研究を進め、これまで考えられていた限界（自由境界理想安定限界）を超える高い規格化ベータ値 3.0 のプラズマを約 5 秒という長時間維持することに世界で初めて成功したほか、国際装置間比較実験に参加した。

核融合工学の研究開発については、原型炉の技術基盤を構築するための研究開発を実施し、増殖ブランケットの開発では、実規模大モックアップを製作し、性能実証試験等を行い、ITER 試験用ブランケット・モジュールの基本要件を明らかにした。また、ブランケット模擬容器を製作し、核融合中性子源施設（FNS）により実際の核融合炉ブランケットと同じ環境による中性子照射を行い､内部に生成したトリチウムの回収試験を世界に先駆けて実施し、ほぼ 100%のトリチウム回収率が得られることを世界で初めて実証する成果を得ている。さらに、構造材料の研究開発では、米国 HFIR 炉を用いた低放射化フェライト鋼の中性子照射試験を継続して 35dpa までの照射を達成し、機械特性データや耐腐食特性に関する基礎データを蓄積している。

那珂核融合研究所（駐在）：〒311-0193　茨城県那珂市向山 801-1
編集者：伊世井　宣明

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I. Annual Report of Fusion Research and Development Directorate of JAEA

from April 1, 2008 to March 31, 2009

FOREWORD

In FY2008, in the research and development for utilization of fusion energy, JAEA steadily implemented the basic plan established by the Atomic Energy Commission of Japan, and at the same time has fulfilled appropriate obligations as a domestic agency responsible for the ITER project and as an implementing agency of the BA activities. This paper reports some of the major results and progresses in FY2008 concerning research and development on fusion energy in JAEA.

Concerning the progress in the ITER project, fabrication of superconducting conductors for toroidal field coils, which was commenced in 2007 ahead of other countries, was fully in progress according to the construction schedule made by the ITER Organization in accordance with the ITER Agreement and its attached documents. In addition, a procurement arrangement concerning coil windings and structures for nine toroidal field coils was concluded with the ITER Organization in November 2008, showing the steady progress in the ITER project at home and abroad. Besides, research and development which was necessary for the final decision of the technical specifications was conducted for other equipment (divertors, remote maintenance equipment, heating devices, and instrumentation devices) that Japan is in charge of their procurement.

Concerning the BA activities, activities related to the International Fusion Energy Research Center (implementation of review of design guidelines and restrictions of prototype reactors, preliminary technological development related to low-activation structural materials, and reviews necessary for selection of computers), Engineering Validation and Engineering Design Activities for the International Fusion Materials Irradiation Facility (IFMIF) (design, fabrication, etc. of accelerator-related equipment etc.), and research activities on Satellite Tokamak (detailed design and fabrication of equipment that Japan is in charge of, improvement/maintenance of related equipment and facilities, etc.) were conducted according to the project plan set forth by the BA management committee comprising governmental institutions in Japan and Europe in accordance with the BA Agreement and its attached documents. The Rokkasho site was also developed.

For research and development on fusion plasma, the JT-60 experiment continued for 23 years and four months was completed on August 29, 2008. The experiment of JT-60 was started in April 1985. In 1996, the world's highest temperature of 520 million degree and the break-even plasma conditions were achieved. In 1998, the energy multiplication factor 1.25 (world record) was achieved. Since its commencement, it had developed research and development which was necessary for sustainment of high-pressure plasma over a prolonged period of time, which was required for economical nuclear fusion reactors. In FY2008, another instability arising from fast ions was found, and at the same time its stabilization method was developed, which led to the world's first sustainment of high-pressure (normalized beta value 3.0) plasma, which exceeded the free-boundary ideal stability limit, for approximately 5 seconds. It was also incorporated into the ITER's operation plan. In this way, JAEA made a great contribution to the advance of fusion research and development not only in Japan but also in the world.

For research and development on fusion engineering, JAEA succeeded in the fabrication of packed bed structures constituting part of the ITER Test Blanket Module, which will be attached to ITER to conduct performance tests in the future, and a full-scale mock-up of side wall as well as a performance demonstration test (high-temperature flow test, mechanical test, etc.) for the first time in the world, validating its design and fabrication methods.

FY2008 was an important milestone for JAEA to make the next leap forward by steady progress in the ITER project and the BA activities, especially the completion of the JT-60 experiment. JAEA hopes to continue to utilize international cooperation proactively, and manage its organization considering the construction of the All Japan structure supported by solid cooperation with universities, research institutes, and the industries to further promote research and development on fusion energy.

二宮博正

Hiromasa Ninomiya
Director General
Fusion Research and Development Directorate
Japan Atomic Energy Agency

1. ITER Project

1.1 ITER Construction Activities

1.1.1 ITER Tasks

Out of 74 ITER transition arrangements (ITA) tasks that Japan was assigned for the purpose of procurement of equipment according to the ITER construction start-up schedule set up by the ITER International Fusion Energy Organization (hereafter called “ITER Organization”), 73 tasks have been already completed including a final report that has been submitted to the ITER Organization. Also for the remaining one task (divertor mock-up evaluation test), a report will be submitted shortly. As to the ITER tasks, which Domestic Agencies of the Parties undertook for addressing requirements resulting from the design review performed by the ITER Organization and for finalizing procurement technical specifications as the activities have moved from the ITA stage to Construction Stage, seven have been completed, while nine tasks are now in operation and three are in the process of contract conclusion. As to the research works commissioned by the ITER Organization (non-voluntary tasks), a report has been submitted for one task, while nine tasks are in operation and two are in the process of agreement.

1.1.2 Manpower Contribution

As in the previous year, JAEA supported recruiting procedures of the ITER Organization in Japan. In FY2008, the number of Japanese professional staff has become 19 in total (including nine senior staffs consisting of; one Head of the Project Office, one internal auditor in Office of Audit Service, one Head of the Organization Director-General’s Office, one Chief of ITER Council Secretariat, one Head of Tokamak Dept., Vacuum Vessel Division, one chief scientist in Fusion Science & Physics Dept./ Plasma Physics, one section leader in Central Engineering & Plant Support Dept./ Fuel feeding facility, one scientist in Fusion Science & Physics Dept./ Plasma Physics, and one senior engineering specialist of quality assurance), after resignation of one professional staff and new assignment of five staff. In addition, two are expected to join in April, 2009. As for support staff, four are already working and additional two will start working in April, 2009.

Beside the above mentioned staff who are directly employed by ITER, JAEA dispatched about 30 staff a month to the ITER Organization, while having 398 domestic team staffs in total participate in the design review and different technical meetings, including coordination meeting for integrated procurement, organized by the ITER Organization as of Jan. 16, 2008. JAEA also participated in and contributed to policymaking for the ITER plan, etc. in attending the ITER Council as well as Management- and Science & Technology Advisory Committees (one commissioner and three specialists participated in ITER Council, one commissioner and two specialists in Management Advisory Committee, and three specialists in Science & Technology Advisory Committee).

1.1.3 External Contracts

Information was transmitted within Japan concerning 20 external contracts to be consigned by the ITER Organization to research institutes and companies. Application documents from 16 companies were submitted to the ITER Organization, out of which two companies were under negotiation with the ITER Organization.

1.1.4 Quality Assurance Activities

As a Domestic agency, JAEA conducted quality assurance activities necessary for procurement, based on the quality assurance plan and quality-assurance related documents (control standard documents, control manual, etc.).

1.1.5 Transmission of Information

In order to promote citizen’s understanding, information on construction of ITER was disclosed and transmitted proactively as follows:

・Briefing and reporting sessions on ITER plan were newly organized for promotion of understanding of ITER plan, in which information was transmitted on the overview and present status of ITER plan as well as on the equipment to be procured by Japan（superconductive coil, heater, etc.） (Four sessions in total in Hokkaido, Osaka, Nagoya, and Ibaraki Universities)

・Information was widely provided in academic conferences, including 36 presentations on fabrication of ITER equipment (13 in Joint Conferences for Fusion Energy, 11 in Meetings on Cryogenics and Superconductivity, 6 in Plasma Fusion Conference, 2 in the Society of Maintenology, 2 in the Society of Instrument and Control Engineers, and 2 in Takasaki Advanced Radiation Research Symposium)

・ITER-related latest information was placed periodically (bimonthly) and continuously in an academic journal on plasma fusion

・Four briefing sessions for ITER-related companies were held to inform them on the status of the ITER plan, procurement plan, agreements on TF coil procurement, etc. and to exchange opinions (101 companies in total participated)

・Briefing sessions for recruiting of the ITER Organization were newly planned and organized in Japan and abroad (16 sessions in total, including two in France, as of end of January); in parallel, a new prospective staff registration system has been established and is operated for more effective and efficient information provision (91 persons registered as of January)

・Information was transmitted through the website of JAEA.

1.1.6 Procurement Activities and Preparation for Procurement

The followings are major achievements which JAEA performed for procurement and preparation for procurement as a Domestic Agency of the ITER Agreement:

1.1.6.1 Superconductive Coil

① Procurement of TF coil conductors

For procurement of TF coil conductor which has been assigned to Japan, JAEA signed four contracts in total, ahead of other DAs, at the end of the last year concerning manufacturing of the followings; Nb_3Sn wires for two TF coils (2 contracts), Nb_3Sn strand (1 contract), and superconductive coil conductor (1 contract). After coordination of a QA plan and operation plan with these awarded contractors, manufacturing has been started this year, and the first shipment of Nb_3Sn wire (24km) was carried out in January, 2009. As for manufacturing of strands, trial production was performed using copper wires and superconductive wires as preparation for actual production that is scheduled for FY2009. For manufacturing of the conducting body for superconductive coils, detailed design of the manufacturing plant (total length of 1km) and jigs has been completed, and plant construction was started in parallel with start of jig fabrication in January 2009, as scheduled. Procurement of conducting bodies for superconductive coils was assigned to six Parties, among which Japan was the first to start preparation of the manufacturing facilities. It is an important progress that gives traction to the ITER construction plan.

② Technical verification of the TF coil winding

Concerning the process of “welding a cover plate to the radial plate” which is a part of the major production process of TF coil winding, production test was performed, in welding a machine-worked cover plate to a radial plate part model which is about 1m long, demonstrating that the requirement concerning antiplane deformation after welding (2mm) can be satisfied. Further, trial production was carried forward for the cover plate of the curved section, in using a three-point bending technique, in which a prospect could be obtained for satisfying the required allowance of ±0.2mm as well as for realizing rationalization of manufacturing by reducing the man-hour of the machining process. With these trial productions, technical verification required for starting procurement has been completed, and now JAEA is ready to proceed to the detailed design and manufacturing of a full-scale prototype as the first step of procurement (see ④).

③ Technical verification of the TF coil structure

Trial production of steel forgings made of 316LN steel with high-nitrogen content was conducted in cooperation with a German steelmaker, and this material was evaluated in JAEA for the tensile property at the temperature of liquid helium (4K) to be proved as satisfying the characteristics required by ITER. This provides possibility for JAEA to procure forgings made of 316NL steel also from abroad, in addition to domestic manufacturers, providing a prospect for mass production which is essential for production of actual units. In addition, a 1m-long mock-up with the same cross-section with the TF coil container of the actual equipment was fabricated experimentally to obtain data concerning deformation of a narrow groove TIG after welding, while soundness of the welding section was checked in a radiographic test. With these processes, technical verification required for starting procurement has been completed, and now JAEA is ready to proceed to the detailed design and manufacturing of a full-scale prototype as the first step of procurement (see ④).

④ Procurement of TF coils

Procurement of nine TF coils assigned to Japan will be performed according to two agreements, i.e. “Agreement on TF Coil Procurement” (manufacturing of TF coil winding and integration into the TF coil container) and “Agreement on TF Coil Structure Procurement” (manufacturing of TF coil container). JAEA prepared the text (general terms), Annex A (administrative specification), and Annex B (technical specification) of these agreements in cooperation with the ITER Organization. On Nov. 19, 2008, these agreements were signed between JAEA and the ITER Organization, demonstrating nationally and internationally satisfactory development of the ITER plan. In parallel to this, opinions of the industry were solicited concerning the technical specification related to the procurement of TF coils and structures (opinion solicitation by means of a bulletin). JAEA has been considering placing a packaged order for manufacturing of TF coil winding and structure including integration of these components. As the industry shared the same opinion, JAEA decided to procure the items mentioned in the above two procurement arrangements with a single contract, and on Dec. 12, 2008, published a tender notice for “Detailed production design and manufacturing of a full-scale prototype of a TF coil” (to implement detailed production design, design & manufacturing of production jigs, and full-scale technical verification) as the first step. Following this, a contract was signed in February of this year, creating a base for full-swing preparation works for TF coil procurement from FY2009 in concerted efforts of JAEA and the industry.

⑤ Test of the PF insert coil

According to the three-party contract signed by the ITER Organization, Europe, and JAEA, a test of an NbTi superconductive coil made in Europe (PF insert coil) was conducted in the superconductive coil test unit in Naka Fusion Institute. This is a very important test for the ITER Organization to check the technical specification of the NbTi conductor for poloidal field (PF) coils, and thus, researchers from Europe, Russia and USA participated in the test in addition those from the ITER Organization.

The coil was installed in the test unit in January 2008 (Fig. 1), and the cooling process was started in May where the temperature was lowered gradually by circulating cooling helium gas, till the temperature reached about 9K in June, realizing the superconductive status. In the energizing test after that (Fig. 2), the performance required for ITER PF coil conductor was successfully achieved; i.e. current so large as 52kA in the magnetic field of 6.4T and temperature of 4.5K. Following this, the current sharing temperature (i.e. max. temperature at which superconductivity can be maintained) was measured in order to get detailed knowledge on the superconductive property of the NbTi conductor. As a result, it was confirmed that superconductivity can be maintained up to the temperature of 6K, with the magnetic field of 6.4T and current of 52kA. The results of this and other measurement with different magnetic fields and temperatures showed coincidence with the estimated performance of about 1,000 NbTi superconductive wires consisting the conductor (Fig. 3), demonstrating adequacy of the conductor design for the PF coil. This result justified start of procurement of conductors for PF coils by Europe, Russia and China. Though this equipment is outside the direct procurement assignment of Japan, JAEA could make an important contribution to the ITER plan through this.

Fig. 1: Installation of the PF insert coil (January, 2008)

Fig. 2: Test in Naka Institute
In total, 21 researchers from ITER Organization, Europe, Russia, and USA participated in the test (June, 2008)

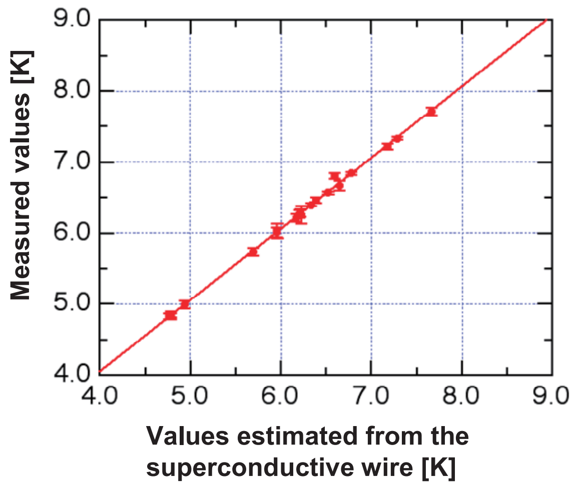

Fig. 3: Measurement results and estimated values of the current sharing temperature
They showed coincidence, confirming adequacy of the design

1.1.6.2 Blanket Remote Maintenance Equipment

In order to finalize the technical specification of the remote maintenance equipment of the blanket, the following works were performed in this fiscal year:

- Basic experiments were performed concerning the most difficult process for remote maintenance of the blanket, namely connecting divided rails of the traveling route of the maintenance robot arm, using a full-scale part model which was fabricated last year, confirming the feasibility of the basic design concept and clarifying the structural points which need to be improved.
- It was confirmed that the slip ring, which is indispensable for a compact design of the cable winding section, does

not give noises to the cable signal system as previously concerned, using a full-scale part model which was fabricated also last year for verification of handling property during transport of the multi-core composite cable (cable in which power lines and signal lines are twisted together; the total number of the cables is 300).

- An irradiation test was conducted for the instrumentation amplifier, which is indispensable for control of the maintenance robot arm, under the same radiation condition as in actual maintenance of ITER, using the gamma radiation facility of Takasaki Radiation Chemistry Research Establishment, to select an instrumentation amplifier that is durable in ITER.
- Evaluation of the work hours was conducted, assuming that a maintenance robot arm is used for installation works of the blanket to the Vacuum vessel during construction of ITER. As a result, preconditions for installation completion within the predefined time were identified.
- The design conditions were clarified concerning the interface with the cask used for transport of the blanket remote maintenance equipment between the Vacuum vessel and hot cell, to provide relevant information via the ITER Organization to China who is assigned to procurement of the cask. JAEA participated in the meeting of the parties related to the cask design to discuss for smooth inter-agency procurement operation.

1.1.6.3 Development of EC (Electron Cyclotron Heating & Current Drive)

The electron cyclotron resonance heating is a prospective technology for heating of nuclear burning plasma, maintaining of plasma current, and controlling the stability. In development of the 170GHz-band high-power & high-frequency oscillator (gyrotron), the core of the above system, ITER's target performance was achieved last year (Output: 1 MW, Pulse width: 500 sec, Efficiency: 50%). This year, a stand-alone performance test of the gyrotron was conducted, demonstrating its high reliability to further justify its application to ITER, through verification of the stable oscillation with output of 0.8MW, pulse width of 1 hour, and efficiency of 56% and achievement of the total output energy of 200 giga joule. Responding a request from the ITER Organization, an operation mode test was also conducted, in which oscillation assumed for ITER (pulse width of 400sec) was repeated every 30 minutes, demonstrating that this mode is feasible. These results contribute to examination of the ITER operation plan. For the development of a high-frequency heater for ITER based on the series of achievement with the gyrotron, JAEA won the Award of the Minister of Education, Culture, Sports, Science and Technology (Science & Technology Award, Research Section).

1.1.6.4 Development of NBI (Neutral Beam Injector)

- Upon request from the ITER Organization, JAEA performed comparative test of the accelerators for the ITER NBI between two concepts (Fig.4); i.e. single-aperture single-gap system (SINGAP; a robust system proposed by EU) and multi-aperture multi-grid system (MAMuG; a conventional system that JAEA has developed) using a JAEA's test facility. The test result indicated the superiority of the MAMuG system in achievable high voltage holding and less electron accelerations. According to this result, the ITER Organization decided to adopt a MAMuG accelerator as the baseline design for the ITER NBI. This is a result showing achievement of high technology of JAEA.
- After that, a long-pulse beam acceleration test of the MAMuG accelerator was started, where JAEA succeeded in acceleration of a negative ion beam of 550 keV, 131 mA (57 A/m^2) for 5 seconds, because the used accelerator was the one for short pulses without any cooling structure within the electrode.
- For high-voltage bushing which supplies power to the ion source and accelerator placed in vacuum (Japan is expected to be assigned to procurement upon request from EU), design has been initiated based on the 3-dimensional electric field analysis, while trial soldering of the large-sized and thick kovar plate that is a sealing metal connecting ceramic and metal flange were carried forward.
- Japan, Europe and ITER Organization worked jointly concerning development of detailed functional specification and design of interfaces of NBI power supply, for which procurement work is shared by Japan and Europe.

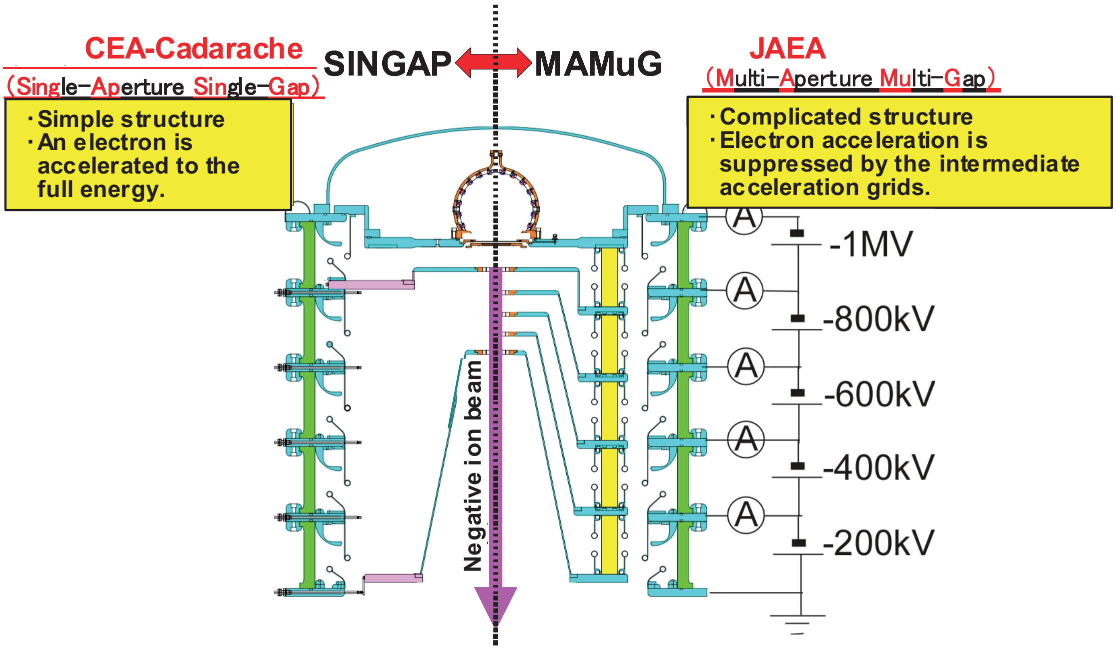

Fig. 4: Cross-section of SINGAP (left) and MAMug (right) accelerators
SINGAP is of a simple structure, with the intermediate acceleration grids removed from MAMuG, and thus no electron acceleration suppression by the intermediate acceleration grids.

1.1.6.5 Diagnostics Systems

- With the edge Thomson scattering diagnostics, a prototype test of the YAG laser amplifier was carried forward, achieving extraction energy of 1.76J per laser rod which is higher than the value required in ITER (1.6J) ; a good prospect was thus obtained in development of the amplifier.
- For the divertor impurity monitor, full-scale evaluation of the optic performance was conducted, in combining prototype optical devices, to identify problems and find countermeasures.
- For the micro fission chamber, tie-in was re-adjusted due to a design change of a different component in the Vacuum vessel, while evaluation was conducted using a Monte Carlo code, concerning the effect of streaming neutrons on the measurement.
- For the poloidal polarimeter, design of the far-infrared laser and preparation of the prototype test have been completed, while design of optical devices in the vacuum vessel was carried forward.

1.1.6.6 Shield Blanket

- Prior to procurement of the first wall, an agreement with the ITER Organization was concluded for an evaluation test to check the manufacturing technology of the Procuring Party. Based on this, fabrication of a mock-up for the evaluation test of the first wall, transport to the test site (Sandia National Laboratories, USA), and preparation for the test start-up have been completed. Fabrication of the second mock-up has been initiated.
- JAEA dispatched researchers to the ITER Organization to proceed with the design & analysis works of the shield blanket in cooperation with the ITER Organization. Besides, JAEA conducted electro-magnetic force evaluation for the entire components in the vacuum vessel, and started consistency evaluation of the analysis results with other Parties.

1.1.6.7 Divertor

- Prior to procurement of the actual divertor, fabrication of a test divertor, namely Qualification Prototype, for evaluation as shown in Fig 5 was completed in order for the ITER Organization to check and evaluate the manufacturing technology of the Parties assigned to procurement (Japan, Europe, and Russia), while a high-temperature load test was conducted in Efremov Institute. In this test, the first Qualification Prototype manufactured by Japan was qualified (as the first among others) to have sufficient durability compared to the design thermal load of the ITER divertor, so that the ITER Organization certified that the Domestic Agency of Japan has sufficient technical capability for scheduled procurement of the divertor. The fabrication of the second Qualification Prototype has been completed, and a thermal load test has been started in Efremov Institute to obtain reliability data.

- For procurement of the actual divertor, discussion on the content of the procurement arrangement with the ITER Organization was carried on.

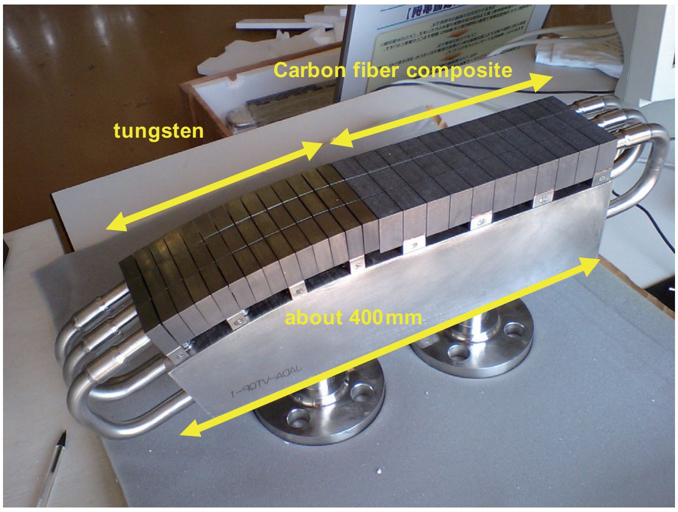

Fig. 5: Completed divertor test piece for evaluation

1.1.6.8 Tritium System

- JAEA conducted design of the ITER tritium detritiation system (DS) in cooperation with the ITER Organization. Since the design was changed to adopt a scrubber column in DS, JAEA supported the ITER Organization in preparation of the SRD (System Requirement Document) and conducted re-evaluation of the system cost. HAZOP (Hazard & Operability) analysis of DS has been also started.
- As research commissioned by the ITER Organization, evaluation of the deuterium retention in tungsten was conducted by means of blistering. This proved that retention increases with the irradiation temperature till it has the maximum value at 530K and then decreases, as shown in Fig 6.

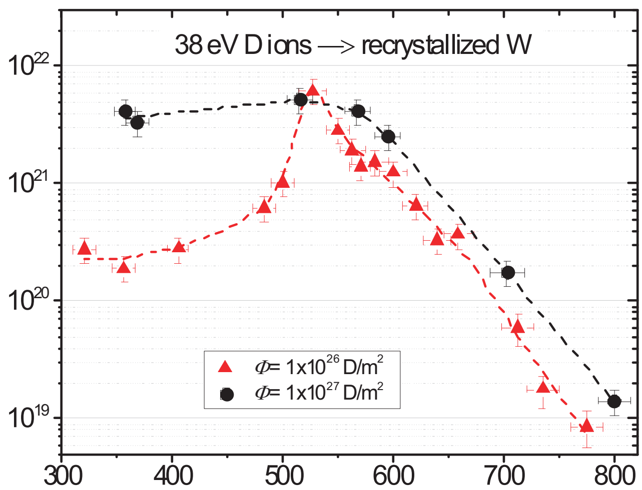

Fig. 6: Influence of the temperature on deuterium retention in recrystallized tungsten
(38 eV D ions at ion flux of 10^{22} D/m^{2}s to fluences of 10^{26} and 10^{27} D/m^2)

<Remarks>

○ Concerning TF coil winding & structure to be procured by Japan, a final proposal of the procurement arrangement has been prepared with support from related sections of JAEA, and was concluded with the ITER Organization in the 3rd ITER Council on Nov. 19, 2008. Since TF coil is of the largest scale among ITER major components, conclusion of this agreement demonstrated nationally and internationally that the ITER construction was making a big progress.

○ A performance test of the "PF insert coil" was completed, as a research commissioned by the ITER Organization and EU, confirming that the conductor for the ITER polodail magnetic-field coil satisfies the performance requirement. This showed that manufacturing of this coil can be already started.

○ Static oscillation at 0.8MW (1 hour operation) was conducted successfully with the gyrotron for high-frequency heating. After simulation of the 1-day operation pattern of ITER, it was proved that continuous repeated operation is possible, showing a good prospect for use in ITER.

○ A press release was issued on "Solved the task for large-current operation with a niobium-titanium superconductor" (PF insert coil test) (September, 2008)

1.2 Development of a Burning Plasma Control Method for ITER

In order to obtain a guideline for a burning plasma control method, a burning plasma simulation scheme has been developed using two groups of NBIs for the simulation of α-particle heating (where the heating power for the α-particle heating simulation is proportional to the square of the temperature multiplied by the square of the density, simulating a burning plasma with a fusion gain of 5 − 30) and for the simulation of external heating. Then, a real-time control using particle control system and external heating simulation system is applied to a simulated burning plasma. Fig. 1 shows time evolutions of plasma parameters in case that the burning plasma simulation scheme is combined with the real-time feedback control of the plasma stored energy via the external heating simulation system. As the α-particle heating simulation power increases/decreases, the external heating simulation power changes, so as to control the plasma stored energy almost as the reference value. Also after the particle control by means of gas jet from t = 4.5 sec, the plasma stored energy can be controlled. In addition, real-time control of α-particle heating simulation power can also be controlled by particle control with gas-puffing. In this way, real-time control of a simulated burning plasma was demonstrated using a particle control system (gas jet and gas-puffing) and NBIs.

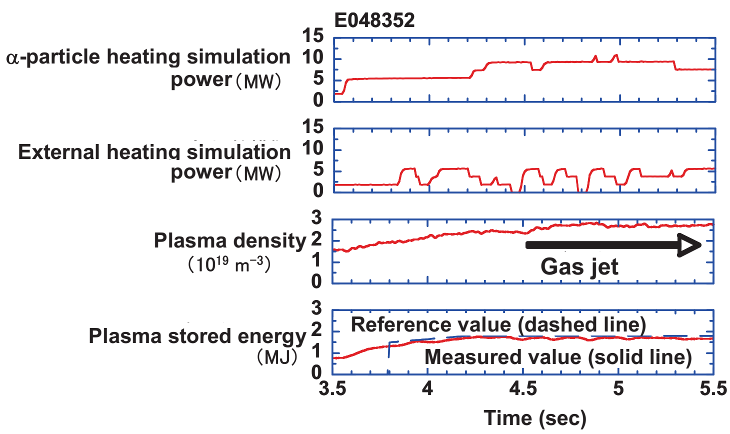

Fig. 1: Example of real-time control of a simulated burning plasma

For the purpose of enhancement of the neutron distribution measurement technology required for burning control, a neutron distribution measurement device has been developed that measures with high time resolution the output wave pattern of a Stilbene detector of high spatial resolution (7 chords; see Fig 2), realizing the world's first simultaneous discriminative measurement of generation amount of gamma ray, DD neutrons, and DT neutron, respectively. In joint research with Tohoku University, JAEA applied a technique of software n-γ discrimination where signal wave patterns of the detector with the time constant of about 50ns are captured by a high-speed digitizer, in developing necessary hardware, software, and analysis logic (charge integration method). Further, simultaneous measurement of generation amount of DD neutrons (D+D -> ^{3}He + n (2.5MeV)) and DT neutrons (D+T-> α + n (14MeV)) could be realized, by means of wave height analysis of the discriminated neutron signals. An example of measurement is shown in Fig. 3.

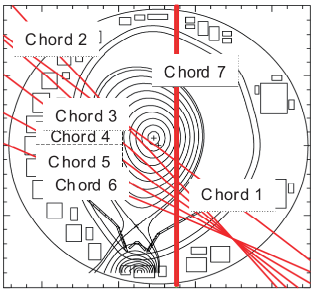

Fig. 2: Chords in neutron measurement

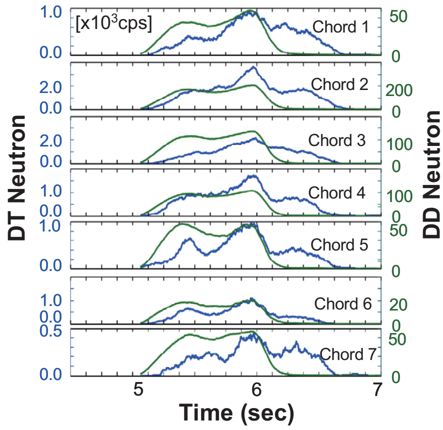

Fig. 3: Example of measurement of amount of DD- and DT neutrons generated in reaction in each spatial chord.

Through experiments performed in JT-60, JAEA has contributed to the inter-machine experiments (29 cases) as well as to providing data for the major two databases (pedestal parameter & plasma rotation) for ITER in international tokamak physics activity (ITPA). Fig 4 shows comparison between the experimental values and values predicted by the model that was jointly established in ITPA. A model which is consistent with experimental data has been obtained, enabling highly reliable prediction of the pedestal pressure in ITER. Five international collaborative papers, including this result, have been written.

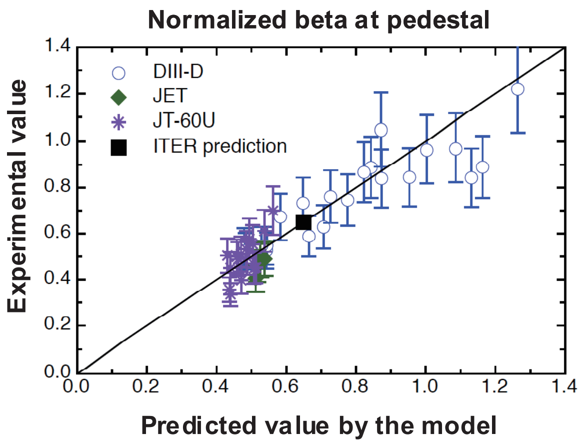

Fig. 4: Comparison of experimental values and values predicted by the model which has been jointly established in International Tokamak Physics Activity.

ITER design review concerning the magnetic field ripple, energetic ion loss, H-mode characteristics, etc. have been completed. Fig 5 shows evaluation result on the energetic ion loss due to magnetic field ripple. The method verified in JT-60 and JFT-2M, i.e. a method to improve confinement of energetic ions by placing ferritic steel to reduce non-uniformity of the magnetic field, has been adopted for ITER as well. Upon request from the ITER Organization, evaluation of the amount the energetic ion loss in ITER was carried out using a 3D Monte Carlo cord developed by JAEA. The result showed that, if optimization of the ferritic steel amount is conducted in the standard magnetic field (5.3T), its effect is reduced significantly in a lower magnetic field (2.65T) in which commissioning experiments are scheduled. Thus, information necessary for design optimization in future was provided. On the other hand, it was found out that local non-uniformity in the magnetic field due to the test blanket module (which uses ferritic steel as a structural material) gives only small influence on confinement of energetic ions.

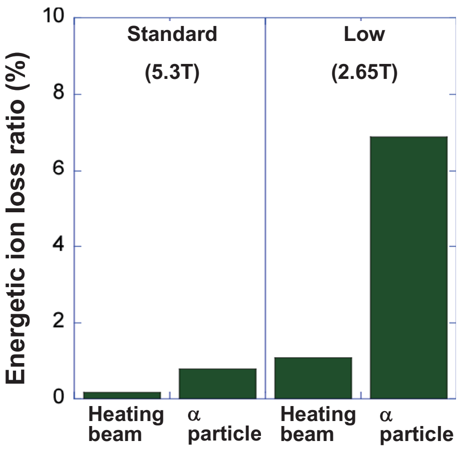

Fig. 5: Comparison of the high-energy ion loss ratio, with the ferritic steel amount optimized in 5.3T

1.3 Fusion Energy Forum Activities

1.3.1 Overview

As a national organization newly established in 2007 at the request of the Working Group in Fusion Research set up in Ministry of Education, Culture, Sports, Science and Technology (MEXT), the Fusion Energy Forum of Japan (FEF) assembles fusion researchers and engineers from a broad range of industries, academia, and research institutes as well as leaders and experts in many fields in order to support and promote fusion research and development so as to realize the potential of fusion energy. The former organization was the Fusion Forum of Japan (FF) that had been established in 2002.

1.3.2 Records of Organized Meetings

The Fusion Energy Forum of Japan consists of the steering committee, the coordination committee and the ITER/BA technical promotion committee. Its structure is shown in Fig.1. In FY2008, Two meetings of steering committee, four ones of coordination committee, and seven ones of ITER/BA technical promotion committee were held, respectively.

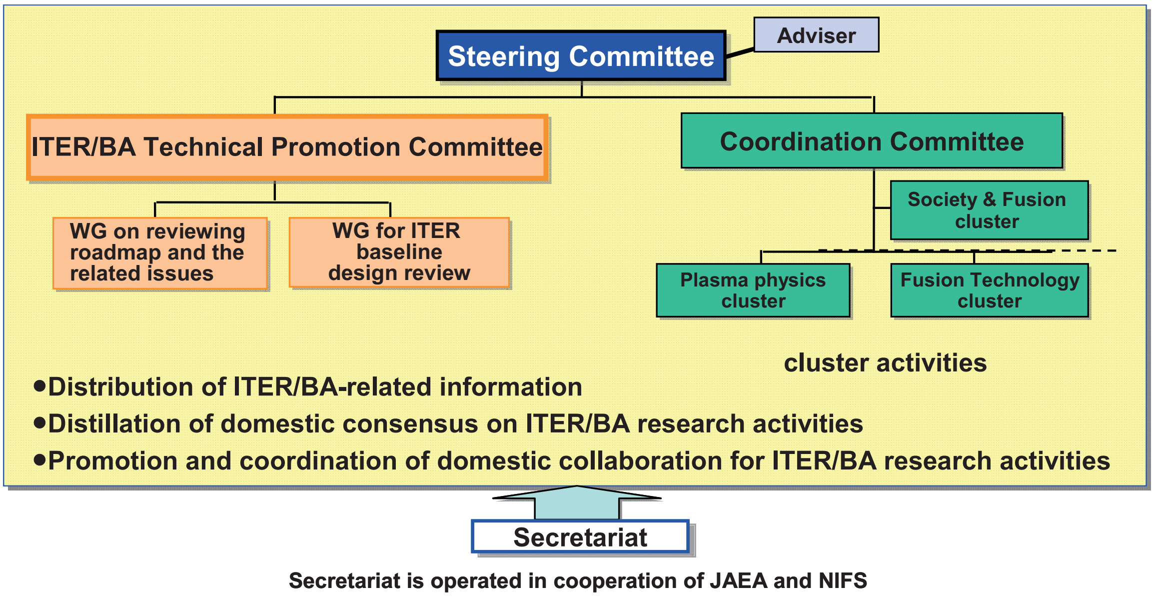

Fig. 1: Framework of the Fusion Energy Forum

Under the ITER/BA Technical Promotion Committee, five meetings were held in Working Group (WG) on reviewing roadmap and the related issues, and seven meetings were held in WG for ITER baseline design review. As specialized cluster activities under Coordination Committee, six cluster board meetings, two sub-cluster board meetings, one informal meeting, one round-table talk, and 25 sub-cluster meetings were organized.

1.3.3 Support for Operation, Promotion of Achievement Inter-Feedback and Collaboration Works, Enhancement of Information Distribution and Understanding of Fusion Energy

The FEF Secretariat of JAEA side (The Secretariat) provided necessary support for smooth organization of various meetings, while contributing to transmission of information and enhancement of understanding on the current status of fusion energy R&D, by posting reports of meetings, including presentation materials of cluster-related activities, on its website.

As a support for organization and operation of ITER/BA Technical Promotion Committee, pre-coordination was made among MEXT, industries, universities, research institutes, and JAEA, concerning the date and agenda in accordance with the international schedule, in cooperation with board members of secretariat of NIFS. Concerning the matters related to

ITER Council, ITER Science and Technology Advisory Committee (STAC), BA Steering Committee and its three project committees, special efforts were made to enhance functions of the ITER/BA Technical Promotion Committee as might be expected from its nature, by providing necessary communication to/from the committee and gradually establishing necessary processes so that opinions of domestic researchers all over Japan are reflected on the operation. As a part of this effort, voluntary activities of different special sub-clusters (modeling simulation, blanket, and neutron source) were introduced to get consensus on their significance and solicit for opinions. Application for IFERC projects and for joint researches related to IFMIF-EVEDA project were supported, after confirming the framework of the joint research implemented by BA Implementing Agency, to contribute to promotion of collaboration and concrete establishment of a framework for ITER plan and BA activities in Japan.

As to the WG on reviewing roadmap and the related issues, which was established last year under ITER/BA Technical Promotion Committee in order to address requests from MEXT, the Secretariat supported it in completing two reports in June (“A Road map and Technical Strategy toward the Commercial Use of Fusion Energy” and “A Study Report on Human Resource Plan toward the Implementation of Tokamak type DEMO Reactor Development”) , while supporting the WG for ITER baseline design review in preparing a status report on evaluation of the ITER baseline design in November, and contributed to reflect the distillate of domestic experts opinions on ITER Science and Technology Advisory Committee (STAC) through STAC’s Japanese commissioner.

On the other hand, in special cluster activities under the Coordination Committee, the Secretariat undertook following activities; 1) as the discussion on evaluation study of ITER design has shifted into high gear in the ITER/BA Technical Promotion Committee and the Working Group for ITER baseline design review, the Secretariat promoted energized discussion also in the related sub-cluster activities, including skull sessions on ITER engineering design of the scrape-off layer, divertor physics, reactor engineering cluster, 2) supported promotion of intercommunication among domestic fusion research activities, and 3) contributed to inter-feedback of achievement and fostering of collaboration. The “Fusion Glossary” which has been worked on by the web public-relation sub-cluster was posted on “Weblio”, a special site of online glossary (June), contributing to expansion of the base for wide understanding of fusion energy.

1.3.4 “Fusion Energy Award” in 2008

For the “Fusion Energy Award” which has been established in the previous year to recognize outstanding accomplishments or prospective research & development activities by young researchers and engineers, JAEA supported the selection committee in preparation of the application guidebook and amending application form to solicit application widely (April). After selection by the Coordination Committee based on the evaluation result submitted from the selection committee, notification to the award winners were made and subsidy from JAEA was granted without delay (August). The awarding ceremony for one outstanding-performance-award winner and four incentive-award winners was held in the 3rd plenary meeting (March, 2009). As consensus of the subsidy donor and Steering Committee was obtained concerning the English name of this award, “Masaji Yoshikawa Prize for Fusion Energy “ as proposed by the Coordination Committee, award winners can use this title in their personal history of award winners starting from 2009, when those winners want to start working in a overseas institute or organization.

＜Remarks＞

○Submission of ITER/BA Technical Promotion Committee Report to MEXT

Two reports prepared by the ITER/BA Technical Promotion Committee (“A Road map and Technical Strategy toward the Commercial Use of Fusion Energy” and “A Study Report on Human Resource Plan toward the Implementation of Tokamak type DEMO Reactor Development”) have been worked on in the WG on reviewing roadmap and the related issues in a country-wide collaboration system with participation also from the industries since last year, upon request from MEXT. In order to reflect comments from the Steering Committee and industries on them, meetings of the working group were held more frequently since end of May, and the Secretariat supported especially in addition of Section 1-1 “Concept of target of the fusion development road map from the viewpoint of sustainable human development” as well as in change of the structure of Section 3 of “Road map and technical strategy for practical use of fusion energy”. With the consent of ITER/BA Technical Promotion

Committee, the Secretariat supported submission of these reports to MEXT within June in the name of the Chairman of Fusion Energy Forum of Japan. It was confirmed in discussion with MEXT that the copyright of these reports exist in Fusion Energy Forum (July). Based on this, these have been posted to the website of the Forum, receiving many accesses and contributing to information transmission and enhancement of understanding on the activities for realization of fusion energy utilization.

2. Broader Approach Activities

2.1 Activities related to the International Fusion Energy Research Center （IFERC）

2.1.1 Overview

・JAEA seconded one specialist (Project Leader) to the Project Team and provided 12 supporting staffs for a year.

・ For design of the DEMO reactor, study on common design issues and merits and demerits study for the steady-state and quasi-steady state operation were conducted in the technical coordinators meeting on the DEMO design activities. Seven R&D-related staff participated in the 3rd DEMO Reactor Design and R&D Workshop to report the progress status of 2008 and specific work plan for 2009, etc.

・ Concerning R&D tasks of the DEMO reactor, procurement arrangements were signed in December with the EU Implementing Agency, after getting consent of the Project Leader, for R&D tasks related to the SiC/SiC composite, structural material for reduced-radioaction structural material of the blanket, tritium technology, advanced tritium breeder, and advanced neutron multiplier, and the works related to those R&D tasks have been initiated. Design of the multipurpose RI facility to be newly established in Rokkasho was carried on.

・For the Fusion Computer Simulation Center project, four experts were dispatched to the special working group （SWG-1） for selection of the computer, and selection of the benchmark codes has been completed. For Japan-EU discussion on the cooling system for the computer building, survey work has been initiated concerning the configuration, cost, etc. of the cooling system, taking the interface with the computer into consideration.

・Details and major achievements of each activities are mentioned below.

2.1.2 Activities related to the DEMO Design and R&D Coordination Center

2.1.2.1 Conceptual Design Activities for DEMO Reactor

・In accordance with the work program on the Phase-One activities, opinions were exchanged between Japan and EU in workshops and technical meetings, concerning various aspects of the reactor, including fusion development programs toward DEMO, requirements for DEMO, reactor concepts and design drivers. The necessity of technical discussion was raised on comparative assessment of the steady-state and pulse operation of the DEMO reactor.

・In order to identify constraints of the DEMO reactor design, reviews have been initiated concerning the following design issues in cooperation with experts from research institutes, universities and industry: 1) Physics design: analysis of correlation among plasma shaping factors (aspect ratio, elongation, triangularity); 2) Engineering design: study on design methodology for application of Nb_3Al conductor for increasing the magnetic field of the superconducting coil, assessment of various maintenance schemes; 3) System design: comparison of steady-state reactor and pulse reactor.

2.1.2.2 R & D Activities for DEMO Reactor

・ SiC/SiC composites: : selection of test methods for failure strength evaluation; preparation of the test system to be placed in the DEMO R&D building in Rokkasho; fabrication of reference materials. Besides, a test piece holder for in-situ measurement of electrical resistivity during irradiation has been designed. In particular, relevant R&D has been initiated in joint research with universities.

・ Tritium technology: For manufacturing of multi-purpose RI facility to be established in Rokkasho, detailed design of tritium removal facility and safety analysis for obtaining approval and license were conducted. Besides, coordination was performed with Rokkasho Construction Team concerning the interface between the site building and RI handling facilities (electric capacity, equipment layout, utilities, etc.).

- Material engineering for DEMO blanket (reduced-activation ferritic steel): preliminary R&D has been started for welding technology optimization and development of irradiation effect prediction technology in joint research with a university, etc. Besides, preparation work of the test unit to be placed in the DEMO Reactor R&D building in Rokkasho was performed.
- Advanced neutron multiplier for DEMO blanket: detailed design of the beryllium handling facility to be established in the DEMO Reactor R&D building in Rokkasho was conducted, while preliminary fabrication test and characterization were carried out. Notification documents to the Labor Standards Inspection Office were prepared concerning the facilities that handle specified chemical substance, such as beryllium.
- Advanced tritium breeder for DEMO blanket: detailed design of the key equipment for the R&D on advanced tritium breeder to be established in the DEMO Reactor R&D building in Rokkasho was conducted, while preliminary fabrication test and characterization were carried out.

2.1.3 Fusion Computational Simulation Center（CSC）

A meeting of the Special Working Group for Computer Procurement and Benchmark Code Selection（SWG-1）was held in Europe (Geneve and Lausanne) (October 18, 20, and 21, 2008) for selection of benchmark codes. In this meeting, all the three benchmark codes proposed by Japan (turbulent transport simulation code, etc.) were adapted. This is an important achievement in terms of realizing Japan’s requests in decision of the computer specification in future.

For selection of benchmark codes, an all-Japan approach was taken in cooperation with National Institute for Fusion Science (NIFS) and universities. Namely, information was disseminated thoroughly through Fusion Network, Fusion Energy Forum, etc., and a database was established for survey and selection of prospective benchmark codes. Besides, a meeting was held (Meeting of Fusion Energy Forum Modeling and Simulation Sub-cluster) (July 31, 2008), in which SWG-1 members selected benchmark codes to be proposed by Japan, with consent of participants of the meeting. The result of this SWG-1 meeting was reported in the Fusion Energy Forum（the above mentioned sub-cluster）(Dec. 12, 2008）.

In the 5th technical meeting on CSC, a briefing was conducted to confirm the contribution allocation, which has been started last year (4 & 5 Nov, 2008). It was decided there that Japan-EU consultation should be held concerning the share of the cooling system of the computer building. Survey has been started on the configuration, cost, etc. of the cooling system, considering the interface with the computer.

Since CSC will be constructed in Rokkasho, remote use through a network will be one of the main utilization form, regardless of whether it is used from Japan or from Europe. Network data transmission tests have been initiated to perform examination on establishment of infrastructure for remote use in Japan and Europe. Results of these tests will be reported to SWG-1 to use them in discussion of technical requirements of CSC computer.

2.2 Engineering Validation and Engineering Design Activities for the International Fusion Materials Irradiation Facility (IFMIF/EVEDA)

2.2.1 Overview

- Three specialists were seconded and four support staffs were provided to the Project Team.
- As the activities related to the target system, consultation and coordination with the Project Team and the EU Contributing Institutes were carried forward toward conclusion of the Procurement Arrangement, in parallel to contract procedures, design studies, joint research with universities that were necessary for the start of the construction of the lithium test loop.
- As the activities related to the accelerator system, drafts of the Procurement Arrangements were created for the control system and RF coupling system, and coordination toward conclusion was made with the Project Leader and EU Contributing Institutes. Consultation and coordination were also carried on with EU concerning safety and interface of the accelerator facility.
- As Activities related to the test cell system, consultation and coordination with the Project Team and EU Contributing

Institutes were conducted, in parallel to the necessary contract procedures, design studies, joint research with universities.

- Details of activities and achievement are shown below for each system.

2.2.2 Activities related to the Target System

For finalizing the order specification of EVEDA lithium test loop, baseline design was performed, clarifying major specifications of the test loop, including the overall configuration, amount of lithium, and necessary electric power. Fig. 1 shows the overall configuration of the EVEDA lithium test loop. Concerning the procurement arrangement on design, construction, and operation of the lithium loop, coordination with EU Implementing Agency has been completed; Japan and the Project Leader have signed it already, and only signing of the EU Implementing Agency is pending. The contract for fabrication of the lithium test loop will be concluded within February, 2009. As for the remote operation verification task, the lip seal welding method was evaluated for development of a exchangeable target back wall, and preparation work has been initiated for manufacturing of a welding test piece using fiber laser which presents no big welding influence. In collaboration with a university, diagnostics devices and ports were studied for precision improvement of free-surface flow measurement as a diagnostics task, while circulation test units were studied for control of the concentration of nitrogen and tritium as a purification task. In engineering design, thermal stress evaluation of the target back wall was performed with a multi-purpose thermal stress analysis code (ABAQUS), proving that temperature control at the start-up of equipment operation is necessary for reduction of thermal stress.

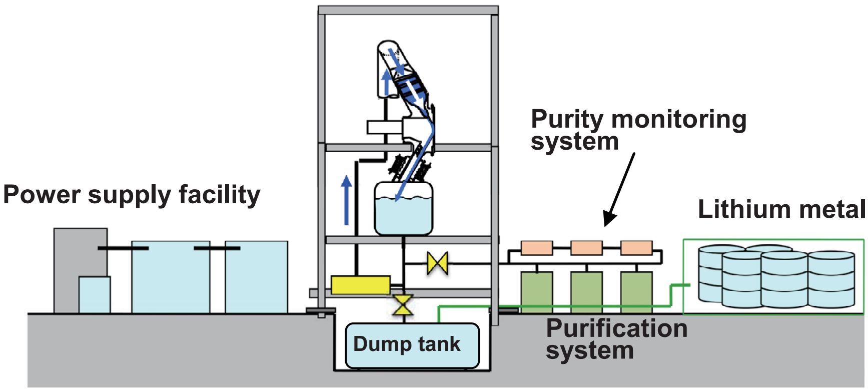

Fig. 1: Configuration of the EVEDA lithium test loop

2.2.3 Activities related to the Accelerator System

RF windows of 4-1/16 and 6-1/8 inches coaxial waveguide which are used in RFQ of IFMIF/EVEDA prototype accelerator were designed and the RF loss was calculated with the MW-Studio code. RF loss of the window for 6-1/8 inches coaxial waveguide was 25 W and total RF loss of the coupler except for loop antenna was 405 W at the nominal operating condition, such as input power of 200 kW and the reflected power of 20 kW at the operating frequency of 175 MHz. The design review meeting about the RF coupler was held by experts. The analysis and tests for RF couplers were authorized in the meeting and agreed by Project Team, EU Contributing Institute and JAEA. EPICS drivers for VME modules of timing system and for PLC used in personal protection system and machine protection system were developed and tested for operation. Conceptual design of center control system, LAN, PPS, MPS and TS was finished. The conceptual design review by experts was held.

The first working group meeting about safety management of accelerator facility was held in Rokkasho BA site. Preparation for licensing procedure of “Laws Concerning the Prevention from Radiation Hazards” was started. The workshop on accelerator’s commissioning was held at Tokyo with Project Team, EU Contributing Institute and JAEA. Experts from eight accelerator facilities such as J-PARC, SNS and CERN were invited and discussed about design and commissioning of IFMIF/EVEDA prototype accelerator and other accelerator. A lot of significant information and advices were given by experts and they may be reflected in the commissioning plan.

2.2.4 Activities related to the Test Cell System

Concerning tasks assigned to Japan, i.e. development of a small-size specimen test technique (SSTT), development of a high-flux test module (HFTM), and design of a post-irradiation examination facility, consultation and coordination were carried on with the Project Team and EU Contributing Institutes for conclusion of the procurement arrangement. For development of SSTT and HFTM, JAEA started joint researches with universities. For the former development, the study was evaluated to internationally standardized technologies and methods of measurement of fracture toughness and fatigue of small-sized test pieces. For the latter, evaluation was made on the latest HFTM design concept as well as on the compatibility concerning the tie-in with other equipment in the test cell environment where it is used, in order to design a test module which can be used in high-temperature irradiation conditions. For design of a post-irradiation examination facility of IFMIF, evaluation was made on the classification of radiation-dependent handling substances and on the handling process of HFTM irradiation rig and implementation to enable efficient data acquisition which will be obtained from a series of tests of small-sized test pieces that is necessary for the design of DEMO reactor.

2.3 Support for BA Activities in Rokkasho

2.3.1 Overview

・ Construction of the buildings for IFERC and IFMIF/EVEDA was continued.
・ For establishment of the Rokkasho site, construction and installation of the necessary utility facilities was continued for the research facilities to be constructed at this site; JAEA provided support of processes necessary for construction and installation of utilities.
・As one of support activities of the Aomori Research and Development Centre, support for researchers dispatched from EU to the Project Team and staying in Rokkasho was implemented. Also public relation activities for increased understanding of public, especially local communities, were done.
・Details of the activities and achievements are shown below.

2.3.2 Construction of Buildings for IFERC and IFMIF/EVEDA

・For IFERC-related buildings, IFMIF/EVEDA Accelerator Building and their utility facilities, construction and installations were continued based on the procurement arrangements on the design and construction of buildings agreed with the EU Implementation Agency. The progress of construction/installation at the end of Dec. 2008 reached 69% for the Administration & Research Bldg., 49% for the Computer & Remote Experiment Bldg. 29% for the DEMO Reactor R&D Bldg., and 18% for the IFMIF/EVEDA Development Experiment Bldg. (see Fig 2). Among them, the Administration & Research Bldg. will be completed within FY2008 as scheduled.

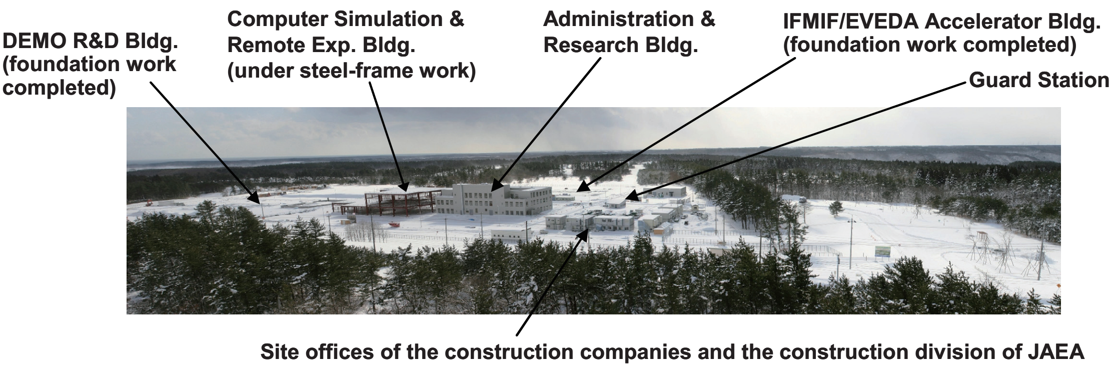

Fig. 2: Current status of the Rokkasho BA site (photo taken on Jan. 19, 2009)

2.3.3 Site Establishment and Support for Base Activities

・For establishment of the Rokkasho site, construction and installation of utility facilities necessary for the research facilities (Water Supply & Drain Processing Facilities, Guard Station, Central Power Station, roads, drain lines, etc.) were continued; JAEA supported various procedures concerning supply and use of electricity, water, effluent, etc.

Collecting data and materials were collected for licensing in compliance with the regulations, including "Laws Concerning the Prevention from Radiation Hazards due to Radioisotopes and Others", and examination and preparation for application were continued.

・As one of support activities for researchers dispatched from EU to the Project Team and staying in Rokkasho, JAEA prepared documents necessary for office procedures, while supporting Aomori Prefecture and Rokkasho village in improving the education environment for foreign researchers' children (establishment of an international class).

・In order to promote public understanding (especially that of local communities), proactive efforts were made to disclose and transmit information, including three briefings for local governments, four research information briefing at local events, five lectures in universities, etc., and one media meeting on the project plan.

＜Remarks＞

○ Enhancement of activities for promotion of understanding at the Rokkasho site

・Visit of the French Prime Minister at the BA site (Apr. 12, with 100 participants)

・2nd ITER Council's BA site tour (June 19, with 47 participants)

・BA site tour for participants of Fusion Energy Joint Conference (June 20, with 128 participants)

2.4 Satellite Tokamak（JT-60SA）

2.4.1 Overview

An Integrated Design Team consisting of members from the Project Team and the Implementing Agencies of Japan/EU has been organized, which proceeded with integrated design and prepared a design change report. The report was approved by the Broader Approach Steering Committee of Japan and EU governments, after examination and approval by the Project Committee Design Review Committee and Project Committee. Figures 1 and 2 show a birds-eye and section views of the JT-60SA device, respectively, Table 1 summarizes the main plasma parameters, and Fig. 3 shows the construction & operation schedule. The major points of this design change were made in order to satisfy and improve the original mission (i.e. defined in the Conceptual Design Report); improvement includes enhancement of the suppliable magnetic flux at the plasma current flat top, reduction of toroidal magnetic field ripple, and increase in the plasma shaping factor), while meeting the cost requirements. Thanks to the decreased aspect ratio, plasma current of 5.5MA, i.e. same as the conventional one, could be secured, while reducing the toroidal magnetic field (2.7T→2.2T). Through optimized configuration of the poloidal magnetic field coils, the number of the equilibrium field (EF) coils was reduced from seven in the conventional system to six. The new design allows independent control of the four center solenoid (CS) systems for enhanced freedom in plasma equilibrium

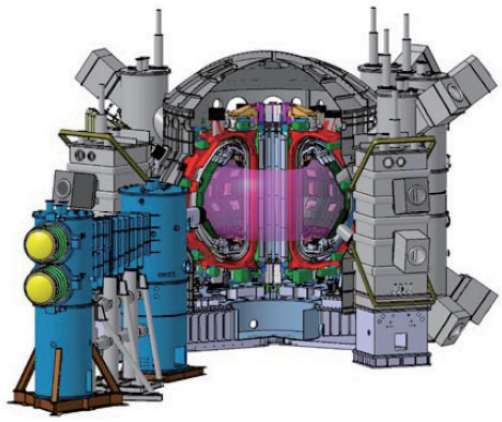

Fig. 1: Birds-eye view of the JT-60SA device

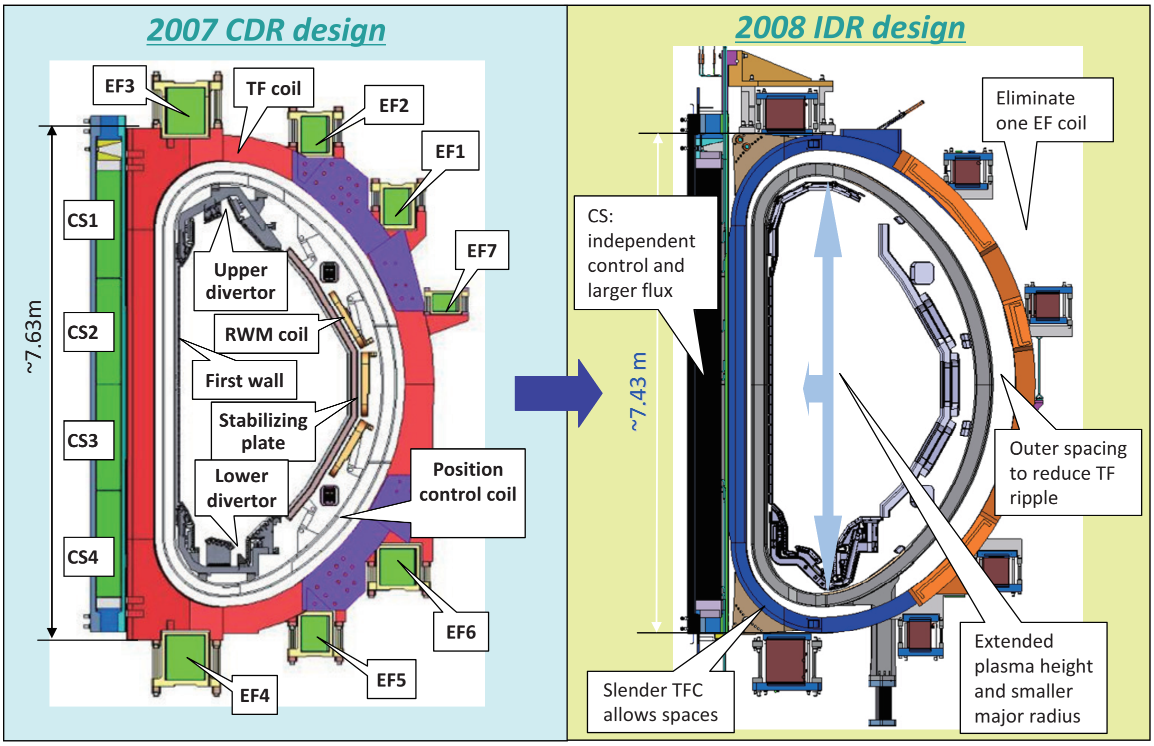

Fig. 2: Cross sectional view of JT-60SA device (comparison between 2007 Conceptual Design Report and 2008 Integrated Design Report)

Table 1: JT-60SA Major parameters

Machine Design	2007 CDR	2008 IDR (Initial Research Phase)	2008 IDR (Extended Research Phase)
Exploitation Plan	Long Pulse for ITER & DEMO	Commissioning, short pulse (limited long pulse) for ITER & DEMO	Longer & higher power for ITER & DEMO
	high beta-N =4.1, full CD with high BS, 5.5MA high Q, Transport, NTM &RWM Control, Pedestal & ELM, High Energy Particle, SOL / divetor		
Eq. Reference	061122_DN_3	080606_LN550_A=2.5_v01a	080629_DN550_A2.5_v01a
Configuration	Low A (DN)	Low A (SN)	Low A (DN)
Plasma Current, I_p (MA)	5.5	5.5	5.5
Toroidal Field, B_t (T)	2.68	2.25	2.25
Aspect Ratio, A	2.66	2.54	2.52
Shape Parameter, S	5.4	5.6	6.1
Major Radius (m)	3.07	2.97	2.97
Minor Radius (m)	1.15	1.17	1.18
Elongation, κ_x	1.89	1.83	1.93
Triangularity, δ_x	0.61	0.50	0.57
Safety Factor, q_{95}	3	3	3
Flattop Duration	100	100	100
Heating & CD Power	41 MW x 100 s	21.5 MWx100s 31.5 MW x 60s 33.0 MW x 5s	41 MW x 100 s
N-NBI	10 MW	10 MW	10 MW
P-NBI	24MW	20 MW	24MW
ECRF	140 GHz, 4 MW 110 GHz, 3 MW	110 GHz, 1.5 MW x 100s 110 GHz, 3 MW x 5s	110 GHz, 7 MW
Divertor wall load	15 MW/m ^{2}	3 MW/m ^{2} x 100s 10 MW/m ^{2} x 10s	15 MW/m ^{2}
Annual neutron yield	4×10^{21}	4×10^{19}	1.5×10^{21}

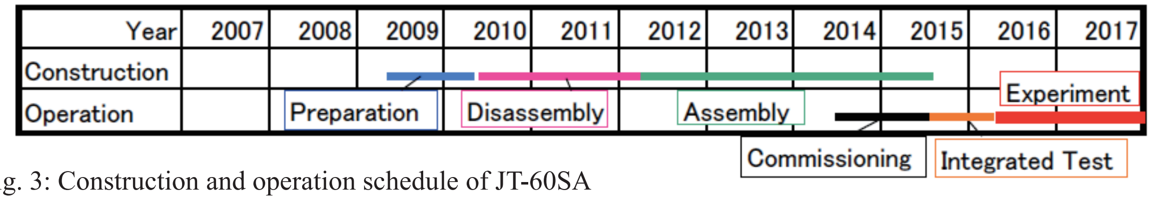

Fig. 3: Construction and operation schedule of JT-60SA

Table 2: JT-60SA Phased Operation Schedule

	Phase	Expected Duration		Annual Neutron Limit	Remote Handling	Divertor	P-NB	N-NB	ECRF	Max Power	Power x Time
Initial Research Phase	phase I	1-2 y	H	-	R&D	LSN partial monoblock	10MW	10MW	1.5MW x100s + 1.5MW x5s	23MW	NB: 20MW x 100s 30MW x 60s duty = 1/30 ECRF: 100s
	phase II	2-3y	D	4E19			Perp. 13MW Tang. 7MW			33MW	
Integrated Research Phase	phase I	2-3y	D	4E20		LSN full-monoblock			7MW	37MW	
	phase II	>2y	D	1E21	Use						
Extended Research Phase		>5y	D	1.5E21		DN	24MW			41MW	41MW x 100s

Japan and Europe agreed to adopt a phased operation schedule with gradual enhancement of the heating power and divertor performance along with the research phases of JT-60SA (Table 2). Since the JT-60SA project is a joint program between the Broader Approach Satellite Tokamak program implemented by Europe and Japan, and the Japanese national program, opinions of the Japanese fusion research community has been collected based on the discussions held in Fusion Plasma Joint Planning Committee and its JT-60SA Special taskforce, subjected to examination in ITER/BA technical promotion committee of the Japanese Fusion Energy Forum, and reflected on Japan-EU consultation.

Fig. 4: Technical Coordination Meeting of Japan and Europe

2.4.2 Manpower Contribution

While supporting the Project Team, JAEA organized meetings for study of integration of design & fabrication and rationalization of design (three technical coordination meetings, 30 pre-coordination meetings, and one design review meeting) with the Project Team and EU Implementing Agency. It also dispatched commissioners and specialists to the 3rd Project Committee, 1st and 2nd Project Committee Design Review Meetings, providing support for arrangement of the place of conference and other meeting-related tasks, and participating in and contributing to the determination on activity guideline.

2.4.3 Procurement

For procurement of items assigned to Japan, i.e. superconductors for the superconductive poloidal magnetic field coils, torus sections of the vacuum vessel, and carbon fiber composite (CFC) for the divertor, relevant works were carried on as scheduled.

2.4.3.1 Superconductive Coil

For fabrication of a superconductive poloidal magnetic field coil and procurement of the divertor cassette, etc., preparation work is proceeding for contract conclusion by the end of FY2008. The progress status of the fabrication is described below.

The configuration of the central solenoid (CS) and equilibrium field (EF) coil is shown in Fig. 5. The cross-section of the superconductor used for the EF coil consists of about 500 superconductive wires of 0.8mm thickness twisted together and a stainless steel pipe covering around them, as shown in Fig. 6. In FY2008, fabrication of the superconductor for CS and for EF was started; besides, Superconductive Coil Winding Bldg. was constructed for EF coil winding work in Naka Fusion Institute.

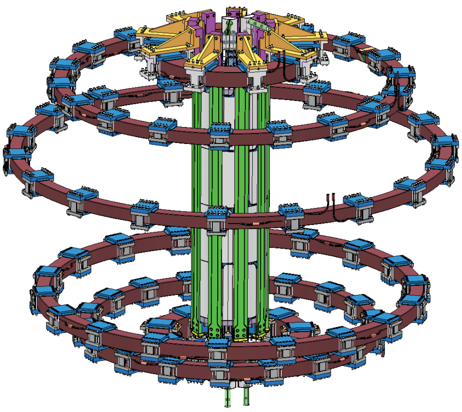

Fig. 5: CS and EF coil for JT-60SA

Fig. 6: Cross-section of the conductor for EF coil (trial product)

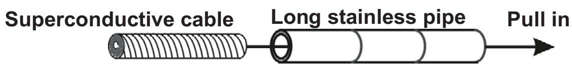

Fig. 7: Superconductor assembly procedure

Manufacturing of parts of the superconductor, i.e. wires, cables, and stainless-steel pipes, was started from trial production. After checking the superconductivity in the coil operation range, mass production of the wire was started. For the cable strands, a 200m-long cable was test-produced using pure copper wires, confirming that the finished size was within the allowance. As for the stainless-steel pile, a trial product was completed, and welding test and other processing were started.

The procedure of superconductor assembly is as follows, as shown in Fig. 7: a 600m long pipe is manufactured in butt welding of 13m pipes, to lead the superconductive cable into it. After that, it is compression-molded and then wound around a transport drum to be completed. To install a jig for conductor fabrication, a 600m-long straight passage (2m wide) was constructed in Naka Institute. Conductor Fabrication Bldg., in which a conductor assembly unit will be installed, is under construction, 600m ahead of the straight passage shown in Fig. 8. A superconductor assembly unit will be installed in April 2009 for start of the production in summer.

Fig. 8: Conductor manufacturing line (600m long)

Fig. 9: Construction of Superconductive Coil Winding Building

As shown in Fig. 5, EF coil is a large ring-shaped coil, of which largest coil has a diameter larger than 12m. Therefore, it is difficult to transport the coil using public roads, and thus a building for coil winding is under construction within Naka Fusion Institute. The construction work (Fig. 9) will be completed at the end of March, 2009; after that, installation of the coil manufacturing facility is started for scheduled start of EF coil winding from 2010. On the other hand, design of CS and EF coil has been completed and summarized into a detailed design sheet, and a procurement arrangement (PA) was concluded with EU side; meanwhile a contract for the 1st phase government procurement of CS and EF coil is being prepared.

2.4.3.2 Vacuum Vessel

The donut-shaped vacuum vessel (Fig. 10) has a double-wall structure in order to secure structural strength and appropriate loop resistance. The 8% boric-acid solution (weight concentration) will flow in the space between these double walls (inside 152 / outside 187mm) as reinforcement of the neutron shield function. During intermission of operation, baking at 200℃ can be conducted by circulation of hot nitrogen gas of 200℃ after discharge of boric-acid solution. The contract for the 1st phase manufacturing of the vacuum vessel (40° sector x three) was concluded in March 2008. Trial production of the upper half of the 20° sector will be started in February 2009.

Delivery of SUS316L plate materials for the above mentioned vacuum vessel was completed (168 pcs, about 200 ton) by the end of October. From now on, plate materials will be supplied on request from the manufacturer of the vacuum vessel. Fig. 11 shows how the plate materials are stored in JT-60 Equipment Storage Bldg in Naka Institute.

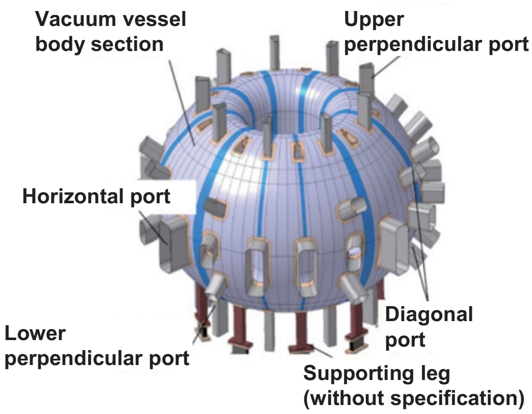

Fig. 10: JT-60SA Vacuum vessel

Fig. 11: Delivered plate materials for the vacuum vessel

2.4.3.3 Divertor Material

As for the carbon fiber composite (CFC) material to be used for the lower divertor, CFC materials are being manufactured for the mono-block target and for bolt-fixed tiles. 500 pieces of CFC materials for mono-block target were delivered in December, and remaining 600 pieces as well as 148 pieces for the bolt-fixed tiles are scheduled to be delivered by the end of March, 2009.

3. Research & Development of Fusion Plasma

3.1 Research for Achievement of Steady State High Beta Operation

3.1.1 Sustainment of the High-Pressure Plasma

In JT-60, exploitation of long-time sustatiment of high-pressure plasma above the free-boundary stability limit, by suppressing the resistive wall mode (RWM) has been carried on for JT-60SA and the DEMO reactor. It was found out that 1) decrease in the toroidal plasma rotation induces RWM onset becoming a cause of disruption and that 2) instability driven by energetic ions (EWM: to be explained later) injected from the perpendicular neutral beams (NB) causes RWM (Fig. 2). Therefore, experiments have been carried out with plasma rotation in the same direction as the plasma current by NB torque input, while restricting the perpendicular NBI power to the requisite minimum. As a result, it was succeeded to sustain high normalized pressure (β_N⌒3.0) above the free-boundary stability limit for about five seconds (world record), as shown in Fig. 1. As the red circles show, the attainment region could be expanded significantly in experiments in 2008. New instability mentioned above, which results from energetic ions and occurs when the free-boundary limit is exceeded, has been discovered (named as EWM: Energetic particle driven Wall Mode), and a method for its stabilization was developed.

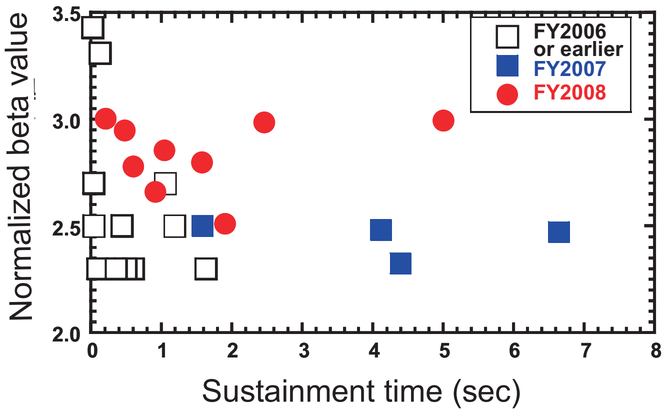

Fig. 1: Sustainment time of high beta plasmas above the free-boundary ideal stability limit.

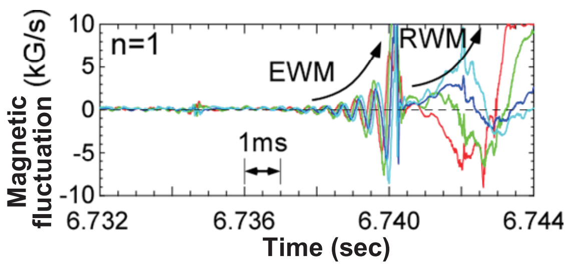

Fig. 2: EWM and EWM-induced RWM

3.1.2 Expansion of the Operation Range of Negative Magnetic Shear Plasma

With its high confinement performance and bootstrap current fraction, the negative magnetic shear plasma, which has been developed in JT-60, is one of the candidate operation scenarios for future fusion reactors. Since one of the tasks to be solved concerning the negative magnetic shear plasma was low MHD stability limit, efforts for optimization of plasma discharge has been made, using configuration close to the vacuum vessel (wall radius / plasma radius ~1.3) so as to enable stabilization effect by the conducting wall. As a result, it was succeeded in obtaining a high normalized beta value (~2.7) exceeding the free-boundary MHD stability limit (normalized beta value ~2). Through this, the operation range of the negative magnetic shear plasma was significantly expanded, while a large bootstrap current fraction (70 – 90%) was achieved in the safety factor area that is assumed in a fusion reactor (Fig. 3). At the same time, conditions assumed for the fusion reactor, including electron temperature ~ ion temperature and low momentum input, are also satisfied. Besides, as shown in Fig. 4, plasma parameters that are assumed in the ITER steady-state operation scenario are also roughly satisfied; namely, plasmas with high integrated performance could be obtained.

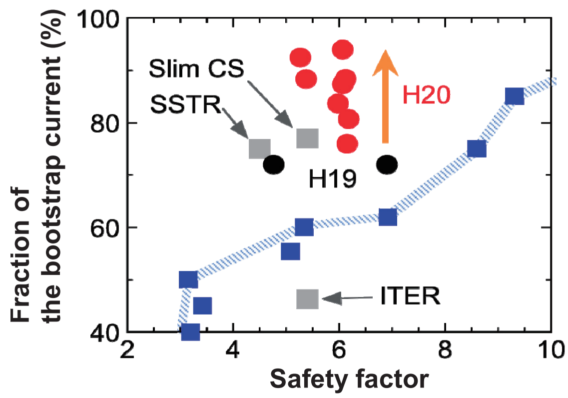

Fig. 3: Expansion of the operation range of the negative magnetic shear plasma by means of utilization of configuration that enables wall stabilization

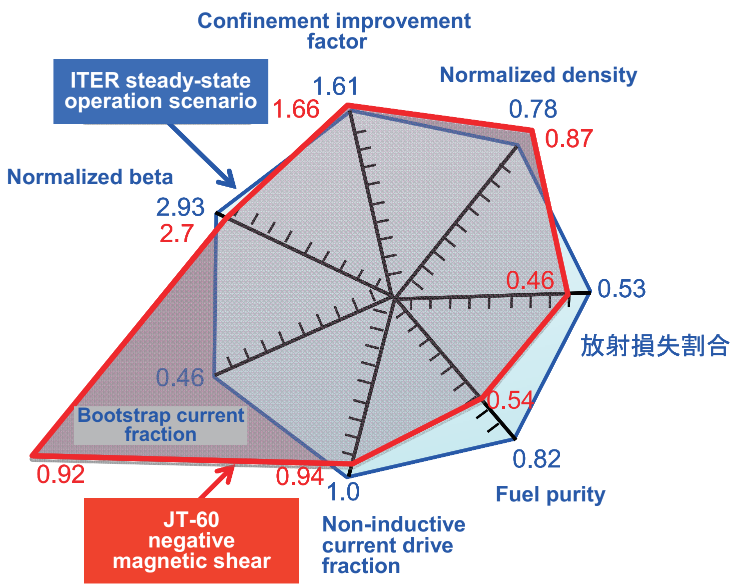

Fig. 4: JT-60 negative magnetic shear discharge compared to the ITER steady-state operation scenario

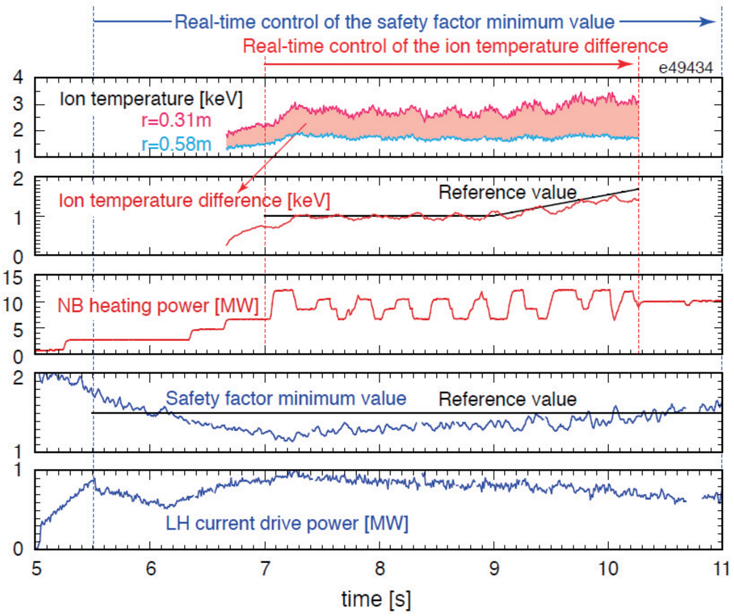

Fig. 5: Example of a simultaneous control of i) ion temperature gradient control with neutral beam power and ii) real-time control of the safety factor minimum value via lower hybrid wave current drive

3.1.3 Development of Real-Time Control

Concerning development of real-time control, simultaneous real-time control of plasma pressure and current profiles has been substantiated. In the example of Fig. 5, real-time control of ion temperature gradient via neutral beam power and control of the safety factor minimum value via lower hybrid wave current drive are combined. Further, non-linear control using the plasma temperature and density was conducted successfully. In the example of Fig. 6, real-time control of the temperature difference between the shoulder section and foot section of the internal transport barrier (temperature gradient) was substantiated, by varying the proportional gain of the ion temperature gradient control as a function of the ion temperature itself. Thus, through control of advanced plasma, its effectiveness for maintaining stability has been confirmed.

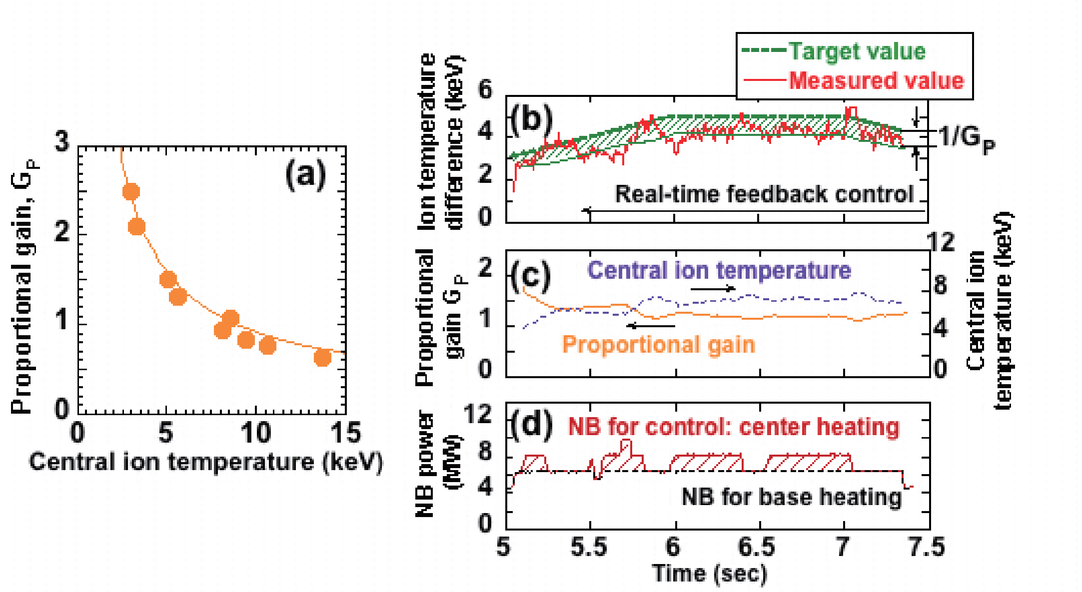

Fig. 6: Example of non-linear control: Temperature difference between the shoulder- and foot sections of the internal transport barrier was controlled on a real-time base, using the proportional gain as a function of the ion temperature itself.

3.1.4 Inter-Machine Experiments

In JT-60, comparative experiment was conducted together with JET device of Europe and DIII-D device of the USA, making a contribution to 29 inter-machine experiments. Fig. 7 shows the result of comparison with the JET device. This comparative experiment was conducted, matching non-dimensional parameters, such as the plasma size, cross-section shape, beta value, and normalized Larmor radius. Comparison was made concerning such conditions of internal transport barrier formation and profile structure that are effective for improvement of confinement performance, demonstrating that, confinement is improved in both devices from the inner side starting from the point at which the safety factor is “2”, and that the temperature distribution gets almost the same steep gradient in almost the same time.

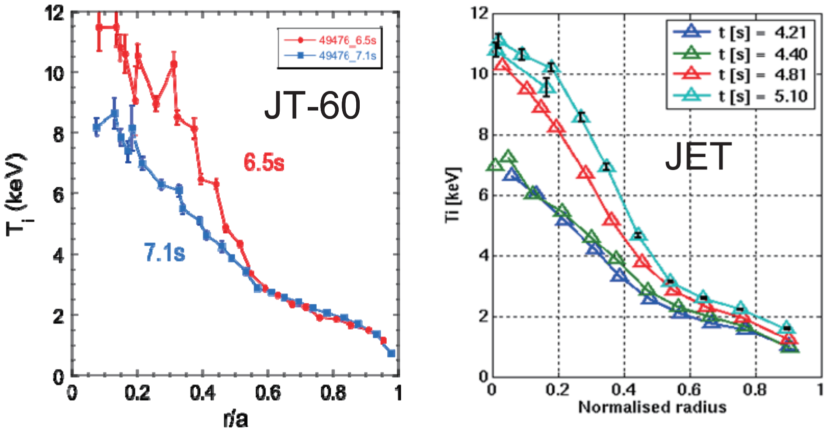

Fig. 7: Comparison of the temperature profile of plasmas which have an internal transport barrier, between JT-60 and JET devices

＜Remarks＞

○ On August 29, 2008, experiments in JT-60 have been completed after 23 years and four months. Since start of the experiment in 1985, JT-60 evolved a series of research and development necessary for long-time sustainment of high pressure plasma which is required for economic fusion reactors, after achieving the world-record high temperature of 520 million degree and break-even conditions in 1996 and an energy multiplication factor of 1.25 (world record) in 1998. JT-60 set up various world records, including success in sustainment of high normalized pressure ($\beta_N \sim$ 3.0)plasma exceeding the free-boundary ideal stability limit for five seconds in 2008, while providing data for major tasks for realization of ITER burning plasma. The operation was completed after obtaining maximum experimental data that could be achieved with the current equipment, as originally targeted. Especially, in the last two months before completion of the experiments, all the necessary data were obtained with support of 19 researchers from abroad and more than 50 Japanese researchers. After the overview talk on JT-60 on the first day of the 22nd Fusion Energy Conference organized by IAEA in October in Geneva, all the participants stood up and respectfully applauded the completion of the experiment.

Fig. 8: JT-60 team celebrating completion of the experiments

○ “Young scientist award” was granted in recognition by the Minister of Education, Culture, Sports, Science and Technology in the field of science and technology in 2008.
Dr. Naoyuki Oyama, Assistant Principal Researcher: research work: “Study for performance enhancement of tokamak plasma through plasma rotation control”

○ The 13th Science Incentive Award was granted by Plasma / Fusion Academic Society to:
Dr. Maiko Yoshida, research staff: “Study on the plasma rotation velocity distribution and momentum transport”

3.2 Development of Equipment Technique

3.2.1 Neutral Beam Injector

JT-60 Negative-ion-based Neutral Beam Injection unit (N-NBI) succeeded in continuous injection of a neutral beam exceeding 2MW to a core plasma for 30 seconds, as the first such machines, achieving the world record incident energy of 80MJ (Fig. 1). This was realized by reducing the thermal load on the grid in the negative ion source to the allowable level for the long pulse injection of (<500KW), which was obtained by optimizing the grid shape to suppress the beam expansion around the grid. Research on steady-state high beta plasmas has been progressed significantly through the long pulse injection of the neutral beam. The pulse width obtained here was three times as big as the original rated value of the N-NBI unit, and therefore was restricted by the allowable heating time that has been specified for protection of the JT-60 facilities. In this operation, the temperature of the cooling water of the grid saturated in about 25 seconds. Through this, a prospect was obtained for water cooling design of the negative ion source for JT-60SA which requires incident of 100 seconds.

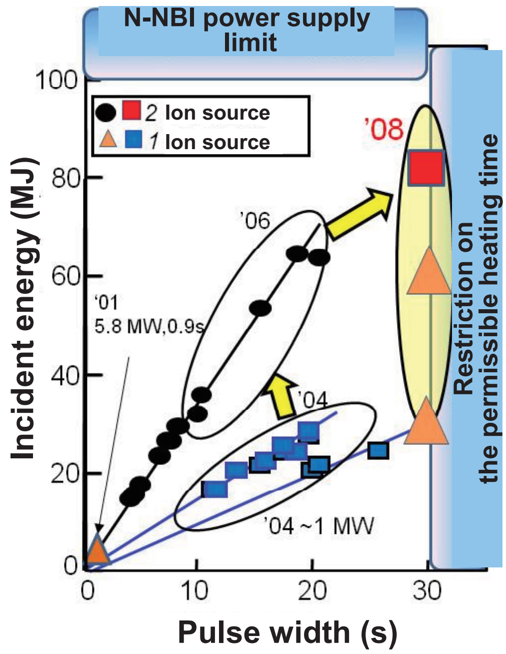

Fig. 1: Development of the pulse width and incident energy of the Negative-ion-based Neutral Beam Injection unit (N-NBI)

3.2.2 Radio-Frequency Heating System

In development of the electron cyclotron wave heating system development of the power modulation technology was carried on which is necessary for stabilization of the neoclassical tearing mode (NTM) in ITER, successfully realizing the modulation frequency of 10KHz (which is a world record for the output of 1MW) (Fig. 2). This result was achieved without modifying the main power supply unit for electron beam acceleration, by adopting such a method that oscillation is controlled by means of high-speed switching of the voltage applied to the pitch angle control electrode (anode). In addition, real-time feedback control has been developed, in which electron cyclotron waves are injected into the magnetic island with precise synchronization and phase control, in order to stabilize the neoclassical tearing mode. In modulation of the incident power to JT-60 plasmas by 5 – 7KHz using this technology, high stabilization effect was successfully and clearly demonstrated, proving effectiveness of this incident power modulation technology.

Another problem, i.e. a problem of electric discharge at the small-bore diamond vacuum window (bore diameter about 3cm) at the antenna section where a high voltage develops, was solved through improvement of the arc detection circuit, enhancing the high-power transmission performance. Besides, efforts were made for extension of the pulse width in high power, by combining achievements so far on evaluation technology of the thermal load distribution in different sections of the gyrotron. As a result, gyrotrons in four units could be successfully operated with the rated output (1MW and 5 seconds) simultaneously, achieving the injection power to JT-60 of about 3MW (Fig. 3).

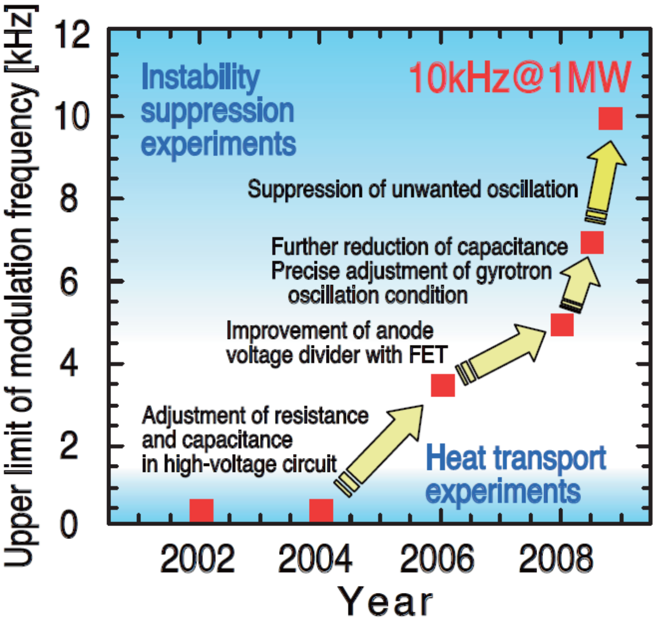

Fig. 2: Progress of development of the gyrotron power modulation technology

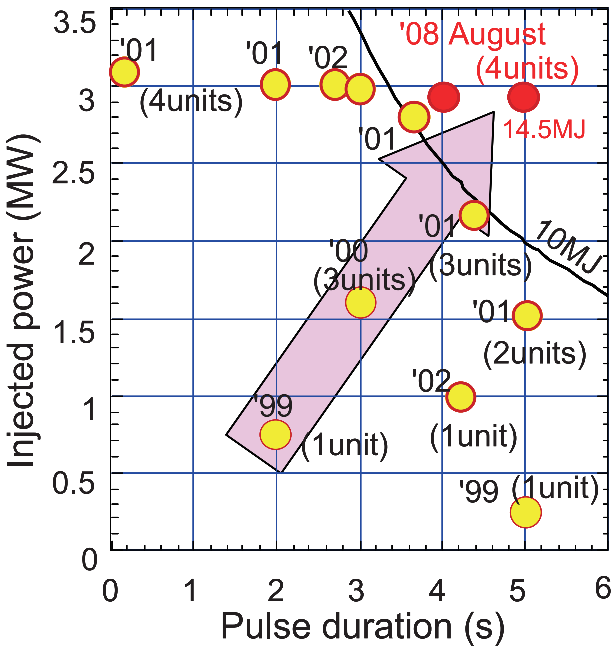

Fig. 3: Enhancement of the injection performance of the electron cyclotron wave heating system

3.2.3 Diagnostics Systems

Concerning upgrading of the plasma diagnostics system, the time evolution measurement of the density distribution (world's first) and the current profile measurement were realized successfully, in installing an edge current profile measurement diagnostics (Li beam probe), which has been developed in the previous year, to JT-60. Through this, data were measured with high time resolution of 0.5msec for a phenomenon of the edge density collapse due to the edge localized mode (ELM), which occurs when the edge transport barrier was generated and the edge density evolved in an H-mode plasma (Fig. 4). The edge current profile was also measured in the H-mode plasma where small scale ELMs occured (Fig. 5). These detailed measurement at the edge pedestal region have significantly promoted understanding of dynamics of the edge pedestal structrure, one of the largest tasks for ITER.

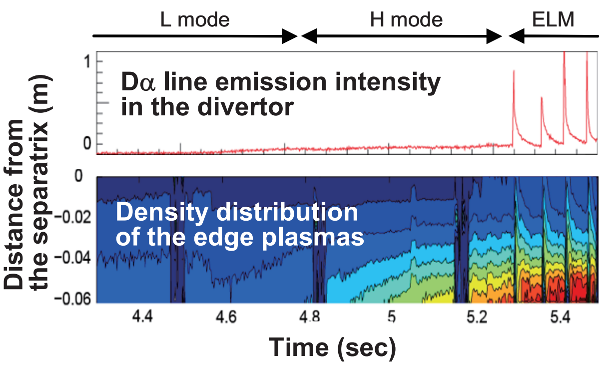

Fig. 4: Time evolution of the density distribution at the edge pedestal section

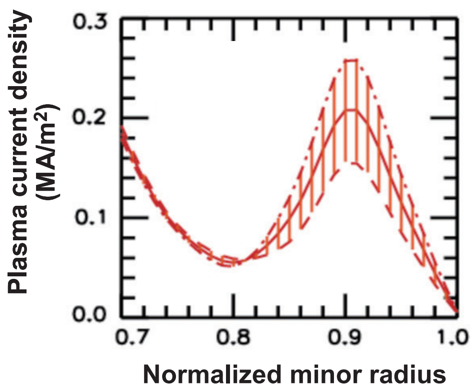

Fig. 5: Successfully measured edge current density distribution (average in two seconds: upper and lower dotted lines are error bars)

Using a spectroscopy which enables simultaneous observation of three spectral lines of neutral helium (He I) in the same field of view, spatial distribution measurement of electron temperature & density was successfully performed for the first time, with the time resolution of 100 microseconds. Fig. 6 shows a measurement example. Change in the divertor plasma electron temperature / density due to ELM was measured with multiple channels and high time-resolution. At the outer divertor, the electron temperature as well as the electron density increased just after ELM, while no major parameter change was observed for the inner divertor.

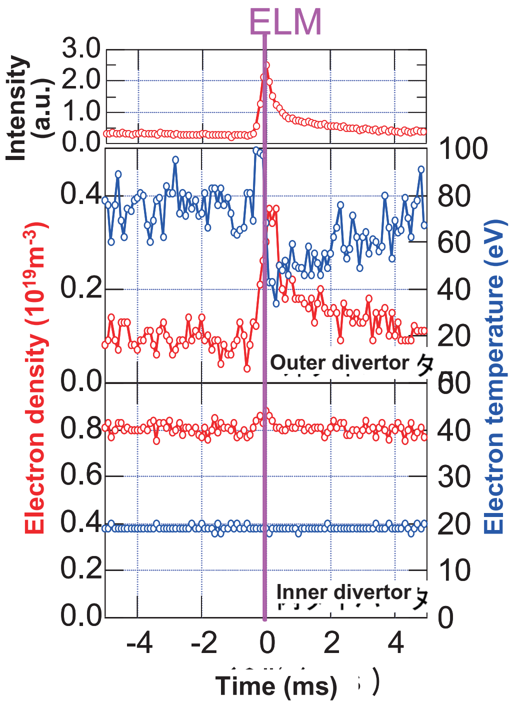

Fig. 6: High time-resolution measurement of the electron temperature and electron density of the divertor plasma

3.3 Code Development

For integrated simulation of the fusion plasma, integration of different models, including magnetofluid stability model, fusion burning model, transport improvement model, and SOL/Divertor model, is in progress based on the transport code. In FY2008, neutral particles transport model and wall recycling model were integrated into the model of magnetofluid stability determined by the pressure and the plasma current, clarifying dependency of the energy loss due to intermittent MHD instability (ELM) at the plasma edge on the collision frequency and the pressure gradient inside the pedestal (Fig. 7). In addition, anomalous transport of α particles due to instability was modeled in assumption of an Alfven Eigenmode due to energetic particles, using 2-dimensional Fokker-Planck code, including the processes of α particle generation, α heating, and He ash generation. This model has been integrated into the transport code to enable fusion burning simulation.

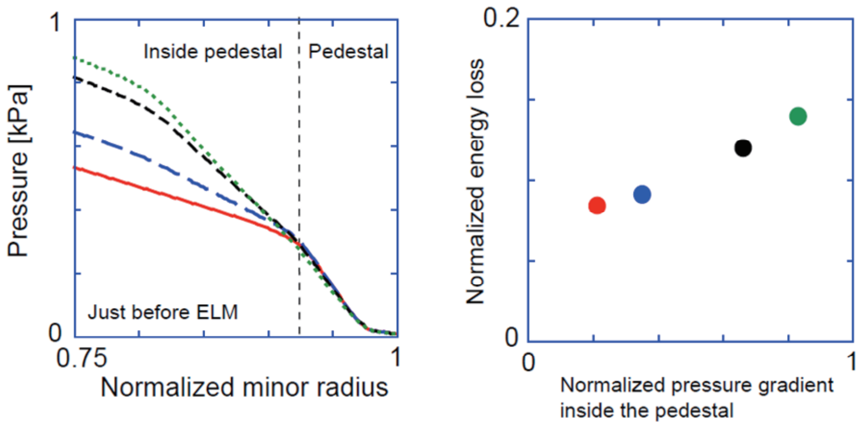

Fig. 7: Pressure profile dependency of the ELM energy loss: As the pressure gradient inside the pedestal increases, ELM instability mode grows, increasing energy loss.

3.4 Collaboration with Universities and Fostering of Human Resources

In cooperation and collaboration with universities, etc. the following organizations were established and organized: Fusion Plasma Joint Planning Committee, JT-60 Special Committee, JT-60SA Special Committee, and Theory & Simulation Special Committee. For joint research related to JT-60, 26 joint research projects were performed in an open-application system, after selection and adoption of the themes in the Fusion Plasma Joint Planning Committee (149 people participated in the researches) (Fig. 8). For 10 joint research themes on JT-60 that have been completed in FY 2007, a debrief session was held. As fruits of these joint researches, 53 research papers were submitted in joint authorship with researchers of universities, etc. In the 22nd IAEA Fusion Energy Conference, 21 presentations were made by JT-60, out of which seven were made by researchers of universities, etc. As more than a half of the participants in JT-60 were assistant professors and graduate students, a big contribution could be made through this also from the viewpoint of human resource development (Fig. 9).

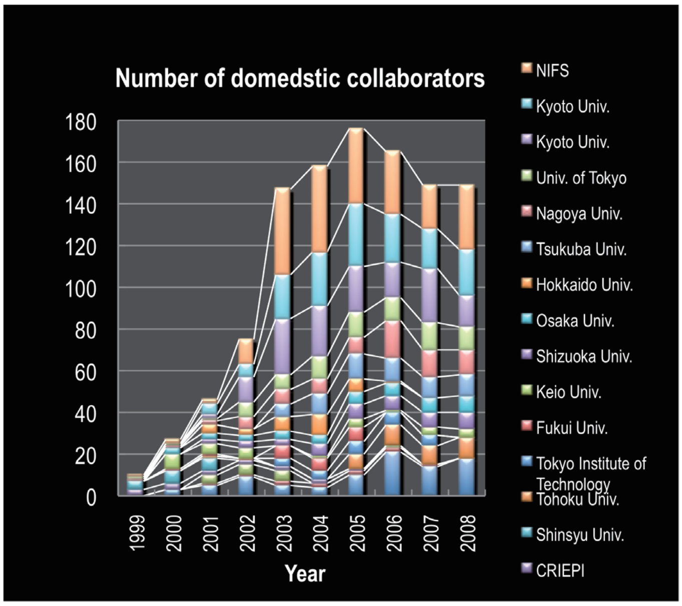

Fig. 8: Number of co-researchers on JT-60 in Japan

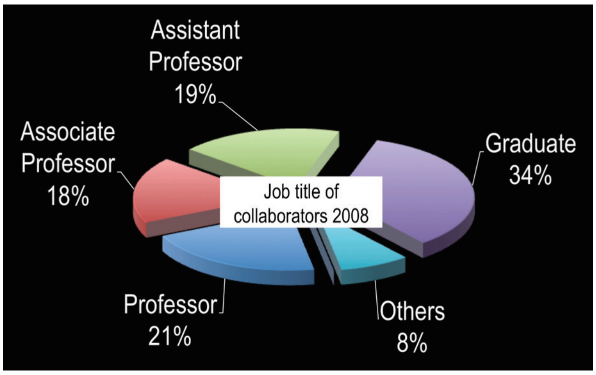

Fig. 9: Breakdown of co-researchers

3.5 Theory & Simulation Studies

In the course of the midterm plan concerning theory & simulation studies, the understanding of the turbulence structure of fusion plasmas was advanced, in parallel to development of a theory and computational methods concerning magnetohydrodynamics behaviors of plasmas for the purpose of obtaining a theoretical guideline for control of confinement and stability. During FY2008, the following achievements were made through these activities.

○ It is known that plasma inertia and electric resistance act only near the rational surface, while such approximation is effective in remote areas from the rational surface that the status is as per the ideal MHD equation (Newcomb equation) without any inertia effect. An analysis model which numerically realizes this approximation has been formulated, and a code has been developed which can analyze the plasma rotation effect on the resistive wall mode. These achievements have been presented in the 22nd IAEA Fusion Energy Conference.

○ A turbulent transport code based on the gyrokinetic Vlasov equation has been extended to the torus geometry, the code has been verified in comparison with the conventional particle code, and the results was published (Fig. 1). Besides, the heat source and particle source was implemented to establish a basis towards long-term turbulence simulations of open-system plasmas with nuclear burning and external heating. The achievement was presented in the 22nd IAEA Fusion Energy Conference.

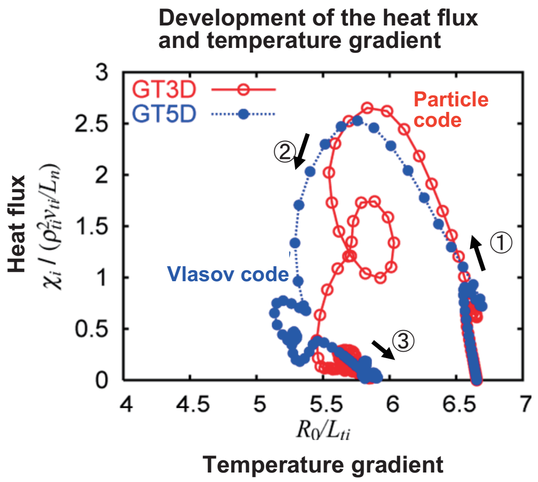

Fig. 1: Comparisons of ion turbulence simulations in a torus configuration between a new Vlasov code and a conventional particle code. The saturation level of the heat flux and the nonlinear critical temperature gradient show quantitative agreements.

4. Research & Development in Fusion Engineering

4.1 Research & Development of Breeding Blankets

Based on the development plan concerning the heat-, flow-, mechanical properties as well as tritium recovery performance, among all, of the breeding blanket, engineering-scale performance tests have been conducted, in which the following achievements were made.

4.1.1 Packed Bed Structure

Concerning the packed bed structure, adequacy of the design- and fabrication methods were evaluated, in performing a high-temperature flow test, trial fabrication of a full-scale mockup of the side wall, etc. and mechanical test. First, as for the high-temperature test, it was confirmed that no abnormal deformation, crack in the welding section, or other failure occurs in a high-temperature heating test up to maximum temperature of 760◦C, using a full-scale mockup of the packed bed structure fabricated in 2007, as shown in Fig. 1. For the flow test, the above mentioned mockup was packed with same small pebbles as those will be used in the actual component as the breeding material to perform evaluation test of the packing status of the pebbles using an X-ray CT scanner and other devices. After that, a flow test was performed using helium purge gas. In the pebble packing status evaluation test using an X-ray CT scanner, etc., as shown in Fig. 2, it was confirmed that pebbles were filled without any gap even around the cooling tube, and that the actual packing rate was within the range of 65% ± 1%, namely it satisfies the design value for pebbles of 65%. In the flow rate test using helium purge gas, it was confirmed that, with the design flow rate of 5L/min, the pressure loss in the pebble packing layer was 2kPa (about 0.02 atmosphere）, i.e. sufficiently small and within the acceptable range of the design value of the pressure loss, as shown in Fig. 3. The results of these high-temperature heating test, packing condition evaluation, and purge gas flow test demonstrated that the design and fabrication methods are adequate. As for evaluation of the full-scale mockup fabrication technology, a cooling channel was fabricated in the side wall body which is 32mm thick and 1.5m long, using a gun drill. Metallographic observation and mechanical test were performed. The result demonstrated adequacy of the fabrication method of the full-scale side wall.

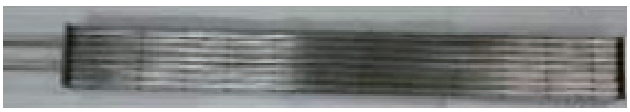

Fig. 1: Full-scale mockup of the packed bed structure
(Length: about 1m, Width: about 11cm)

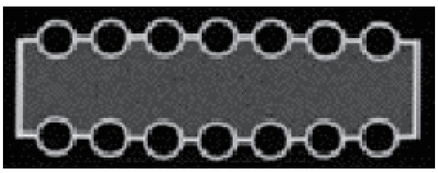

Fig. 2: Cross-section X-ray CT photo of the full-scale mockup of the packed bed structure, packed with breeding pebbles

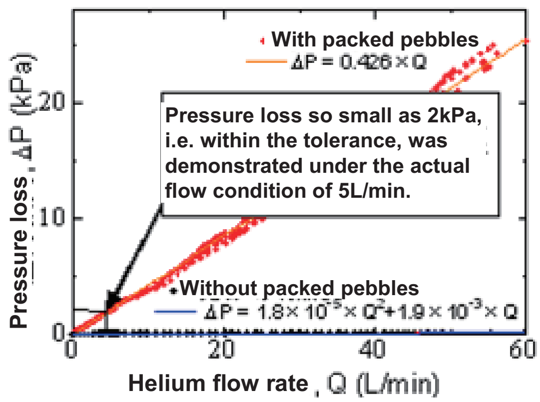

Fig .3: Flow test of the full-scale mockup of the packed bed structure

4.1.2 Study on the Nuclear Characteristics

In the study on the nuclear characteristics, development of the measurement- and evaluation methods has been carried forward, reflecting them on the design of the ITER test blanket module. After applying the Multi-Foil Activation method, a promising method for measurement of nuclear characteristics of the ITER test blanket module, in various simulation systems of the ITER test blanket, it was demonstrated that use of the NEUPAC code is adequate, as a code for derivation of the neutron spectrum (see Fig. 4). It was found out as well that accumulation of experimental data on low-energy neutrons is necessary in order to obtain more precise results.

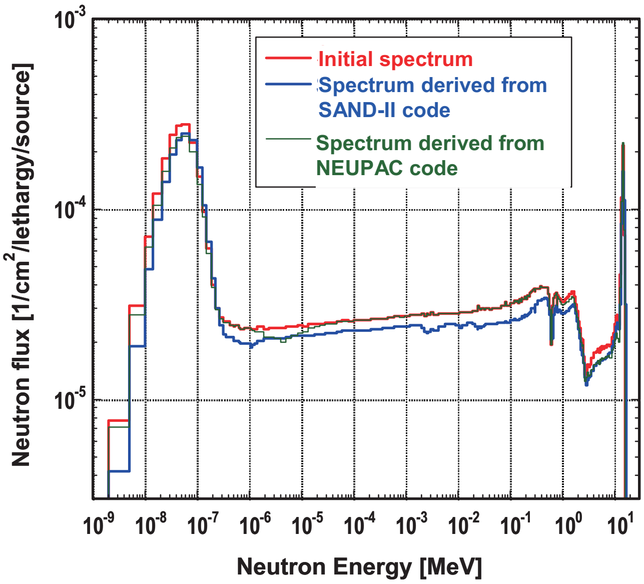

Fig. 4: Neutron spectrums in a beryllium system, at the depth of 152mm, derived from the Multi-Foil Activation method: it was found out that the result of the NEUPAC code is most consistent

4.1.3 Development of Tritium Recovery Technologies

For development of a technology for tritium recovery from the blanket, R & D activities were conducted concerning the tritium water processing system, in clarifying the amount and concentration of the tritium water which is generated inside the blanket. In a development test of a tritium water processing system, the amount of tritium was identified which is generated due to leak of tritium into cooling water. In addition, after obtaining basic data on the water vapor absorption quantity in paying attention to zeolite as a tritium water vapor adsorbent, it was found out that absorption quantity may be able to be controlled with the atmospheric pressure, by increasing the ratio of silica and alumina in the zeolite to 10:1, and thus a good prospect for development of a high-performance absorbent has been obtained (see Fig. 5). As development of a measure to prevent tritium permeation into the cooling water in the blanket, it was found out that gold plating on a metal reduces tritium permeation to about 1/1000.

Basic data have been obtained for the followings; i) high-temperature beta-ray induced X-ray spectroscopy which restricts the tritium memory effect, as a tritium monitor for the breeding blanket, and ii) packed material of micro gas chromatograph for hydrogen isotope separation.

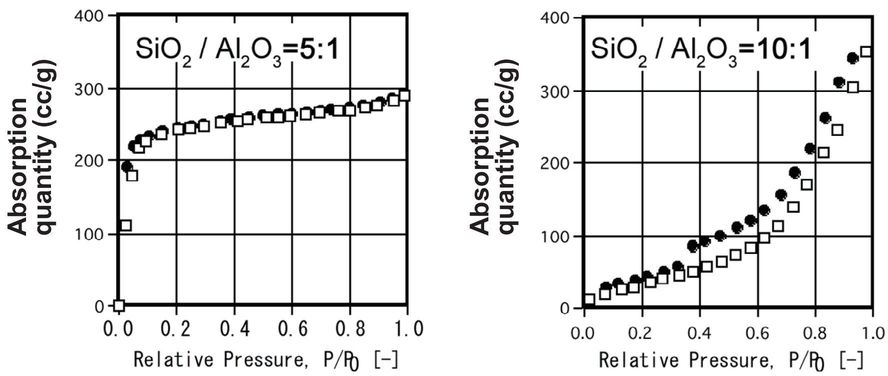

Fig. 5: Transition of the steam adsorption behavior with the silica / alumina rate in the zeolite

4.1.4 Development of Irradiation Technologies

As development of irradiation technologies, preparation of a hydrogen isotope permeation test unit for post irradiation examination (PIE) was started for tritium permeation barrier irradiated in the JMTR. Design review was conducted for the tritium baking unit to be embedded in the capsule disassembly unit for the PIE of irradiated tritium breeder. In this design review, the design was evaluated for each of the following systems; gas supply system (dry air and humidified air), tritium baking system, tritium measurement system, and tritium removal system. Fig. 2-6 shows a structural drawing of the tritium baking system which has been designed based on the structure of the capsule. As a technology for reprocessing and reuse of lithium, which is a rare metal, from used tritium breeder, methods for Li dissolving and removal of impurities have been examined. Through this activity, a high Li dissolving yields as well as high decontamination factor (DF) for the activated impurities could be achieved successfully, by using nitric acid (HNO_3) or peroxide hydrogen (H_2O_2) and a chelate agent (see Table 1). For this achievement, the Prize for Excellent Presenter was granted in the 7th Joint Conference on Fusion Energy.

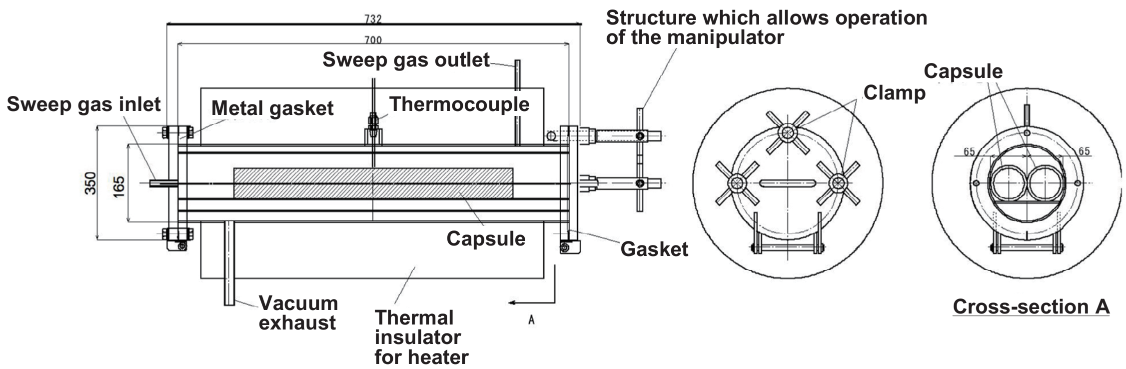

Fig. 6: Configuration plan of the tritium baking system

The structure is decided taking the manipulator operation into consideration. Two capsules (65mm diameter) are charged simultaneously. Sweep gas is introduced and connected to the tritium measurement system and removal system.

Table 1: Experimental results of dissolution of tritium breeders and removal efficiency of impurity

Test sample	Dissolving condition	Dissolving yields of Li	Removal efficiency of ^{60}Co (DF: decontamination factor)
Li_2O	HNO_3	96-100%	99.5% (DF=199)
Li_2TiO_3	H_2O_2 + HNO_3	91±3%	99.9% (DF=1535)
Li_4SiO_4	HNO_3	93±4%	97.6% (DF=41)

＜Remarks＞

○ For the achievement in development of the tritium breeder recycling technology, the Prize for Excellent Presenter was granted in the 7th Joint Conference on Fusion Energy (Award winner: Tsuyoshi Hoshino).

○ Press release on "Fabrication and performance test of a full-scale model of the first wall of the power generation blanket for a nuclear reactor" (August, 2008)

4.2 Research & Development of Structural Materials

○ The neutron irradiation test of radiation-reduced ferrite steel was continued using an HFIR reactor, providing fracture toughness data of the F82H standard material up to 20 dpa level. As a result, it was demonstrated that the ductile-brittle transition temperature index increases to near 100◦C after irradiation (see Fig. 7).

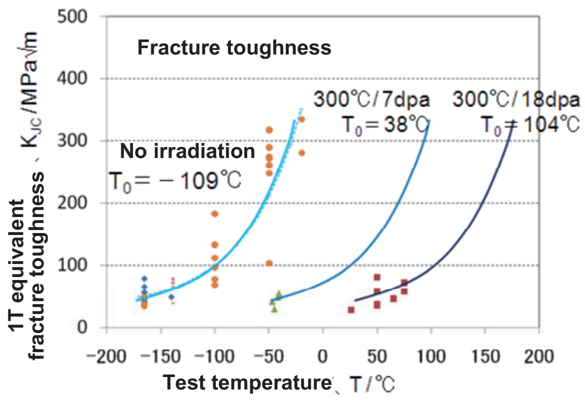

Fig. 7: Toughness data at 300◦C / 20dpa

○ As a thermal processing condition for recovery of the matrix characteristics to be performed after HIP joining, additional heat treatment at 960◦C was performed for 30 minutes, in addition to the conventional high temperature treatment at 1040◦C or above. It was confirmed that grain size become finer with the heat treatment and achieve the impact and the tensile properties as high as the standard material.

○As a preliminary activity for "Broader Approach" (BA) activities, various thickness of plates were fabricated from 1st survey heat of the radiation-reduced ferritic/martensitic steel, and it was confirmed that, those materials have the equivalent mechanical properties of F82H standard material (IEA heat) after standard heat treatment,.

○ As welding technology development for the first wall and side wall, electron beam (EM) welding has been selected in the basic examination and EB weld condition were decided. The design activity of the jig and welding groove shape has been completed.

＜Remarks＞

○ "Excellent Presentation Award" was granted in the 7th Joint Conference for Fusion Energy (Award winner: Hiroyuki Ogiwara)

4.3 Enhancement of Fusion Engineering Technologies

4.3.1 Advanced Superconductivity Technologies

In the field of advanced superconductivity technologies, a method which prevents deterioration of the jacket material's superconductive performance due to thermal processing has been discovered, in measurement of the critical current value using a sample of bismuth-based high-temperature superconductor wire which has an innovative conductivity structure.

4.3.2 Tritium Safety Engineering

In the tritium safety engineering, a basic database has been established for important factors for safe confinement of tritium, including interaction between tritium sorption and materials and long-term stability of the tritium storage bed. As to interaction between tritium sorption and epoxy resin which is often used as a wall- or floor material of a building, data were obtained concerning the tritium decontamination characteristics in conditions similar to the actual usage condition (see Fig. 8).

In joint research with universities and other institutes, basic data were obtained concerning tritium penetration property into concrete (structural material for buildings) as well as for development of a monitoring method of tritium chemical species in facilities where tritium is handled.

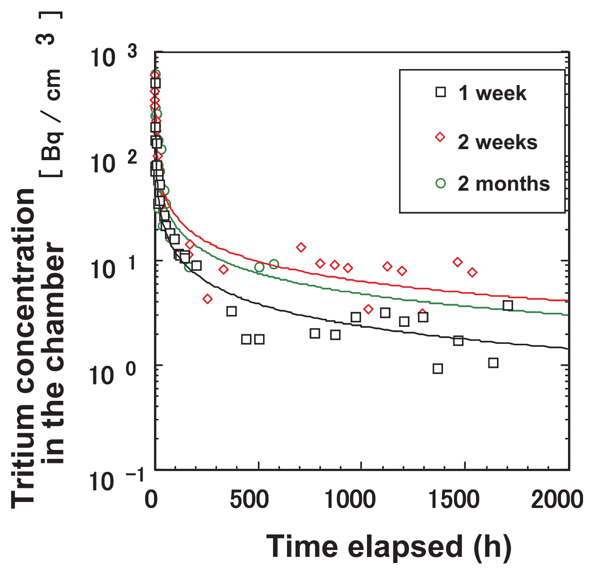

Fig. 8: Decontamination characteristics of epoxy resin: Tritium density transition after a chamber with epoxy resin coating was exposed to tritium steam (740 Bq/cm3 for one week – two months) and then decontaminated with dry air

4.3.3 Neutronics

In the field of neutronics, additional integral experiments were conducted with DT neutrons in order to solve the problem of inconsistency between some experimental data and analysis results on beryllium, which has a big influence on the blanket's core characteristics evaluation. In parallel to it, integral experiments with DD neutrons were newly performed. Results of these experiments demonstrated that it is necessary to improve core data on the thermal neutron elastic scattering by beryllium and on beryllium's neutron capture reaction.

4.3.4 Beam Engineering

Space charge repulsion and deflection among beamlets have been evaluated using a 3-dimensional beam trajectory analysis code, to solve the issue in the negative-ion-based NBI of JT-60. An analysis method has been developed to allow simultaneous analysis of interactions of many negative ion beamlets (50 beamlets), and consequently it was found out that such a correction method of beamlet deflection has been effective, in which the center axis of the grid aperture is intentionally displaced at the exit of the extraction grid in order to correct the beamlet deflection, by distorting the electrostatic lens (see Fig. 9).

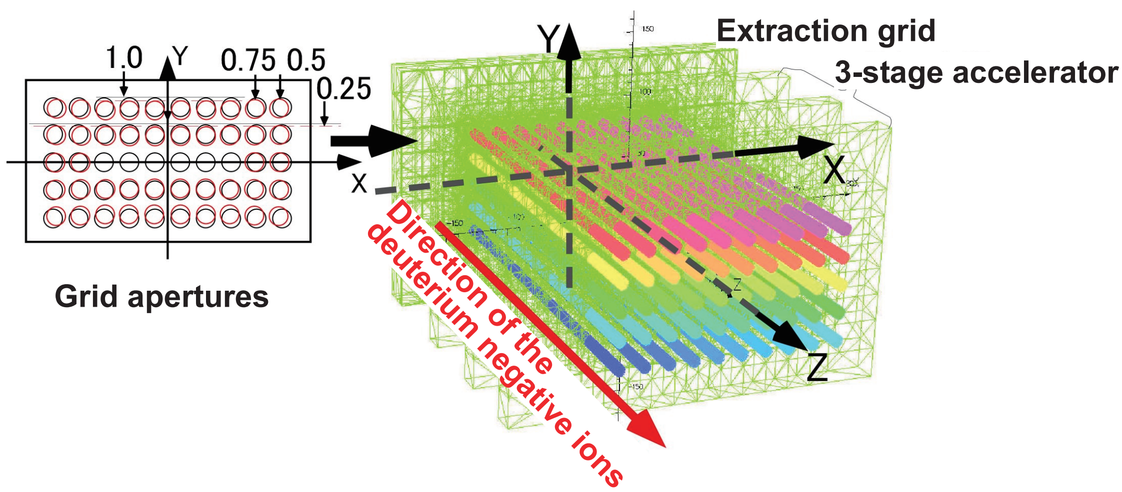

Fig. 9: 3-dimensional beam trajectory calculation: it enables simultaneous analysis of 50 beamlets
The grid apertures are spaced in a lattice arrangement. The beam deflection is corrected by aperture offset, as shown in the picture.

4.3.5 Radio-Frequency Engineering

In the field of radio-frequency engineering, development of such a gyrotron that enables oscillation with multiple frequencies has been carried forward as a part of performance enhancement of the radio-frequency heating apparatus. Through detailed design of a mode converter which can cope with multiple frequencies, it was demonstrated that, in the viewpoint of design, such a gyrotron is feasible with two frequencies (170GHz and 136GHz), output of 1MW and efficiency of 50%.

＜Remarks＞

○ For "Operation & maintenance control and technical development in the Fusion Neutronics Source (FNS) over the years", the Distinguished Service Award was granted by the Kita-Kanto branch of the Atomic Energy Society (Award winners: Chuzo Kutsukake, Shigeru Tanaka, and Yuichi Abe)

○The Most Excellent Presentation Award was granted at the 7th International Workshop on Strong Microwaves (Award winner: Keiji Sakamoto)

○The Excellent Presentation Award was granted in the 7th Joint Conference for Fusion Energy (Award winner: Mieko Kashiwagi)

○The fruit of joint research with Kumagaigumi Co., Ltd., "Development of a structure for concrete walls which enables significant reduction of radioactive waste volume" was press-released (July, 2008)

4.4 Study on Reactor Systems

Concerning high beta operation of the SlimCS DEMO reactor, MHD stability analysis was carried out using the MARG2D code, while the beta limits were analyzed considering safety factor profile, pedestal height, and conductor wall position, clarifying conditions of a beta limit value exceeding the design value (Fig. 10).

As for the divertor feasibility study, divertor simulation was conducted using the NEUT2D/SOLDOR code, obtaining the design guideline, such as the divertor shape, fuel puff amount, and impurity injection amount, in order to satisfy the original design target (peak heat flux on the divertor plate < 10 MW/m^2)(Fig. 11).

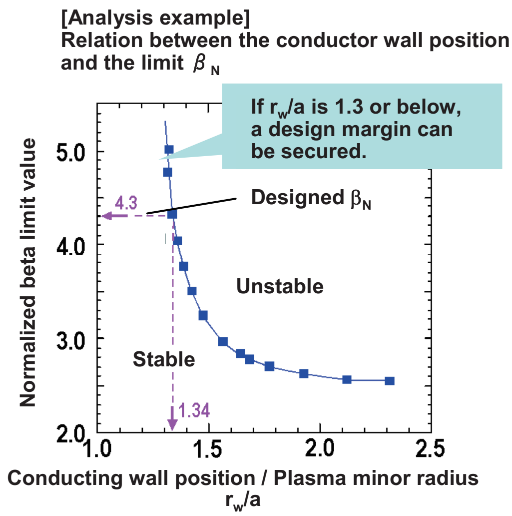

Fig. 10: Dependence of the normalized beta limit on the wall radius / plasma minor radius

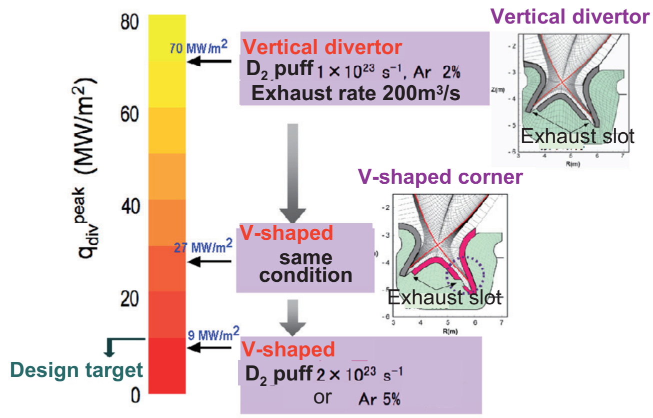

Fig. 11: Design guideline for reduction in the divertor plate peak heat load

Appendix

A.1 Publication List (April 2008 – March 2009)

A.1.1 List of JAEA Report

1) (Ed.) Division of Advanced Plasma Research, "Summary Report of the 21st IAEA Fusion Energy Conference; October 16-21, Chengdu, China," JAEA-Review 2007-058 (2008) (in Japanese).

2) Dairaku, M., Watanabe, K., Tobari, H., et al., "Development of a Plasma Generator for a High Power NBI Ion Source," JAEA-Technology 2008-091 (2009) (in Japanese).

3) Division of Fusion Energy Technology, "Report on the Cooperating Researches Utilizing Fusion Engineering Facilities Completed in the Fiscal Year 2007 (Joint Research)," JAEA-Review 2008-052 (2008) (in Japanese).

4) Fusion Research and Development Directorate, "Annual Report on Major Results and Progress of Fusion Research and Development Directorate of JAEA From April 1, 2006 To March 31, 2007," JAEA-Review 2008-043 (2008).

5) Fusion Research and Development Directorate, "Annual Report of Fusion Research and Development Directorate of JAEA from April 1, 2007 to March 31, 2008," JAEA-Review 2008-061 (2008).

6) Hayashi, K., Nakagawa, T., Onose, S., et al., "Investigation and Design of the Dismantling Process of Irradiation Capsules Containing Tritium, 2; Detailed Design and Trial Fabrication of Capsule Dismantling Apparatus and Investigation of Glove Box Facility," JAEA-Technology 2009-007 (2009) (in Japanese).

7) Iida, H., Kawasaki, N., Konno, S., et al., "Solution of Large Underestimation Problem in the Monte Carlo Calculation with Hard Biasing; In Case with Geometry Input Data Created by CAD/MCNP Automatic Converter," JAEA-Research 2008-050 (2008).

8) Iwai, Y., Hiroki, A., Yamanishi, T., et al., "Radiation Durability of Polymeric Materials in Solid Polymer Electrolyzer for Fusion Tritium Plant," JAEA-Data/Code 2008-027 (2009).

9) Kashiwagi, M., Inoue, T., "Design Study of 500 keV H^- Accelerator for ITER NB System," JAEA-Research 2008-100 (2009).

10) Kawai, M., Akino, N., Ikeda, Y., et al., "Modification of the Drift Ducts Reionization Loss Estimation for JT-60U NBI," JAEA-Technology 2008-069 (2008) (in Japanese).

11) Kikuchi, K., Akino, N., Ebisawa, N., et al., "Update of Control System for Auxiliary Pumping and Primary Water Cooling Facilities in JT-60 NBI," JAEA-Technology 2008-034 (2008) (in Japanese).

12) Kobayashi, K., Hamada, M., Akino, N. et al., "Breakdown Location without Beam Acceleration in the JT-60U Negative Ion Source," JAEA-Technology 2008-042 (2008) (in Japanese).

13) Kondo, K., Ochiai, K., Kutsukake, C., et al., "Characterization of the DD-Neutron Source for the 80 Degrees Beam Line of the Fusion Neutronics Source (FNS)," JAEA-Technology 2008-088 (2009).

14) Matsui, K., Nabara, Y., Nunoya, Y., et al., "Evaluation of Inductive Heating Energy of a PF Insert Coil Conductor by the Calorimetric Method (Contract Research)," JAEA-Technology 2008-085 (2009).

15) Mizuno, T., Inoue, T., Taniguchi, M., et al., "Behavior of Secondary-Particles in a MeV-Class Electrostatic Accelerator," JAEA-Research 2008-120 (2009) (in Japanese).

16) Noto, K., Usui, K., Kawai, M., et al., "Assessment of Water-Cooled Bleeder Resistors for Long Pulse Injection in Acceleration Power Supply on Positive-Ion-Based NBI System," JAEA-Technology 2008-049 (2008) (in Japanese).

17) Oyaizu, M., Hayashi, T., Yamanishi, T., "Permeation Behavior of Tritium Through F82H Stainless Steel; Permeation from Tritiated Water Vapor in Purge Gas for Breeder to Coolant," JAEA-Research 2008-123 (2009) (in Japanese).

18) Sato, K., Seki, F., Hasegawa, S., et al., "ITER Technical Term Bilingual Glossary Year 2008 First Half Edition," JAEA-Data/Code 2008-019 (2008) (in Japanese).

19) Shimada, K., Omori, Y., Okano, J., et al., "Initial Design Study of a DC Power Supply System for JT-60SA," JAEA-Technology 2008-031 (2008) (in Japanese).

20) Shinozaki, S., Honda, A., Oshima, K., et al., "Prototype Development of P-NBI Data Acquisition System for the JT-60SA," JAEA-Technology 2008-048 (2008) (in Japanese).

21) Tanzawa, S., Hiroki, S., Abe, T., et al., "Conceptual Design and Related R&D on ITER Mechanical Based Primary Pumping System," JAEA-Technology 2008-076 (2008).

22) The JT-60 Team, "Review of JT-60U Experimental Results in 2005 and 2006," JAEA-Review 2008-045 (2008).

23) Uehara, K., Nagashima, T., "Parameter Dependence on the Lower Hybrid Driven Current in Tokamaks," JAEA-Research 2008-051 (2008).

24) Usui, K., Noto, K., Kawai, M., et al., "Modification of Power Supplies in the Negative-Ion-Based NBI System for a 100s Operation in JT-60SA," JAEA-Technology 2008-053 (2008) (in Japanese).

25) Yamaguchi, T., Kawano, Y., Kusama, Y., "Sensitivity Study of the ITER Poloidal Polarimeter," JAEA-Research 2007-078 (2008).

26) Yokokura, K., Shimono, M., Hasegawa, K., et al., "Study on Disassembly Work of the Radio Frequency Heating System in the Amplifier Rooms and Heating Power Supply Building," JAEA-Technology 2008-065 (2008) (in Japanese).

27) Yokokura, K., Shimono, M., Suzuki, S., et al., "Study on Disassembly Work of the Radio Frequency Heating System in the JT-60 Torus Hall," JAEA-Technology 2008-058 (2008) (in Japanese).

A.1.2 List of Papers Published in Journals

1) Aiba, N., Hayashi, N., Takizuka, T., et al., "Effect of Equilibrium Properties on the Structure of the Edge MHD Modes in Tokamaks," J. Phys.: Conf. Ser., **123** 012008 (2008).

2) Akiba, M., Enoeda, M., Tsuru, D., et al., "Development of Water-Cooled Solid Breeder Test Blanket Module in JAEA," Fusion Eng. Des., **84** 329 (2009).

3) Alimov, V., Shu, W.M., Roth, J., et al., "Surface Modification and Deuterium Retention in Tungsten and Molybdenum Exposed to Low-Energy, High Flux Deuterium Plasmas," Adv. Mater. Res., **59** 42 (2009).

4) Asai, K., Yukawa, K., (Yamauchi M.), et al., "Multi-Scattering Time-of-Flight Neutron Spectrometer for Deuterium to Tritium Fuel Ratio Measurement in Fusion Experimental Reactors," Fusion Eng. Des., **83** 1818 (2008).

5) Asakura, N., Kawashima, H., Ohno, N., et al., "ELM Propagation in the Low- and High-Field-Side Scrape-off Layer of the JT-60U Tokamak," J. Phys.: Conf. Ser., **123** 012009 (2008).

6) El-Guebaly, L.A., Massaut, V., Tobita, K., et al., "Goals, Challenges, and Successes of Managing Fusion Activated Materials," Fusion Eng. Des., **83** 928 (2008).

7) Ezato, K., Suzuki, S., Dairaku, M., et al., "Critical Heat Flux Experiments Using a Screw Tube under DEMO Divertor-Relevant Cooling Conditions," Fusion Eng. Des., **83** 1097 (2008).

8) Hanada, M., Ikeda, Y., Kamada, M., et al., "Power Loading of Electrons Ejected from the JT-60 Negative Ion Source," IEEE Trans. Plasma Sci., **36** 1530 (2008).

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10) Hayashi, T., Kobayashi, K., Iwai, Y., et al., "Tritium Safety Study Using Caisson Assembly (CATS) at TPL/JAEA," Fusion Sci. Tech., **54** 319 (2008).

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16) Honda, M., Takizuka, T., Fukuyama, A., et al., "Numerical Analysis of the Effect of Fast-Ion Losses on Plasma Rotation in a Tokamak with Toroidal Field Ripple," Nucl. Fusion, **48** 085003 (2008).

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19) Iba, K., Ozeki, T., Totsuka, T., et al., "Development and Verification of Remote Research Environment Based on "Fusion Research Grid"," Fusion Eng. Des., **83** 495 (2008).

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23) Idomura, Y., Ida, M., Kano, T., et al., "Conservative Global Gyrokinetic Toroidal full-*f* Five-Dimensional Vlasov Simulation," Comput. Phys. Commun., **179** 391 (2008).

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29) Iwai, Y., Hiroki, A., Tamada, M., et al., "Radiation Deterioration in Mechanical Properties and Ion Exchange Capacity of Nafion N117 Swelling in Water," J. Phys.: Conf. Ser., **322** 249 (2008).

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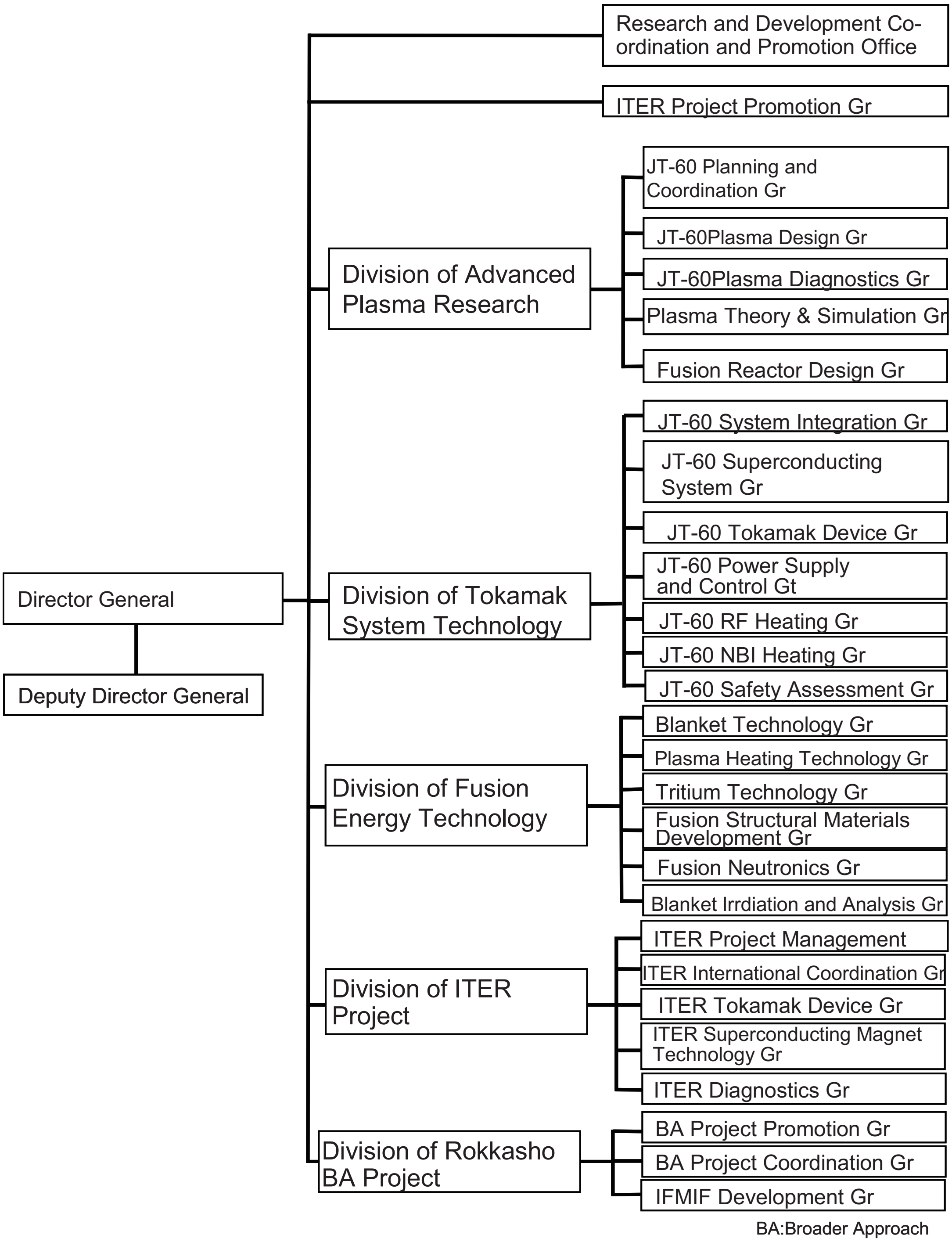
A.2 Organization of Fusion Research and Development Directorate



A.3 Personnel Data

A.3.1 Staff in Fusion Research and Development Directorate of JAEA [at 2009.3.31]

Fusion Research and Development Directorate

TSUNEMATSU Toshihide	(Director General)
NINOMIYA Hiromasa	(Deputy Director General)
OKUMURA Yoshikazu	(Deputy Director General)
TAJIMA Yasuhide	(Deputy Director General)
KIKUCHI Mitsuru	(Supreme Researcher)
YOSHIDA Hidetoshi	(Principal Researcher)
NAGAMI Masayuki (*1)	
SEKI Masahiro	(Invited Researcher)
SEKI Shogo	(Invited Researcher)
SHIMOMURA Yasuo	(Invited Researcher)
MATSUI Hideki	(Invited Researcher)
KOHYAMA Akira	(Invited Researcher)
IDA Katsumi	(Invited Researcher)
KISHIMOTO Yasuaki	(Invited Researcher)
KONISHI Satoshi	(Invited Researcher)
HORIIKE Hiroshi	(Invited Researcher)

Research and Development Co-ordination and Promotion Office

TAKATSU Hideyuki	(General Manager)	
IIZUKA Koji	(Deputy General Manager)	
ISEI Nobuaki	OOHARA Hiroshi	KIMURA Shoko
KOYANAGI Daisaku	MATSUMOTO Hiroyuki	MORITA Hisao
NEMOTO Tetsuo	ONOZAKI Kazutoyo	SATO Yu
TSUCHIDA Tatsuro	MOCHIDA Kazumi	TANAKA Fumiyo
SATO Masaomi	YOSHIDA Hiroshi	

ITER Project Promotion Group

SHIRAI Hiroshi	(Group Leader)
OGAWA Toshihide	

Division of Advanced Plasma Research

MORI Masahiro	(Unit Manager)
OZEKI Takahisa	(Senior Principal Researcher)

JT-60 Planning and Coodination Group

KAMADA Yutaka	(Group Leader)	
KOIDE Yoshihiko	(Deputy Group Leader)	
TAKENAGA Hidenobu	OYAMA Naoyuki	TSUKAHARA Yoshimitsu
KIYONO Kimihiro	KAMIYA Kensaku	MATSUZAWA Yukihiro (*21)
SUZUKI Takashi(*22)	SEIMIYA Munetaka (*1)	

JT-60 Plasma Design Group

OZEKI Takahisa	(Group Leader)	
IDE Shunske	SHIMIZU Katsuhiro	HAMAMATSU Kiyotaka

HAYASHI Nobuhiko	URANO Hajime	KAMATA Isao (*24)
SUZUKI Mitsuhiro (*29)	HONDA Mitsuru (*23)	HOSHINO Kazuo (*23)
TAKIZUKA Tomonori (*1)		

JT-60 Plasma Diagnostics Group

ITAMI Kiyoshi	(Group Leader)	
SATO Masayasu	(Deputy Group Leader)	
HATAE Takaki	SHINOHARA Kouji	SUZUKI Takahiro
SUNAOSHI Hidenori	KITAMURA Shigeru	CHIBA Shinichi
NAKANO Tomohide	YOSHIDA Maiko	MIYAMOTO Atsushi (*21)
TSUTSUMI Kazuyoshi (*21)	NUMATA Hiroyuki (*22)	
SAKUMA Takeshi (*22)	KOKUSEN Shigeharu (*21)	HAMANO Takashi (*22)
UEHARA Kazuya (*1)	HIRANO Yoichi (*1)	YOSHIDA Masafumi(*3)
YANAGIBAYASHI Jun(*3)		

Plasma Theory & Simulation Group

TOKUDA Shinji	(Group Leader)	
IDOMURA Yasuhiro	ISHII Yasutomo	MIYATO Naoaki
AIBA Nobuyuki (*25)	HIROTA Makoto (*25)	SHIRAISHI Junya (*23)

Fusion Reactor Design Group

TOBITA Kenji	(Group Leader)	
ASAKURA Nobuyuki	NISHIO Satoshi	KURITA Gen-ichi
YOSHIDA Tohru (*16)	LIU Changle(*8)	

Division of Tokamak System Technology

HOSOGANE Nobuyuki	(Unit Manager)
USHIGUSA Kenkichi	(Senior Principal Researcher)
KURIHARA Kenichi	(Senior Principal Researcher)

JT-60 System Integration Group

SHIBANUMA Kiyoshi	(Group Leader)	
KUBO Hirotaka	(Deputy Group Leader)	
HOSHINO Katsumichi	KAWASHIMA Hisato	ARAI Takashi
OKANO Fuminori	NISHIYAMA Tomokazu	HOSHI Ryo (*5)
KOBAYASHI Kaoru (*5)	SATO Yoji (*21)	

JT-60 Superconducting System Group

YOSHIDA Kiyoshi	(Group Leader)	
TSUCHIYA Katsuhiko	KIZU Kaname	KASHIWA Yoshitoshi
HONDA Atsushi	MURAKAMI Haruyuki	ASAKAWA Shuji (*4)
TAKENOUCHI Tadashi (*27)	KURAMOCHI Masaya (*29)	ICHIGE Toshikatsu(*29)
KOMEDA Masao (*18)	KAMIYA Koji(*25)	

JT-60 Tokamak Device Group

SAKASAI Akira	(Group Leader)	
HIGASHIJIMA Satoru	MASAKI Kei	SAKURAI Shinji

TAKECHI Manabu	ICHIGE Hisashi	YAGYU Jun-ichi
MIYO Yasuhiko	KAMINAGA Atsushi	SASAJIMA Tadayuki
SHIBAMA Yusuke	HAYASHI Takao	MATSUNAGA Go
ISHIGE Youichi (*22)	MATSUMURA Hiroshi (*5)	MUROFUSHI Akira (*16)
SUZUKI Yozo (*5)	KOMURO Kenichi (*21)	SUZUKI Hiroaki (*21)
SHIMIZU Koichi(*21)	KATAYAMA Masahiro(*28)	

JT-60 Power Supply and Control Group

MATSUKAWA Makoto	(Group Leader)	
NAITO Osamu	(Deputy Group Leader)	
TERAKADO Tsunehisa	OHMORI Yoshikazu	SHIMADA Katsuhiro
YAMAUCHI Kunihito	OKANO Jun	SHIBATA Kazuyuki (*22)
WADA Kazuhiko (*22)	NAKAJIMA Yuta (*14)	KAMIKAWA Masaaki (*14)
SUZUKI Hiroshi (*22)	KAWAMATA Youichi	TOTSUKA Toshiyuki
AKASAKA Hiromi	SAKATA Shinya	SATO Minoru
SUEOKA Michiharu	SUGIMURA Toru (*26)	YAMAGUCHI Taiji (*11)
KOMINATO Toshiharu (*2)		

JT-60 RF Heating Group

MORIYAMA Shinichi	(Group Leader)	
YOKOKURA Kenj	ISAYAMA Akihiko	SHIMONO Mitsugu
HASEGAWA Koichi	SAWAHATA Masayuki	SUZUKI Sadaaki
TERAKADO Masayuki	HIRANAI Shinichi	IGARASHI Koichi (*21)
SATO Fumiaki (*21)	WADA Kenji (*21)	SHIBAYAMA Minoru (*21)
KOBAYASHI Takayuki (*23)	HINATA Jun (*10)	

JT-60 NBI Heating Group

HANADA Masaya	(Group Leader)	
KAWAI Mikito	(Deputy Group Leader)	
OOASA Kazumi	AKINO Noboru	KAZAWA Minoru
KOMATA Masao	USUI Katsutomi	SHINOZAKI Shinichi
MOGAKI Kazuhiko	SASAKI Shunichi	KIKUCHI Katsumi (*22)
OSHIMA Katsumi (*21)	NOTO Katsuya (*21)	SEKI Norikatsu(*22)
SHIMIZU Tastuo (*21)	NEMOTO Shuji (*21)	ENDO Yasuei (*21)
KOJIMA Atsushi(*25)	TANAKA Yutaka(*23)	KISAKI Masahi (*3)

JT-60 Safety Assessment Group

MIYA Naoyuki	(Group Leader)
SUKEGAWA Atsuhiko	OIKAWA Akira (*1)

Division of Fusion Energy Technology

AKIBA Masato	(Unit Manager)
NISHITANI Takeo	(Senior Principal Researcher)

Blanket Technology Group

ENOEDA Mikio	(Group Leader)	
HOMMA Takashi (*1)	SUZUKI Satoshi	TANZAWA Sadamitsu
NISHI Hiroshi	SEKI Yohji (*23)	HIROSE Takanori
TANIGAWA Hisashi	TSURU Daigo	EZATO Koichiro
YOKOYAMA Kenji		

Plasma Heating Group

SAKAMOTO Keishi	(Group Leader)	
INOUE Takashi	(Deputy Group Leader)	
WATANABE Kazuhiro	YAMAMOTO Masanori (*5)	TAKEMOTO Junpei (*13)
KASHIWAGI Mieko	DAIRAKU Masayuki	UMEDA Naotaka
TANIGUCHI Masaki	TOBARI Hiroyuki(*25)	MIZUNO Takatoshi (*23)
KASUGAI Atsushi	TAKAHASHI Koji	IKEDA Yukiharu
NARUI Norio (*21)	KOMORI Shinji (*22)	KAJIWARA Ken (*25)
ODA Yasuhisa (*23)	HAYASHI Kazuo (*21)	

Tritium Technology Group

YAMANISHI Toshihiko	(Group Leader)	
HAYASHI Takumi	KAWAMURA Yoshinori	NAKAMURA Hirofumi
YAMADA Masayuki	SUZUKI Takumi	KOBAYASHI Kazuhiro
ISOBE Kanetsugu	IWAI Yasunori	HOSHI Shuichi (*22)
INOMIYA Hiroshi(*22)	ALIMOV Vladimir (*7)	SATO Katsumi (*21)
OYAIZU Makoto (*23)		

Fusion Structural Materials Development Group

TANIGAWA Hiroyasu	(Group Leader)	
ANDO Masami	NOZAWA Takashi (*25)	SAWAHATA Atsushi (*6)

Fusion Neutronics Group

KONNO Chikara	(Group Leader))	
SATO Satoshi	KUTSUKAKE Chuzo	TANAKA Shigeru
OCHIAI Kentaro	ABE Yuichi	KAWABE Masaru (*22)
OGINUMA Yoshikazu (*22)	TAKAKURA Kosuke (*21)	
OHNISHI Seiki (*25)	KONDO Keitaro (*23)	TATEBE Yosuke (*3)

Blanket Irradiation and Analysis Group

NISHITANI Takeo	(Group Leader)	
NAKAMICHI Masaru	HOSHINO Tsuyoshi	HASEGAWA Teiji (*22)
NAMEKAWA Yoji (*22)	YONEHARA Kazuo (*13)	

Division of ITER Project

YOSHINO Ryuji	(Unit Manager)
KOIZUMI Koichi	(Senior Principal Researcher)

ITER Project Management Group

KOIZUMI Koichi	(Group Leader)	
NEYATANI Yuzuru	(Deputy Group Leader)	
KITAZAWA Siniti	YAGUCHI Eiji (*16)	Tod Tollefson (*21)
TAKAHASHI Go (*29)	SATO Koichi (*29)	IWAMA Yasushi (*21)

ITER International Coordination Group

SUGIMOTO Makoto	(Group Leader)	
ANDO Toshiro	(Deputy Group Leader)	

ITER Tokamak Device Group

KOIZUMI Koichi	(Group Leader)	
KAKUDATE Satoshi	(Deputy Group Leader)	
TAKEDA Nobukazu	TAGUCHI Kou (*22)	MATSUMOTO Yasuhiro (*28)
KOZAKA Hiroshi (*21)		

ITER Superconducting Magnet Technology Group

OKUNO Kiyoshi	(Group Leader)	
NAKAJIMA Hideo	(Deputy Group Leader)	
TAKAHASHI Yoshikazu	ISONO Takaaki	KOIZUMI Norikiyo
KAWANO Katsumi	NUNOYA Yoshihiko	HAMADA Kazuya
MATSUI Kunihiro	NABARA Yoshihiro	HEMMI TSUTOMU
SEO Kazutaka (*19)	OSHIKIRI Masayuki (*22)	TAKANO Katsutoshi(*22)
OHMORI Junji (*28)	TSUTSUMI Fumiaki (*29)	SHIMANE Hideo (*16)
NIIMI Kenichiro (*15)	SHIMIZU Tatuya (*16)	YOSHIKAWA Masatoshi（*12）

ITER Diagnostics Group

KUSAMA Yoshinori	(Group Leader)	
OGAWA Hiroaki	SUGIE Tatsuo	KAWANO Yasunori
KONDOH Takashi	SATO Kazuyoshi	ISHIKAWA Masao (*25)
IWAMAE Atsushi (*25)	HAYASHI Toshimitsu (*20)	ONO Takehiro (*21)
YAMAMOTO Tsuyoshi (*11)	MIYAMOTO Seiji (*25)	

Division of Rokkasho BA Project

KIMURA Haruyuki	(Unit Manager)

BA Project Promotion Group

EJIRI Shintaro	(Group Leader)

BA Project Coordination Group

OHIRA Shigeru	(Group Leader)

IFMIF Development Group

KIMURA Haruyuki	(Group Leader)	
NAKAMURA Hiroo	(Deputy Group Leader)	
IDA Mizuho (*9)	MAEBARA Sunao	MIYASHITA Makoto (*28)
KIKUCHI Takayuki	KOJIMA Toshiyuki (*22)	KONDO Hiroo
KUBO Takashi (*17)	YONEMOTO Kazuhiro (*14)	WATANABE Kazuyoshi (*29)

A.3.2 Staff in ITER Organization and Project Teams of the Broader Approach Activities

ITER Organization

Office of Director-General

MATSUMOTO Hiroshi (Head)

Project Office

TADA Eisuke (Head)

Department for Administration

IDE Toshiyuki

Department for Fusion Science & Technology

SHIMADA Michiya

Department for Central Engineering & Plant Support

MARUYAMA So

SHU Wataru

Depertment for Tokamak

NAKAHIRA Masataka

Project Teams of the Broader Approach Activities

International Fusion Energy Research Center

ARAKI Masanori	(Project Leader)
HAYASHI Kimio	SAKAMOTO Yoshiteru

Satellite Tokamak Programme

ISHIDA Shinichi	(Project Leader)	
FUJITA Takaaki	SEKI Masami	OSHIMA Takayuki
SATO Masayasu	KAWASHIMA Hisato	

IFMIF EVEDA

SUGIMOTO Masayoshi	(Deputy Project Leader)	
ASAHARA Hiroo(*21)	NAKAMURA Kazuyuki	OHTANI Keiji(*24)
SHINTO Katsuhiro(*25)		

A.3.3 Collaborating Laboratories
Tokai Research and Development Center
Nuclear Science and Engineering Directorate
Irradiation Field Materials Research Group

JITSUKAWA Shiro	(Group Leader)	
FUJII Kimio	OKUBO Nariaki	TANIFUJI Takaaki
WAKAI Eiichi	YAMAKI Daiju	

Research Group for Corrosion Damage Mechanism
MIWA Yukio

Quantum Beam Science Directorate
Nanomaterials Synthesis Group
TAGUCHI Tomitsugu

Oarai Research and Development Center
Technology Development Department

MIYAKE Osamu	(Deputy Director)

Advanced Liquid Metal Technology Experiment Section

YOSHIDA Eiichi	(General Manager)
HIRAKAWA Yasushi	

Advanced Nuclear System Research and Development Directorate
Innovative Technology Group

ARA Kuniaski	(Group Leader)
OTAKE Masahiko	

*1 Contract Staff
*2 Customer System Co., Ltd.
*3 Fellow of Advanced Science
*4 Fuji Electric Co., Ltd.
*5 Hitachi, Ltd.
*6 Ibaraki University
*7 Institute of Physical Chemistry and Electrochemistry of the Russian Academy of Sciences
*8 Institute of Plasma Physics, Chinese Academy of Science
*9 Ishikawajima-Harima Heavy Industries Co., Ltd.
*10 Japan Advanced Systems, Inc.
*11 Japan EXpert Clone Co., Ltd.
*12 Japan Superconductor Technology Inc
*13 KAKEN Co., Ltd.
*14 Kandenko Co., Ltd.
*15 Kawasaki Heavy Industries, Ltd.
*16 KCS Corporation
*17 Kumagai Gumi Co., Ltd.
*18 MAYEKAWA MFG. CO., LTD
*19 National Institute for Fusion Science
*20 NEC Corporation
*21 Nippon Advanced Technology Co., Ltd.
*22 Nuclear Engineering Co., Ltd.
*23 Post-Doctoral Fellow
*24 Research Organization for Information Science & Technology
*25 Senior Post-Doctoral Fellow
*26 Systems Co., Ltd.
*27 Tomoe Shokai Co., Ltd.
*28 Toshiba Corporation
*29 Total Support Systems

II. Annual Report of Fusion Research and Development Directorate of JAEA

from April 1, 2009 to March 31, 2010

FOREWORD

In FY2009, in the research and development for utilization of fusion energy, JAEA steadily implemented the basic plan established by the Atomic Energy Commission of Japan, and at the same time fulfilled appropriate obligations as a domestic agency responsible for the ITER project and as an implementing agency of the BA activities. This paper reports some of the major results and progresses in 2009 concerning research and development on fusion energy in JAEA.

Concerning the progress in the ITER project, the manufacturing plant combining state-of-the-art technologies was completed for fabrication of superconducting conductors for toroidal field coils, which was commenced in 2007 ahead of other countries, according to the construction schedule made by the ITER Organization in accordance with the ITER Agreement and its attached documents, where manufacturing of superconducting coil conductors was commenced ahead of other countries, demonstrating steady advance in the procurement activities in the ITER project. Besides, research and development which was necessary for the final decision of the technical specifications was conducted for other equipment (divertors, remote maintenance equipment, heating devices, and instrumentation devices) that Japan is in charge of their procurement.

Concerning the BA activities, activities related to the International Fusion Energy Research Center (implementation of review of conceptual design of prototype reactors, preliminary technological development related to low-activation structural materials, and reviews necessary for selection of computers), Engineering Validation and Engineering Design Activities for the International Fusion Materials Irradiation Facility (IFMIF) (design, fabrication, etc. of accelerator-related equipment, lithium test loop, etc.), and research activities on Satellite Tokamak (detailed design and fabrication of equipment that Japan is in charge of, maintenance/repair of related equipment and facilities, and preparation for dismantling of the JI-60 equipment) were conducted according to the project plan set forth by the BA management committee comprising governmental institutions in Japan and Europe in accordance with the BA Agreement and its attached documents. The Rokkasho site was also developed.

For research and development on fusion plasma, analysis of the JT-60 experimental data was promoted, and joint experiment on stability and control of high-pressure plasma was conducted in fusion experimental facilities (DIII-D, RFX) in the US and Italy as international research cooperation. Moreover, JAEA joined 12 inter-machine experiments and promoted research on the realization of steady state and high beta plasma.

For research and development on fusion engineering, JAEA succeeded in the tritium generation/recovery test, which was considered as impossible without a large-scale neutron source such as ITER, for the first time in the world in the development of breeding blankets which constitute a component indispensable for future nuclear fusion reactors. It also succeeded in fabrication of module-scale chassis mock-up for the ITER Test Blanket Module which will be attached to the ITER to conduct performance tests in the future, and conducted a thermomechanical test using the fabricated mock-up. This clarified the fundamental requirements related to the fabrication and design of the ITER Test Blanket Module structure with the results of the past developments.

The energy-recovery type high-power gyrotron developed by JAEA was acclaimed as a “significant material in the history of science and technology which is important for demonstrating important results in the history of the development of science and technology and passing them on to next generations” by the National Museum of Nature and Science, Tokyo, and registered as an Essential Historical Material for Science and Technology of the museum (future technology heritage) in October 2009.

In addition, the contribution of the “Large Tokamak, JT-60” to the development of fusion energy over the past quarter century was highly acclaimed, and won the “Atomic Energy Historic Award” of the Atomic Energy Society of Japan in April 2009. Besides, the “conversion of basic physical experimental level concept into a fusion reactor leading to power generation” by JT-60, which is a large-scale electric system, was highly acclaimed from the viewpoint of electrical engineering, and won the “One Step on Electro-Technology” award of the Institute of Electrical Engineers of Japan in March 2010.

FY2009 was a year of progress for JAEA to close the primary-stage midterm goal period started in October 2005 by significant progress in the ITER project and the BA activities as well as high evaluations of the past results. JAEA hopes to continue to utilize international cooperation proactively, and manage its organization considering the construction of the All Japan structure supported by solid cooperation with universities, research institutes, and the industries to further promote research and development on fusion energy.

二宮博正

Hiromasa Ninomiya
Director General
Fusion Research and Development Directorate
Japan Atomic Energy Agency

1. ITER Project

1.1 ITER Construction Activities

1.1.1 ITER Tasks

Out of 74 ITER transition arrangements (ITA) tasks that Japan was assigned for the purpose of procurement of equipment according to the ITER construction start-up schedule set up by the ITER International Fusion Energy Organization (hereafter called “ITER Organization”), 73 tasks had been already completed, and for the remaining one task, a final report was submitted to the ITER Organization. As to the ITER tasks, which Domestic Agencies of the Parties undertook for addressing requirements resulting from the design review performed by the ITER Organization and for finalizing procurement technical specifications as the activities have moved from the ITA stage to Construction Stage, 14 have been completed or a final report has been submitted, while six tasks are now in operation. As to the research works commissioned by the ITER Organization (non-voluntary tasks), four tasks have been completed, a report has been submitted for one task, and 16 tasks are in operation.

1.1.2 Manpower Contribution

As in the previous year, JAEA supported recruiting procedures of the ITER Organization in Japan. In FY2009, the number of Japanese professional staff has become 23 in total (including eight senior staffs consisting of; one Head of Office for Central Integration & Engineering, one Head of Office of the Organization Director-General, one Head of ITER Council Secretary, one Head of Vessel Division / Department for Tokamak, one chief scientist in Divertor & Plasma-Wall Interactions Section / Dept. for Fusion Science and Technology, one section leader in Fuelling Facility Section / Dept. for Central Engineering & Plant Support, one scientist in Plasma Stability & Control Section / Dept. for Fusion Science & Technology, and one senior engineering specialist in Quality Assurance Division / Dept. for Safety & Security), after resignation of two professional staff and new assignment of six staff. In addition, one staff is expected to join in April, 2010. As for support staff, six are already working and additional one will start working in April, 2010.

Beside the above mentioned staff who are directly employed by ITER, JAEA dispatched about 6 staff a month to the ITER Organization, while having 466 domestic team staffs in total participate in the design review and different technical meetings, including coordination meeting for integrated procurement, organized by the ITER Organization as of Jan. 20, 2010. JAEA also participated in and contributed to policymaking for the ITER plan, etc. in attending the ITER Council as well as Management- and Science & Technology Advisory Committees (one commissioner and four specialists participated in ITER Council, one commissioner and three specialists in Management Advisory Committee, and three specialists in Science & Technology Advisory Committee).

1.1.3 External Contracts

Information was transmitted within Japan concerning 30 external contracts to be consigned by the ITER Organization to research institutes and companies. Application documents from 8 companies were submitted to the ITER Organization.

1.1.4 Quality Assurance Activities

As a domestic agency, JAEA conducted quality assurance activities necessary for procurement, based on the quality assurance plan and quality-assurance related documents (control standard documents, control manual, etc.).

1.1.5 Transmission of Information

In order to promote citizen’s understanding, information on construction of ITER was disclosed and transmitted proactively as follows:

- For promotion of active participation in bids for components to be procured by Japan as well as in the ITER plan from the Japanese industry, three briefing sessions for ITER-related companies were held in cooperation with the Japan Atomic Industrial Forum to inform these companies on the status of the ITER plan and component procurement status as well as to exchange opinions. (46 companies in total participated). In addition, a briefing was made concerning the current status of the ITER project and order placement schedule from now on, in Aomori Prefecture's ITER/BA Company Briefing held in Aomori City (July 30).

・For promotion of understanding of the ITER project, a presentation on the plan was made in two exhibition events, in which information was transmitted on the overview and present status of the ITER project as well as on the components to be procured by Japan（superconductive coil, heater, etc.）

・Information was widely provided in academic conferences, including 26 presentations on fabrication of ITER components (7 in Meetings on Cryogenics and Superconductivity, 4 in Plasma Fusion Conference, 4 in Asia Plasma and Fusion Association, 3 in Atomic Energy Society of Japan, 2 in Takasaki Advanced Radiation Research Symposium, 2 in the National Symposium on Welding Mechanics & Design, 2 in the Society of Instrument and Control Engineers, 1 in the Japan Society of Mechanical Engineers, and 1 in the Advanced Quantum Beam Technologies Conference on the stress and strain effect of superconductive materials).

・ITER-related latest information was placed periodically (bimonthly) and continuously in an academic journal on plasma fusion

・10 briefing sessions for recruiting of the ITER Organization were organized and implemented in Japan (Sapporo, Aomori, Morioka, Sendai, Tokyo, Kyoto, Tokai and Naka); in parallel, a staff registration system was operated for more effective and efficient information provision (176 persons registered as of the end of December).

・Information was transmitted through the website of JAEA.

1.1.6 Procurement Activities and Preparation for Procurement

The followings are major achievements which JAEA performed for procurement and preparation for procurement as a Domestic Agency of the ITER Agreement:

1.1.6.1 Superconductive Coil

① Procurement of TF coil conductors

Fabrication of 40 tons of Nb_3Sn wires, i.e. material for two TF coils, which had been initiated in FY 2007 was completed in FY2009. This accounts for about 40% of the Nb_3Sn wires to be procured by Japan (about 100 tons). In addition, a 760m copper dummy strand (the same length as that of the actual machine) was fabricated, establishing a strand technology for the actual TF coil conductor. Further, two Nb_3Sn strands to be used for trial fabrication of a full-scale TF coil and one Nb_3Sn strand for the actual TF coil component have been fabricated.

For a conductor fabrication process in which a completed strand is inserted into a metal pipe (jacket) to be subjected to bore-reduction processing, a new manufacturing plant of a conductor (total length of 1km) has been completed. In trial production there, a copper dummy conductor which is as long as the actual TF conductor was fabricated using the above mentioned 760m-long copper dummy strand, establishing the conductor fabrication technology. Using this technology, two full-scale conductors were fabricated for use in trial production of a full-scale TF coil, and thus JAEA has become ready for TF coil conductors, as the first DA.

② Procurement of CS coil conductors

A procurement arrangement on fabrication of full amount of the superconductive conductors for CS coils was signed in December, 2009. For evaluation of the performance of this superconductor, fabrication of a full-scale shorter conductor test sample has been initiated. With this, preparation works were carried forward in order to perform evaluation of this sample in FY2010 using a Swiss test unit and to start procurement of CS coil conductor for the actual component.

③ Technical verification by means of trial production of a full-scale coil winding

In accordance with the agreement with the ITER Organization, a contract was concluded with a Japanese manufacturer in February 2009 for “Detailed fabrication design and full-scale trial production of a TF coil”, which presents the first step of the phased procurement of the TF-coil, starting verification of manufacturing technology for the TF coil winding and set-up of the production schedule. In FY2009, examination of the production plan and optimization of the manufacturing tolerance were carried forward for the TF coil winding section, and a rough production schedule, i.e. 1st Manufacturing Plan, was set up based on this. Production of a 140mm-thick milled plate material was also carried on to use it for full-scale trial production of stainless-steel radial plate which will carry a huge electro-magnetic power inside the winding. In addition, a processing test of a small-scale radial plate model was conducted for the purpose of optimization of the radial plate processing method, in parallel to a winding test using a shorter simulation conductor for verification of a winding technology. Through these, all the preparation works have been completed to proceed with full-scale trial production of the TF coil winding in FY2010, reflecting the results of these tests and using the full-scale radial plate and full-scale conductor fabricated in ①.

④ Technical verification in full-scale trial production of the TF coil structure

Also for the TF coil structure, examination of the production plan as well as the optimization of the manufacturing tolerance were carried forward in the “Detailed fabrication design and full-scale trial production of a TF coil” contract, as with the TF coil winding, and the first Production Plan (i.e. a rough production schedule) was established based on those. Production of the forged steel product for trial production of a full-scale model was forwarded, while trial production of a welding part was started to complete preparation work for mock-up trial production for the TF coil structure that is usable in the actual component structure.

1.1.6.2 Blanket Remote Maintenance Equipment

In order to fix the procurement specification for the blanket remote maintenance equipment (remote maintenance robot), the following works were done in this fiscal year:

- The remote maintenance robot will mount a very heavy blanket with the final position precision of 0.5mm or less, inserting the blanket into a narrow positioning key. It has been a technical problem in high-precision handling technology that the blanket may come into contact with the key during this insert process, resulting in generation of “scuffing” accompanied by an excessive reaction force. Therefore, as a control method to prevent this “scuffing”, a “torque restriction control method” was invented and efficiency of which was evaluated in a full-scale evaluation equipment.
- For placement of a robot traveling rail into the vacuum vessel, arc-shaped rail segments should be connected each other, before the traveling rail of 180 degrees consisting of six links and five joints is placed. A technical challenge concerning this rail placement is establishment of a connecting mechanism and connecting procedures in order to connect segments with high precision of 0.1mm or less. For this purpose, a connecting mechanism and procedure which enable this high precision connection were evaluated using a full-scale part model, demonstrating adequacy of the design.
- Since the remote maintenance robot is driven by 20 AC servo motors each of which has the max output of 1.5kW, multi-core composite cable consisting of a bundle of about 370 wires is used for its power line and control signal line. A big problem with this multi-core composite cable was that the signal system is influenced by the noises from the power line. However, a method was invented to avoid noises to the signal line by a synchronization control method in which the timing of the motor drive and that of measurement are staggered. Effectiveness of this

method was demonstrated using full-scale multi-core composite cables.

- For design of the tie-in section between the blanket and remote maintenance robot, JAEA participated in the ITER Organization's "Blanket Integration Manufacturing Team", to proceed with the design of the tie-in structure and to evaluate the current design of the cooling piping layout, positioning structure (key arrangement) and gripping structure, making a contribution to the blanket design.

1.1.6.3 Development of EC (Electron Cyclotron Heating & Current Drive)

The electron cyclotron resonance heating is a prospective technology for heating of burning plasma, maintaining of plasma current, and controlling the stability. Concerning its core part, namely the 170GHz-band high-power & high-frequency oscillator (gyrotron), a reliability confirmatory experiment was conducted. In simulation of the ITER operation, operation with the output of 0.8MW, pulse width of 10 minutes, and energy conversion efficiency of 55% was repeated every 30 minutes for eight days (i.e. more than 100 shots) to obtain statistic data. The result of it demonstrated that output of 10 minutes can be obtained in 80% of the shots without any stop in mid-course. This result was highly appreciated by the ITER Organization, as very useful information for EC system design and creation of operation scenarios from now on. In addition, a high-speed power modulation experiment was initiated for plasma NTM control. As a result, feasibility of the power modulation of 5kHz required for ITER was demonstrated, though the realized pulse was a short one.

The energy-recovery type high-power gyrotron developed by JAEA was acclaimed as a "significant material in the history of science and technology which is important for demonstrating important results in the history of the development of science and technology and passing them on to next generations" by the National Museum of Nature and Science, Tokyo, and registered as an Essential Historical Material for Science and Technology of the museum (future technology heritage) in October 2009.

1.1.6.4 Development of NBI (Neutral Beam Injector)

- For high-voltage (HV) bushing (to be procured by Japan) for the ITER NBI which supplies electric power and cooling water to the ion source and accelerator placed in vacuum while sustaining an insulation of up to 1MV, a full-scale test mockup (see Fig. 1) was manufactured. This mockup simulates one stage of the HV bushing out of the five-stage structure, and a high voltage insulation test was conducted using it. The result demonstrated that the mockup bushing had insulation performance required for the ITER NBI, while sustaining 240 kV stably for 86 minutes, which is by 20% higher than the rated voltage. This is a result of challenges on the vacuum insulation of high voltage which had been faced in the course of NBI development since the ITER EDA (Engineering Design Activities), while demonstrating high technical capabilities of Japanese industries as well.
- As a part of development of the accelerator for the ITER NBI, gap distance between the acceleration grids were extended based on a database of the vacuum insulation distance and sustainable voltage for existing accelerator systems. As the result, rated voltage of 1 MV for the ITER accelerator has been successfully sustained for longer than one hour by the MeV accelerator.
- With a MeV-class accelerator that simulates the accelerator for the ITER NBI, a long-pulse negative ion beam acceleration test was conducted. As the result of introduction of water-cooled acceleration grids, the pulse width, which has stayed so short as 0.2 s conventionally in high-power operation, was successfully extend to the level of 10 s, and beam accelerations of; a) 750 keV, 221 mA, 5 s and b) 650 keV, 131 mA, 10 s have been achieved.
- In cooperation with the ITER Organization and Europe Domestic Agency, preparation of technical documents for procurement as well as design of intefaces has been carried forward for the NBI power supply, of which

procurement is to be shared by Japan and Europe.

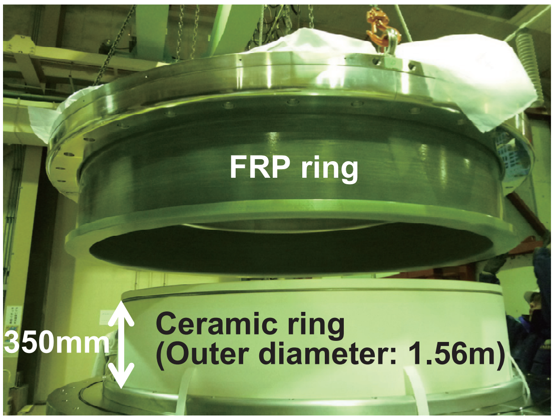


Fig. 1: Manufactured mockup bushing
Double wall structure, with a ceramic ring at the inner side and a FRP (fiber-reinforced plastic) ring at the outer side

1.1.6.5 Diagnostics Systems

・For the edge Thomson scattering diagnostics, assembly work of a prototype high-output laser has been completed using four prototype YAG laser amplifiers which had been fabricated in FY2008, and oscillation adjustment was carried forward (see Fig. 2) in parallel to evaluation of the laser characteristics of each section, obtaining output energy of about 50% of the design value (5J). In response to the change of the position of this device from the upper port to the horizontal port of ITER, optical design was performed concerning about light-collecting optical system and laser injection optical system that are to be mounted in the horizontal port plug.

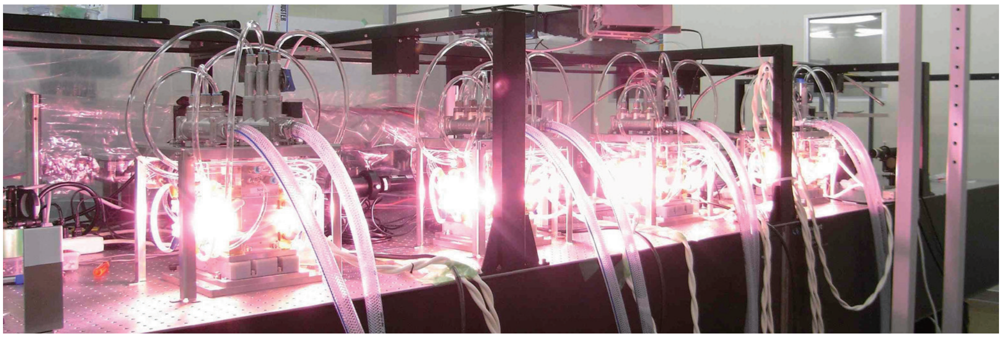


Fig. 2: Four amplifiers were illuminated simultaneously for oscillation adjustment

・For the divertor impurity monitor, mechanical design was performed for the tip-section optic system, relay optic system, measurement support rack, etc to be installed within the divertor port. Through measurement of the spectral transmission in the ultra-violet region using a full-scale upper port optical system, it was confirmed that the spectral transmission rate can be improved about ten times by applying a optical fiber with small end-face loss, and thus a good prospect was obtained for manufacturing of the actual system.

・For the micro fission chamber, the cable layout within the vacuum vessel was designed based on the result of the characteristic evaluation with the minimum bending radius that was carried out in the previous fiscal year. Besides, influence on neutron measurement given by the nuclear heat generation amount in the cable as well as by the cooling tube of the blanket module was evaluated to reflect the result on the design.

・For the poloidal polarimeter, following works were done; i) layout design of the components in the port plug, ii) evaluation of the nuclear heat generation amount of the mirror in the port plug, using Monte Carlo code, iii) design of the mirror which will be mounted inside the vacuum vessel. Besides, assembly of a prototype far-infrared laser unit was carried forward, while a characteristics evaluation test was initiated.

・In examination of the port plug design, electro-magnetic analysis, static analysis, and dynamic analysis of the common section of the port plugs were conducted upon request from the ITER Organization, as they are essential for evaluation of the structural soundness. As a result, such a prospect could be obtained that structural soundness can be secured, by changing the structure of the connection at the front part of the manifold, where high stress is concentrated, from bolt tightening to welding connection.

・For the divertor far-infrared thermography, of which procurement has been newly assigned to Japan by the ITER Council held in June, 2008, evaluation of the light amount and design of the optical system have been started.

1.1.6.6　Shield Blanket

・In the Sandia National Laboratories, USA, a thermal load test of the evaluation test piece of the first wall was conducted, in which ITER’s requirements on the thermal load condition were satisfied.

・Design and analysis works of the shield blanket were carried on in cooperation with the ITER Organization, confirming that the result of electro-magnetic analysis of the vacuum vessel including components in it was consistent with those performed by other Parties with a good precision to verify adequacy of the analysis model and analysis method.

1.1.6.7　Divertor

・Concerning procurement of the perpendicular target outside the divertor, assignment to Japan, a Procurement Arrangement was concluded with the ITER Organization on June 17, 2009 (see Fig. 3), and fabrication of a full-scale prototype of the outer perpendicular target was started, as the first step of the procurement.

・On June 30, 2009, a tender notice was announced concerning fabrication of a plasma facing unit for the full-scale prototype, and a contract was conclude on September 10, 2009.　In parallel to it, another contract was signed for procurement of materials necessary for the fabrication, such as tungsten, preparing for a high-temperature load test of the plasma facing unit which will be started in FY2010 in Russia.

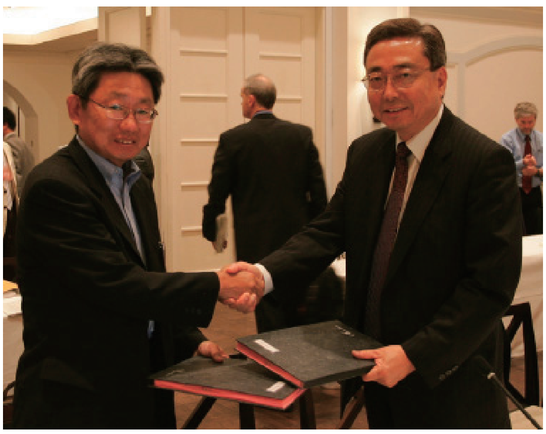


Fig. 3: Mr. Nagaoka, International Manager of JAEA (left) and Mr. Ikeda, Director-General of ITER (right) shaking hands after signing a Procurement Arrangement for the target outside the divertor

1.1.6.8 Tritium System

- As a design work for the ITER detritiation system (DS), JAEA established a database in Japan for dynamic characteristic analysis and RAMI analysis, in cooperation with the ITER Organization. As a design change was performed to adopt a scrubber tower to DS, JAEA supported the ITER Organization in preparation of a Preliminary Safety Analysis Report (RPrS).
- Concerning a scrubber column, JAEA agreed with the ITER Organization that a detritiation demonstration test shall be implemented by Japan as a R&D task, fabricating a unit of a pilot plant scale. This task is a very important for obtaining data concerning ITER licensing and approvals. For fabrication and test of the unit, a procedure has been initiated to modify the licensing of TPL.

1.2 Development of a Burning Plasma Control Method for ITER

1.2.1 Overview

In order to resolve issues for realization of burning plasmas in ITER, JAEA participated in 12 of the inter-machine experiments, while making a contribution in nine joint research papers and presentations in conferences. Two submissions were made to the physics database for ITER through the International Tokamak Physics Activities. In addition, responding to a request from the ITER Organization, JAEA participated in and performed analysis of the test blanket module simulation experiment on the DIII-D tokamak in order to evaluate the acceptable strength of the toroidal magnetic field ripple in ITER, while taking charge of an ITER Physics Task. In the above-mentioned activities, ITER plasma prediction precision has been enhanced and the guideline for the control has been obtained. The following describes major achievement concerning control of the neoclassical tearing mode, deepening of understanding of momentum transport, and evaluation of the influence of the toroidal magnetic field ripple, for which JAEA's worldwide initiative is especially anticipated for realization of ITER burning plasmas.

1.2.2 Inter-Machine Experiments related to Stabilization of the Neoclassical Tearing Mode

Though it is necessary to keep high-pressure plasmas in a fusion reactor, instabilities appear as the plasma pressure increases, resulting in the reduction of the pressure; thus it is necessary to establish methods to control these instabilities. One of the instabilities which needs to be suppressed in ITER is the neoclassical tearing mode (NTM), and localized current drive at the mode location by electron cyclotron wave, electron cyclotron current drive (ECCD), is considered to be the most effective method. In order to establish an NTM stabilization scenario, clarification of its mechanism is necessary; however, experimental parameters are restricted within a single device, and thus it is considered that comparative research between different devices will provide a result of a higher degree of certainty. This time, experimental data of NTM stabilization of JT-60 and ASDEX-Upgrade (Max-Planck Institute für Plasmaphysik in Germany) were applied to the modified Rutherford equation that describes time evolution of NTM, in order to evaluate the values of the undetermined coefficients in the terms of this equation, which represent contribution of the bootstrap current and ECCD (Fig. 1). The result revealed that evolution of the magnetic island width can be described by almost the same values of the coefficients for the both systems, in spite the fact that those devices have significantly different size and plasma parameters (the major radius of JT-60 and ASDEX-Upgrade is 3.3 m and 1.65 m, respectively). This model equation allowed such a prediction that NTM can be suppressed in ITER with electron cyclotron wave power of about 20MW.

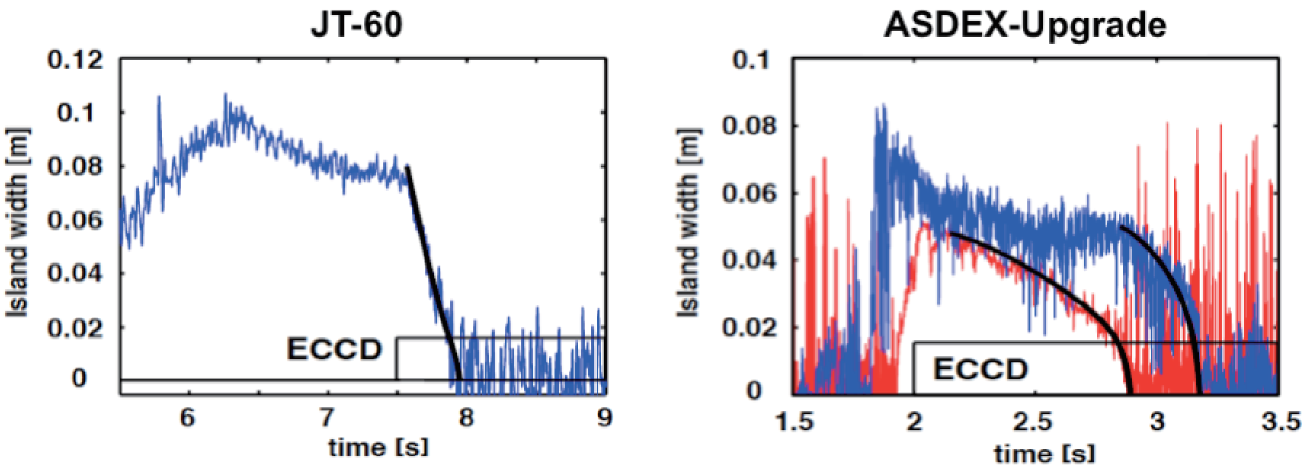


Fig. 1: Time evolution of the NTM strength ("island width") when NTM is stabilized in JT-60 and ASDEX-Upgrade The thin line indicates the experimental data, while the thick line shows the results of the model calculation.

1.2.3 International Tokamak Physics Activities: Establishment of a Momentum Transport Database

As representative parties, researchers of JAEA initiated a Database Activity related to momentum transport for ITER, providing many data from JT-60. Since the momentum transport coefficient is one of the parameters deciding the plasma rotation distribution, on which plasma confinement and stability depend, obtaining knowledge on it is an important task for prediction of the plasma rotation distribution. The purpose of this database activity is to understand the characteristics of such a momentum transport coefficient to contribute to the prediction of the momentum transport and plasma rotation distribution in ITER. JAEA proposed to start this database activity and collected data from five systems (in Japan, USA and Europe), obtaining the data on the relation between the momentum diffusivity and ion heat diffusivity as well as the relation between the momentum diffusivity and convection velocity as shown in Fig. 2. At the same time, a beachhead could be established for start of the discussion on the momentum transport in different systems and prediction for ITER.

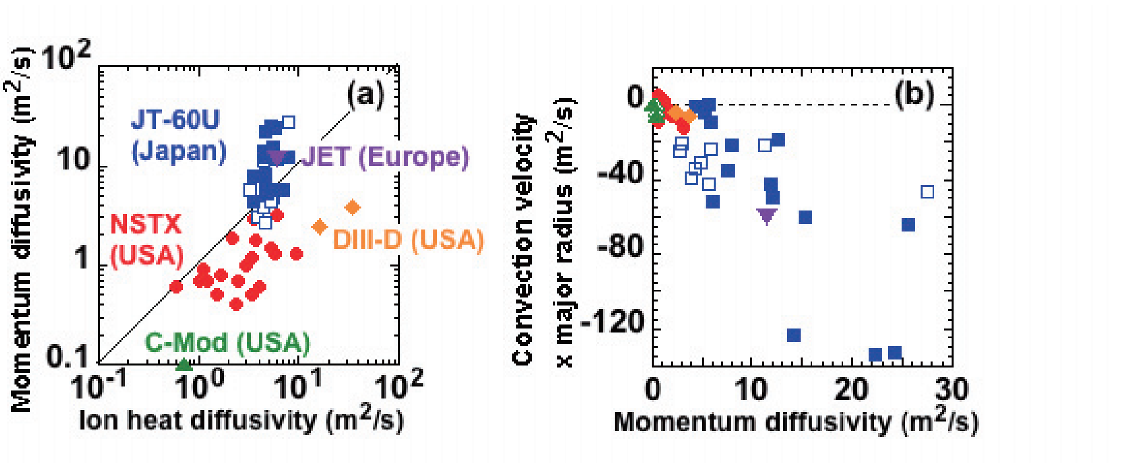


Fig. 2: (a) Relation between the momentum diffusivity and ion heat diffusivity
(b) Relation between the momentum diffusivity and convection velocity
Each color represents a different system.

1.2.4 Evaluation of Influence of the Toroidal Magnetic Field Ripple in ITER

(1) Inter-Machine Experiments

Evaluation of the magnitude of the toroidal magnetic field ripple which is acceptable in ITER is important in deciding the position and thickness of the ferritic steel to be placed. The analysis of the comparative experiment between JET(EU) and JT-60 concerning the toroidal magnetic field ripple, which was performed under the Pedestal Topical Group in the International Tokamak Physics Activity (ITPA), shows that, at a small toroidal magnetic field ripple rate of 1% or less, no significant influence on the pedestal pressure has been found.

(2) Evaluation of energetic particle loss in ITER

It is an important task for the design of ITER to evaluate effects of local toroidal magnetic field ripple due to a feromagnetic material used as a structure material of the test blanket module (TBM). Heat loads resulting from loss of energetic particles due to this magnetic field ripple was evaluated, using the Orbit-following Monte Carlo code (F3D OFMC) developed by JAEA. This analysis was conducted as a part of the inter-code benchmark operation by the ITPA Energetic Particle Topical Group. For the latest shape of the first wall of ITER, loss of the fusion alpha particles was evaluated. The result showed that the loss rate was 0.2%, that the heat load near TBM is small, and that the heat load is big in the position at which the scrape-off-layer plasma comes into contact (near the meshes 113 and 114 in Fig. 3). As a result of this benchmark, usability of the F3D OFMC code was highly evaluated by the ITER Organization, and thus JAEA received an order for another ITER task in November, 2009 to continue detailed analysis.

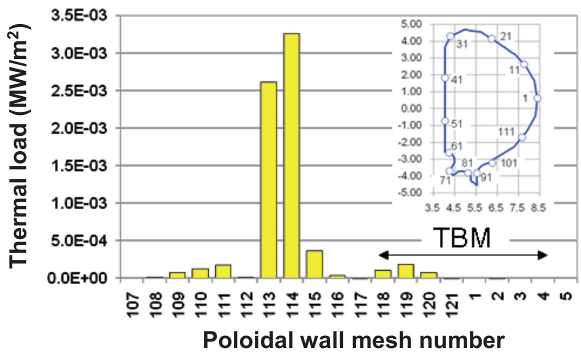


Fig. 3: Poloidal distribution of the thermal

(3) Test Blanket Module (TBM) mock-up experiment in DIII-D

In order to evaluate the effect of the local magnetic field ripple due to the TBM on the plasma confinement, JAEA participated in the local ripple experiment using TBM mock-up coils performed in DIII-D (USA), and performed its data analysis, upon request from the ITER Organization. The result showed that no influence on the plasma performance is observed at a local magnetic field ripple of 2% or less, as shown in Fig. 4. Though there is such a difference that the local ripple in this experiment was at one port, while the TBM will be installed in three ports in ITER, it is considered that a local magnetic field ripple expected in ITER, about 1.3%, may give only small influence.

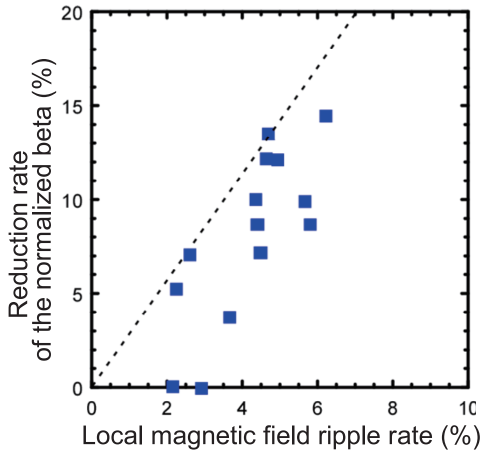


Fig. 4: Reduction rate of the normalized beta [MJ Schaffer et al., Proc. 23rd IAEA Fusion Energy Conference]

1.3 Fusion Energy Forum Activities

1.3.1 Records of Meetings and Operation Supports

The Secretariat supported the Fusion Energy Forum in organizing 72 meetings, contributing to its smooth operation. Two meetings of the Steering Committee, three meetings of the Coordination Committee, and six meetings of the ITER/BA Technical Promotion Committee were held, respectively, while an open-style plenary meeting was held in March. Under the ITER/BA Technical Promotion Committee, eight meetings were held in the WG for ITER baseline design review. The WG on reviewing roadmap and the related issues were closed in 2008. As specialized cluster activities under Coordination Committee, four cluster board meetings, 17 sub-cluster board meetings, 28 sub-cluster meetings, and one informal meeting in the Japan Society of Plasma Science and Nuclear Fusion Research were organized. In addition, an International Business Forum for Fusion/Fission Energy and a symposium for high-school students were held once, respectively.

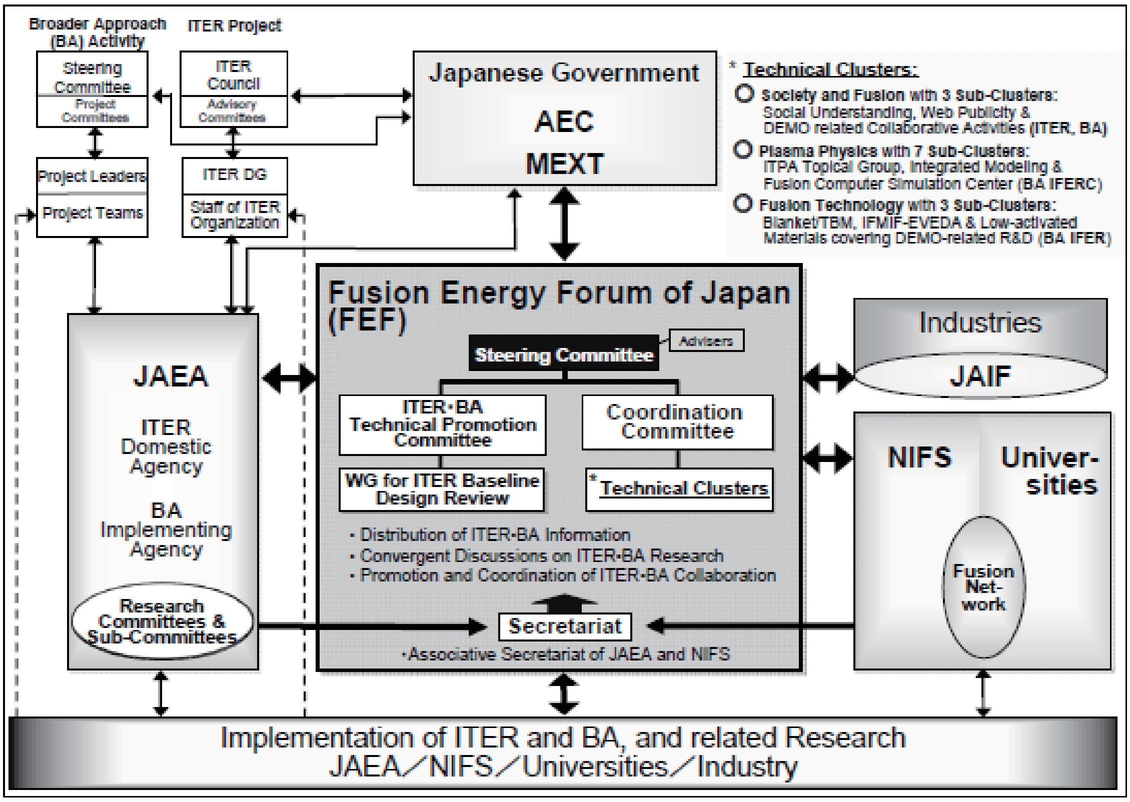


Fig. 1: Implementation and Collaborative Structure for ITER & BA in Japan

1.3.2 Distillation of Domestic Consensus among the Industry, Government and Academia

The secretariat operated in cooperation of JAEA and National Institute for Fusion Science (NIFS) coordinated the meeting schedule and its suitable agenda of the ITER/BA Technical Promotion Committee in accordance with the international schedule. The ITER/BA-related matters concerning Science and Technology Advisory Committee (STAC) and Test Blanket Module Program Committee (TBM-PC) under ITER Council and three Project Committees (BA-PC each for IFMIF/EVEDA, IFERC and STP) under BA Steering Committee were distributed, discussed and well understood through this committee which consists of domestic experts representing universities, research institutes, industries, and Ministry of Education, Culture, Sports, Science and Technology (MEXT). In addition the participation of the Members of STAC, TBM-PC and BA-PCs as members of this committee has gradually enabled the distillate of domestic opinion to be reflected in the discussion at the corresponding committee. Moreover results of discussion and investigation for ITER/BA-related issues by fusion community allover Japan have been stocked in this committee.

Especially in the WG for ITER baseline design review, the Secretariat supported the arrangement of discussion and evaluation points for the ITER baseline design and major design changes, keeping pace with the progress of the ITER project, in order to address the issue requested by MEXT, and obtained approval in this regard of the ITER/BA Technical Promotion Committee held in January, 2010. On the other hand, in order to support participation in STAC as Japanese Party, the Secretariat contributed to getting the distillate of domestic opinion of experts to reflect it on the STAC's recommendation to the ITER Council through STAC Members from Japan. For distillation of domestic consensus on this regard, the Secretariat made exchange of opinions and necessary coordination with the Domestic Agency and industries, while creating opportunities to collect opinions from domestic experts widely through technical cluster activities including Plasma Physics Cluster and Fusion Technology one.

On the other hand, in the Coordination Committee, the examination on the system design has been carried on for fostering and securing young human resources through the ITER project and BA activities, while support was provided in distributing the related reference materials on the existing system.

1.3.3 Promotion of Industry-Government-Academia Cooperation and Inter-Feedback of Achievements

The ITER/BA Technical Promotion Committee recommended the candidates for members of expert group concerning the ITER Research Plan (IRP) or ITER Integration Modeling to be organized by the ITER Organization, making a contribution in dispatching experts through the Domestic Agency. In this case efforts were made to share the latest information and achievements not only in the Domestic Agency but also with universities, research institutes, and industries. In addition to exchange of opinions in technical clusters, the Secretariat contributed to a stock of discussions concerning combination between academic base and industrial one in Japan.

The Secretariat also supported the Coordination Committee and technical cluster meetings to organize them in the right timing keeping pace with the progress of BA activities, in performing necessary communication and exchange of opinions. Especially, concerning BA activity-related consignment research and joint one by the Implementing Agency, the Secretariat made specific coordination on the share assignment and how to proceed, through information provision on the activity content, hearing on the required theme, and exchange of opinions between the Implementing Agency and universities, research institutes, and industries. As a result such an approach made a mechanism of achievement sharing at both sides get on the right track, while contributing to accumulation of the investigating results in fusion community in Japan.

On the other hand, in the ITER/BA Technical Promotion Committee consisting of MEXT and domestic experts including representatives from universities, research institutes, and industries, a mechanism of coordination on the work assignment and organic linkage has been put into orbit, prior to the start of solicitation announcement for consignment research and joint one related to BA activities, in the view of the importance of a link of these activities with academic bases and industrial ones in Japan. The Secretariat also made a contribution in promotion of effective cooperation concerning the BA activities in Japan.

Through organizing the DEMO Conceptual Design Joint Collaboration Activity with participants from universities, research institutes, and industries, the Secretariat supported wide approaches in Japan for the realization of the commercial use of fusion energy, cooperation with the DEMO Design & R&D Coordination Center in the IFERC projects of the BA activities, and distribution of "DEMO Design Newsletter" (joint publication of the DEMO Conceptual Design Joint Collaboration Activity in FEF and Implementing Agency of BA Activities in Japan) which was a new trial approach. It also supported the organization of a study session on realization of fusion reactor which consists of young researchers, mainly in their thirties who should lead the next generation, from universities, research institutes, and industries.

1.3.4 Distribution of Information and Promotion of Understanding

The information on the current status of the ITER project including its design and research plan, as well as on the present condition of the BA activities, has been properly provided not only through ITER/BA Technical Promotion Committee but also through the experts meeting on the ITER engineering design and through technical cluster activities. The Secretariat also made other efforts in order to contribute to information sharing and information transmission to general publics, including sequential posting of meeting reports on its web sites. In a joint effort with the Web Publicity sub-cluster, trail production of new contents of website and its technical review were made for expansion of communication within fusion communities and promotion of a wider understanding of fusion energy by making the website more interesting for general people.

1.3.5 Recognition of Excellent Activities by Young Researchers and Engineers

For the "Masaji Yoshikawa Prize for Fusion Energy" of 2009, which is granted to recognize outstanding accomplishments or prospective research & development activities by young researchers and engineers, application was solicited more widely based on the guideline which had been revised concerning the items pointed out by the Steering Committee, receiving applications of nine applicants, including two from overseas (The name of this award has been changed this year, with the consent of the subsidy donor and the Steering Committee; besides, the recommendation system has been abolished). The Secretariat supported examination and applicant recommendation by the selection committee as well as selection by the Coordination Committee, granting the research subsidy from JAEA to the award winners without delay based on the selection and submitting a report to the Steering Committee (three award winners). The awarding ceremony was held in the 4th plenary meeting (March, 2010). The English name for this award was changed to "Masaji Yoshikawa Prize for Fusion Energy" this year, enabling award winners to write this name in their personal history.

＜Remarks＞

○ Concerning the ITER project and BA activities, a mechanism for the distillation of domestic consensus among the industries, government, and academia to reflect it on these activities has been placed in orbit, while the investigating results were accumulated in fusion community allover Japan. Especially, concerning the evaluation of ITER baseline documents and design changes which have been carried on by the WG for ITER baseline design review upon request from MEXT, the Secretariat supported the arrangement of discussion and evaluation points for the ITER baseline design and major design changes, keeping pace with the progress of the ITER project, and obtained approval of the ITER/BA Technical Promotion Committee held in January, 2010.

○ The Secretariat supported the Coordination Committee and technical cluster meetings to organize them in the right timing keeping pace with the progress of BA activities. In parallel, a mechanism of coordination on the work assignment and organic linkage has been put into orbit in the ITER/BA Technical Promotion Committee consisting of MEXT and domestic experts including representatives from universities, research institutes, and industries, prior to the start of solicitation announcement, especially concerning consignment research and joint ones related to BA activities, while making a contribution in promotion of effective cooperation concerning the BA activities in fusion community in Japan.

○ The Secretariat supported the selection of three award-winners of FY2009 "Masaji Yoshikawa Prize for Fusion Energy," and contributed to early granting of research subsidy from JAEA.

2. Broader Approach Activities

2.1 Activities related to the International Fusion Energy Research Center (IFERC)

2.1.1 Overview

・JAEA seconded one specialist (Project Leader) to the Project Team and provided 12 supporting staffs for a year.

・Concerning design of the DEMO reactor, merits and demerits of major items were examined for clarification of the DEMO design conditions, and problems of different design codes were analyzed and evaluated fot the system desing. 11 experts on the DEMO design participated in the DEMO design workshop to discuss matters concerning the design issues, DEMO design elements, and development of the fusion reactor system code in each field of DEMO concept, plasma physics, plasma engineering, and blanket engineering, to identify research issues on the DEMO design elements, and to clarify common assignments.

・Concerning DEMO R&D, Phase One tasks have been completed for each of the R&D tasks related to the SiC/SiC composite material, reduced-activation structural material of the blanket, tritium technology, advanced tritium breeder, and advanced neutron multiplier, and reports on those tasks were submitted. Based on the results of the Phase one tasks, preparation of the Procurement Arrangement for the Phase Two was performed as a preparatory work for R&D activities to be performed in the facilities which will be completed at the end of this fiscal year.

・Concerning the activities related to the Fusion Computer Simulation Center, experts of the special working group （SWG-1）were dispatched where the work for the machine type selection was continued. Especially, market research was conducted on leading vendors of computers, in cooperation with the European Implementing Agency. For the interface (with the cooling facility and power supply facility), which is periphery equipment indispensable for operation of the computer, cost evaluation was made. Preparation for the Procurement Arrangement has been started after getting a prospect for securing resources in consultation with the Project Team and European Implementing Agency.

・Details and major achievements of each activities are described below.

2.1.2 Activities related to the DEMO Design and R&D Coordination Center

2.1.2.1 Conceptual Design Activities for DEMO Reactor

・In accordance with the work program on the Phase One activities, various opinions were exchanged with European experts in workshops and technical meetings, concerning various aspects of DEMO. The opinions were assembled from various viewpoints, such as development plan & strategy, roadmap, and technical challenges. Based on the result of this exchange of opinions, discussion has been started concerning the framework of the Japan/EU joint activities for the Phase Two.

・In accordance with the project plan of IFERC DEMO design for 2009, evaluation was made on the design limitation for the superconducting coil and blanket, etc.

・For enhanced cooperation with universities, institutes and industry, exchange of opinions were performed in the meetings of the DEMO Conceptual Design Collaboration Activity of the Fusion Energy Forum, while distribution of “DEMO Conceptual Design News” was started.

2.1.2.2 R&D Activities for DEMO Reactor

・SiC/SiC composite: Failure process evaluation, high-temperature / irradiation characteristics evaluation for structural analysis and preliminary R&D for an in-situ resistance evaluation under charged particle irradiation were conducted in joint research with a university.　Besides, preparation work was performed for the test unit to be placed in the DEMO

R&D building in Rokkasho.

・Tritium technology: For the multi-purpose RI facility to be established in Rokkasho, design and manufacturing works were performed. Its core facility, detritiation unit, was fabricated and transported to the Rokkasho site. Based on the above mentioned design information, safety analysis work (evaluation of the internal- & external exposure and evaluation of RI concentration at the stack, etc) were performed as preparation for license and approval application, an application form (draft) was prepared, and preliminary internal examination was initiated in Fusion Dept.

・Material engineering for DEMO blanket (reduced-activation ferritic/martensitic steel): Optimization of reduced-activation ferritic/martensitic steel fabrication technology and welding technology, and development of irradiation effect prediction technology were performed mainly under joint research with a university in order to identify development items for the main activity period. In addition, preparations of experimental equipment to be installed in the DEMO R&D building in Rokkasho were performed.

・Advanced neutron multiplier for DEMO blanket: For the beryllium handling facility to be established in the DEMO R&D building in Rokkasho, procurement of the equipments, etc. were started, while a preliminary test was conducted concerning the fabrication technology using beryllide-simulated intermetallic compound. For the notification of the facilities that handle specified chemical substance, including beryllium, preparation of documentation was carried out.

・Advanced tritium breeder for DEMO blanket: Procurement of the key equipment for the advanced tritium breeder to be placed in the DEMO R&D building in Rokkasho was carried forward, while preliminary studies for development of the pebble fabrication technology and characterization of developed materials were started.

2.1.3 Fusion Computational Simulation Center (CSC)

・At the technical meetings on the CSC (in Paris on June 2; Saclay on July 12; Tokyo on September 8; Tokyo on October 20 & 21, and Tokyo on November 24, 2009), discussion was held mainly on the Procurement Arrangement (PA). In these meetings, correlation among four PAs for establishment and operation of the CSC (building, computer system, interface, enhancement and others) was clarified. Concerning the PA of the computer system, important agreement could be made on the ownership of the computer system and removal after expiration of the BA period.

・In order to prepare a technical specification for procurement of the computer system, JA-IA participated in the market survey conducted by European Implementing Agency (in Tokyo on October 22 and in Paris on October 26 – 28, 2009), obtaining the latest information on the computer system from candidate computer system vendors.

・In the “Modeling and Simulation” sub-cluster meeting under the Physics Cluster (May 29, 2009), Japanese proposals for the “Special working group for computer procurement and benchmark code selection” (SWG-1) were summarized. The minimum requirements on the computer performance and low-level benchmark code were selected.

・In SWG-1 (in Germany on June4, and in Tokyo on November 25 & 26, 2009), it was suggested and agreed that performance evaluation (uniform test) of the benchmark code should be conducted by securing computer resources in Japan and Europe. After that, it was decided that a computer of National Institute for Fusion Science (NIFS) would be used at the Japanese side, and that Professor Nakajima (NIFS) would be the key person of Japan. Further, a small work group was formed in order to prepare a task list for the CSC, and the work has been started. Using the minimum requirements on the computer performance and low-level benchmark code selected by the both sides of Japan/Europe as well as the results of the market research as the reference material, discussion was made on the items to be stated in the technical specification for computer procurement which European Implementing Agency shall submit to candidate computer system vendors.

2.2 Engineering Validation and Engineering Design Activities for the International Fusion Materials Irradiation Facility (IFMIF/EVEDA)

2.2.1 Overview

- Seven specialists were seconded and seven support staffs were provided to the Project Team.
- As activities related to the target system, construction of the lithium loop was continued, and the Procurement Arrangement was concluded with the European Implementing Agency on verification of the lithium purification system. In addition, diagnostics of the lithium flow and element tests concerning safe handling of lithium and remote handling technology, etc. were continued as joint research activities with universities.
- As activities related to the acceleration system, design of the RF couple and preparation for its stand-alone test were carried on, while the Procurement Arrangement was concluded with the European Implementing Agency in November for supply of the Accelerator Prototype Injector, with consent of the Project Leader. Besides, design and fabrication of the auxiliary system, such as the Accelerator Control System were continued. Preparation of documents has been initiated for approval and license application according to the “Laws Concerning the Prevention from Radiation Hazards due to Radioisotopes and Others” related to the Acceleration Facility to be installed in the International Fusion Energy Research Center.
- As to activities related to the Test Cell System, the Procurement Arrangement was concluded with the European Implementing Agency in October concerning the Small Specimen Test Technique Programme, with consent of the Project Leader. Also concerning the Engineering Design of the High Flux Test Module, another Procurement Arrangement was signed with the European Implementing Agency. Further, conceptual design and evaluation works were continued for the post irradiation examination hot cell facility, peripheral equipment and facilities etc, as well as preparation and improvement works of computation codes for the design.
- Details of activities and achievement are shown below for each system.

2.2.2 Activities related to the Target System

Fig. 1: Construction of the lithium test loop was started.
(photo taken on Nov. 10, 2009)

Manufacturing design of the EVEDA lithium test loop was conducted, manufacturing specification of each device of the test loop was fixed, and construction was started at site of the Oarai Research and Development Center in November, 2009 (Fig 1). Main equipment will be installed and subjected to the test and investigation after completion of the loop platform in March, 2009; and then, the entire system will be completed in the end of February, 2011. As for the target assembly (TA), which generates high-speed lithium flows at the velocity of 20m/sec, a TA made of 316L stainless-steel was designed for the Phase One experiment, while another TA was designed with reduced-activation ferritic steel for Phase Two experiment. For the lithium loop purification system, the procurement arrangement was signed by all the parties, i.e. the Implementing Agencies in Japan and Europe and the Project Leader. As to the remote operation verification task, a lip seal welding section was evaluated for development of an exchangeable target assembly, and design activities were carried on for a remote welding device which uses fiber laser to minimize influence of welding. A “lithium burning extinguishing experiment” was conducted, which proved effectiveness of Natrex-L as an extinguishing agent. In joint research with a university, the following works were done; i) fabrication & installation of a test piece with an exchangeable nozzle section and ii) design of a diagnostics device for the EVEDA Li test loop (both of i) and ii) as diagnostics -system related tasks), iii) starting fabrication & experiments of a circulation test unit for nitrogen / tritium control characteristics evaluation, and vi) design of a hot trap for the EVEDA Li test loop (both of iii) and vi) as purification-system related tasks). In the field of engineering design, influence on the flow characteristics given by a bump or deformation of the target section was evaluated using a general-purpose fluid code (FLUENT). Further, with a general-purpose heat structure analysis code (ABAQUS), thermal stress evaluation of the integrated target assembly was conducted, demonstrating that the thermal stress can be decreased compared to the conventional exchangeable back wall.

2.2.3 Activities related to the Accelerator System

RF windows of 4-1/16 and 6-1/8 inches coaxial waveguide which are used in RFQ of IFMIF/EVEDA prototype accelerator were designed and the RF loss was calculated with the MW-Studio code. RF loss of the window for 6-1/8 inches coaxial waveguide was 25 W and total RF loss of the coupler except for loop antenna was 405 W at the nominal operating condition, such as input power of 200 kW and the reflected power of 20 kW at the operating frequency of 175 MHz. The design review meeting about the RF coupler was held by experts. The analysis and tests for RF couplers were authorized in the meeting and agreed by Project Team, EU Contributing Institute and JAEA. EPICS drivers for VME modules of timing system and for PLC used in personal protection system and machine protection system were developed and tested for operation. Conceptual design of center control system, LAN, PPS, MPS and TS was finished. The conceptual design review by experts was held.

The first working group meeting about safety management of accelerator facility was held in Rokkasho BA site. Preparation for licensing procedure of “Laws Concerning the Prevention from Radiation Hazards” was started. The workshop on accelerator’s commissioning was held at Tokyo with Project Team, EU Contributing Institute and JAEA. Experts from eight accelerator facilities such as J-PARC, SNS and CERN were invited and discussed about design and commissioning of IFMIF/EVEDA prototype accelerator and other accelerator. A lot of significant information and advices were given by experts and they may be reflected in the commissioning plan.

2.2.4 Activities related to the Test Cell System

Concerning tasks assigned to Japan, i.e. development of a small-size test technique and of a high-flux test module (HFTM), a procurement arrangement was concluded, respectively. For design of a post-irradiation examination facility, discussion and coordination were forwarded for conclusion of a procurement arrangement with the Project Team and European contributing research institute. For development of the small size test technique and of HFTM, joint research activities with universities were performed, in which, for the former, effects of the test piece size and shape on the fracture toughness and fatigue properties were investigated and examination was carried on to internationally standardize technologies and methods of measurement.

For the latter in design of the high-flux test module, i) capsule design taking remote operability into consideration, ii) selection of instrumentations as periphery devices, iii) manufacturing and performance evaluation of a high performance heater considering radiation-resistance functions, etc. were conducted, based on which results the design was carried forward. For design of the post-irradiation examination facility, evaluation of the shielding property was performed for the hot cell which is necessary for handling of radiated test pieces, while on the other hand evaluation was made on the work process of handing the irradiation rig for HFTM, small test pieces, rear wall of the targets, etc. as well as on the cell layout adequate for it.

2.3 Support for BA Activities in Rokkasho

2.3.1 Overview

・Construction of the buildings for the IFERC and IFMIF/EVEDA projects was continued.

・For establishment of the Rokkasho site, construction and installation of the necessary utility facilities were continued for the research facilities to be constructed and installed at this site; JAEA provided support for various procedures necessary for construction and installation of the utilities.
・As one of support activities of the Aomori Research and Development Centre, support for researchers dispatched from Europe to the Project Team and staying in Rokkasho was implemented. Also public relation activities for increased understanding of public, especially local communities, were done.
・Details of the activities and major achievements are shown below.

2.3.2 Construction of Buildings for IFERC and IFMIF/EVEDA

・For IFERC-related buildings, IFMIF/EVEDA Accelerator Building and their utility facilities, construction and installation were continued based on the procurement arrangements on the design and construction of buildings agreed with the European Implementing Agency, and construction of the other research facilities were carried on, except for the Administration & Research Bldg. which had been competed in the end of March 2009. The progress at the end of Dec. 2009 was 97% for the Computer Simulation & Remote Experiment Bldg., 91% for the DEMO R&D Bldg., and 87% for the IFMIF/EVEDA Accelerator Bldg. The construction works of all the facilities will be completed within FY2009, as scheduled.

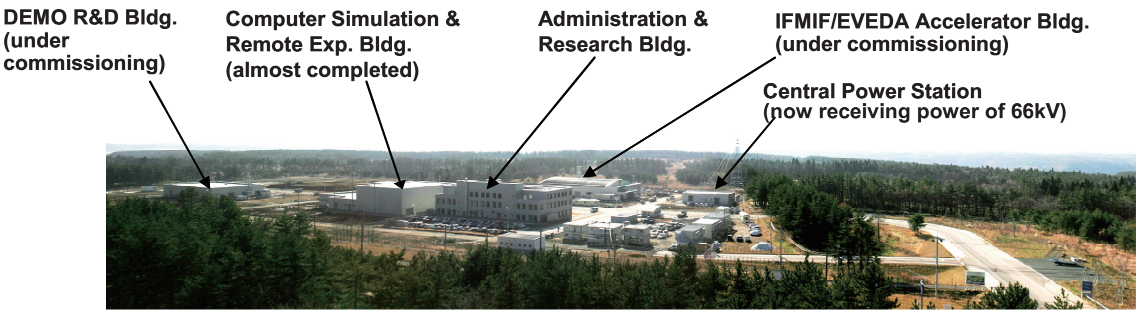


Fig. 2: Current status of the Rokkasho BA site (photo taken on Nov. 24, 2009)

2.3.3 Site Establishment and Support for Base Activities

・As for establishment of the Rokkasho site, electric facilities in the Central Power Station was completed in September 2009 and started receiving the power of 66kV from October, as scheduled. The progress rate of the construction of the power distributing facilities for each facility is about 97%, and all the utility facilities will be completed at the end of the fiscal year, as scheduled. The Fusion Research and Development Directorate cooperates the Aomori Research and Development Center,for establishment of the process of internal review of application for licensing in compliance with the "Laws Concerning the Prevention from Radiation Hazards due to Radioisotopes and Others". In parallel, preparation of a draft of the application for licensing of RI handling for the DEMO R&D Bldg. has been almost completed.
・For four staffs who were newly dispatched from Europe to the Project Team, documents necessary for various procedures were prepared, including immigration clearance, accommodation, etc. Supports to Aomori Prefecture and Rokkasho village were continued in improving the education environment for foreign researchers' children (establishment of an international class).
・In order to promote public understanding (especially that of local communities), proactive efforts were made to disclose and transmit information, including five briefings for local governments, two research information briefing at local events, four lectures in universities, etc., and one media meeting on the project plan.

＜Remarks＞

○ For research and development activities on the free-surface flow of IFMIF liquid metal lithium target, "14th Technology Advancement Award" was granted by the Japan Society of Plasma Science and Nuclear Fusion Research.

○ Excellent understanding promotion activities at the Rokkasho site

・APFA2009 and APPTC2009 were held at the same time from October 26 – 30 in AUGA building in Aomori City, where a poster session and other active discussions were performed. On October 30 and 31, a technical tour to the Rokkasho BA site was organized (with 55 participants), during which overview on its activities and facilities were introduced to researchers from Asian countries, so as to have them recognize its importance as a base of fusion research and development activities in Asia.

・On October 30 and 31, a DEMO Design Platform Meeting was held in the Administration & Research building of the International Fusion Energy Research Center, with 17 and 14 participants from universities and institutes, respectively, mainly consisting of young researchers.

・Autumn session of the "Challenge & Experience on the Atomic Power" program (on November 5; with 59 participants)

2.4 Satellite Tokamak（JT-60SA）

2.4.1 Overview

Based on the procurement arrangements on the superconducting poloidal field (PF) coil conductor, PF coil manufacturing, vacuum vessel, divertor material, and divertor components, respectively, design, fabrication, delivery, and other works have been implemented as scheduled (including seven new contracts). For construction of the Vacuum Vessel Sector Assembly Building, JAEA signed the procurement arrangement with the European Implementing Agency and concluded its construction work contract. In coordination with the European Implementing Agency, JAEA carried forward technical study and examination for the components to be procured by the European side, and signed the procurement arrangements for the quench protection circuit and the the cryostat base. The first draft of the Satellite Tokamak research plan (the JT-60SA Research Plan), was prepared by JAEA, and examination was initiated in Japanese fusion research community as well as with the European side. Set up of the storage place for the JT-60 disassembly jigs and disassembled components have been completed.

2.4.2 Superconductive Magnet Coils

Configuration plan of the i) superconductive poloidal magnetic field coil (central solenoid (CS) and equilibrium field (EF) coil) to be fabricated by Japan and ii) superconductive toroidal field (TF) coil to be fabricated by Europe is shown in Fig 1.

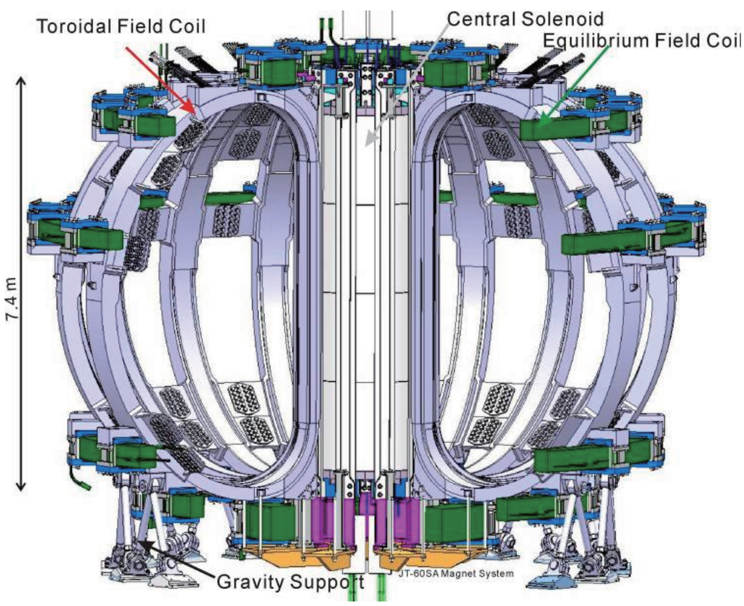


Fig. 1: Superconductive coil system

Manufacturing of the superconductive strands and jacket, i.e. materials of CS and EF coils, was implemented without any problem. The facility for assembling of the conductor has been completed, as shown in Fig. 2, and the conductor assembly process was started in October. First, equipment adjustment was performed using a dummy conductor. Fig. 3 and Fig. 4 show the cross-section of the prototype EF-H conductor and CS conductor, respectively. In November, a 500m-long dummy conductor was inserted into a stainless-steel pipe. The EF-H conductor for the EF4 coil after winding is shown in Fig. 5.

Fig. 2: Conductor assembly set placed in the Conductor Manufacturing Building

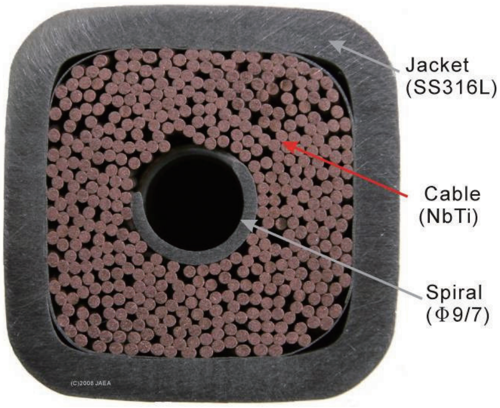


Fig. 3: Cross-section of the EF-H conductor which was trial-produced in the Conductor Manufacturing Building

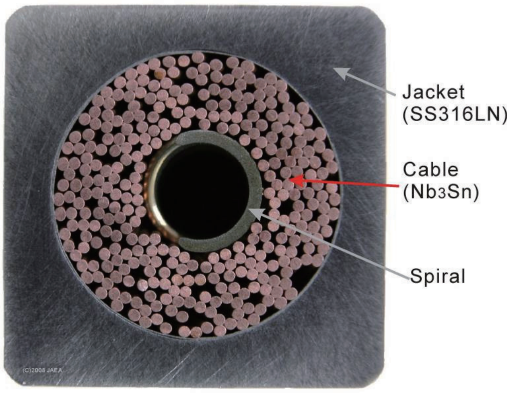


Fig. 4: Cross-section of the CS conductor which was trial-produced in the Conductor Manufacturing Building

For production of the CS and EF coils, design of the coil manufacturing jig and production of a pre-mass production test samples were started. Delivery of the test samples started in December, and cryogenic evaluation experiments of the materials were started. In the Superconductive Coil Winding Building which will be used for coil manufacturing, a 20t bridge crane was delivered (Fig 6) and electric wiring was installed. Since the tasks specified in the "Procurement arrangement for supply of a building for manufacturing of the PF coil" have been completed with the above mentioned works, JAEA made a request for credit allocation (CAS).

On the other hand, as for the TF coil to be supplied by Europe, preparation for a procurement arrangement document has been completed by December. Concerning this coil, contracting procedures for conductor procurement has been started, for the scheduled manufacturing start-up in 2010. For the helium freezer to be manufactured by the European side, examination by the manufacturers were completed to fix the technical specification, and preparation for acceptance (getting approvals, etc.) has been started by the Japanese side.

Fig. 5: EF-H conductor, manufactured using a 500m-long dummy strand and then subjected to the assembly- and winding processes.

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Fig. 6: 20t bridge crane placed on the Superconductive Coil Winding Building

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2.4.3 Vacuum Vessel

As a qualification test for manufacturing of the actual vacuum vessel, data concerning welding deformation, etc. were collected in small-scale model trial production of each part, and trial production of the upper part of the 20° segment was started after that. Fig. 7 shows how the connection was made between the inboard straight section and curved section. In November, trial production of the 20° inboard section was completed and a trial production development report (1) on the inboard section was submitted to the Project Team, to complete the qualification test with it and to start the manufacturing of the actual inboard section in December. Now, rib welding of four inboard straight sections have been completed for the 20° sector of the actual vessel, while rib welding of the curved sections was conducted at the same time.

Fig. 7: Inboard straight section and curved section in trial production of the upper part of the 20° segment

Fig. 8: Trial production of the upper part of the outboard 20° (after boring process of the port pipe stand)

As preparation for manufacturing of the actual outboard section, trail production of the 20° segment of outboard part was carried forward. Fig. 8 shows a scene from trial production of the 20° segment, before mounting of the pipe stand. From now on, a separately fabricated port pipe stand and the outer wall will be welded.

2.4.4 Divertor Component

Procurement of the lower divertor component, as shown in Fig. 9, was started. The lower divertor component consists of a divertor cassette, heat sink, carbon tiles (tiles made of graphite and tiles made of carbon fiber reinforced composite material (CFC)), and cooling water piping. For this lower divertor component, design was forwarded, considering also feasibility of remote maintenance in future, by making the divertor cassette removable.

Procurement was started also for the mono-block target that can resist high temperature load of 15 MW/m^2 which will be applied to a part of the lower divertor component, and one high-temperature load test sample is scheduled to be delivered by the end of this fiscal year. As a fabrication elemental technology test, a brazing test using a copper composite material as well as a bending work test of the outer heat sink, etc. was conducted, as preparation for fabrication of a test sample.

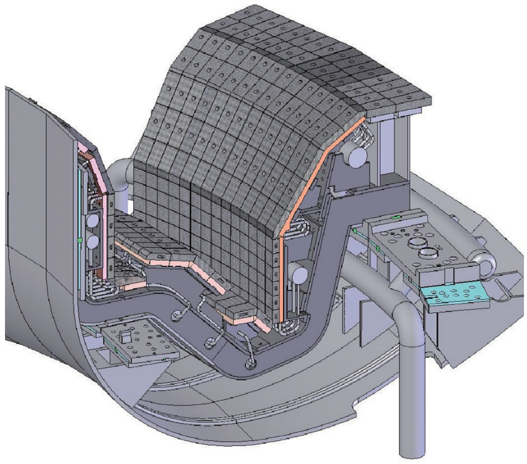

Fig. 9: Lower divertor component

As the CFC material used for the lower divertor, manufacturing of mono-block target CFC material and CFC material for bolt-fixed tiles is in progress. It is scheduled that 810 pieces of mono-block target CFC material and 274 pieces of CFC material for bolt-fixed tiles will be delivered by the end of March, 2010.

2.4.5 Conceptual Study of the Tokamak Assembly

A series of assembly sequences was studied and its animation movie were made, starting from installation of the cryostat base in the torus hall, through the assembly sequence of the major tokamak components in the cryostat, to assembly of equipment and systems around the cryostat, such as valve boxes and coil terminal boxes for superconducting coils.

A basic concept of the assembly frame was studied in order to allow assembly of all the major tokamak components, including the vacuum vessel, thermal shield for the superconducting coils, TF coil, EF coil, CS coil, cryostat, and vacuum vessel ports. As shown in Fig.-10, the assembly frame consists of eight supporting columns and a 30-ton crane, and the TF coils is able to move precisely around the vacuum vessel by using three-staged toroidal rails installed in the assembly frame. The toroidal rails can be also used for fixing the TF coil after fine adjustment and alignment of TF coil in position.

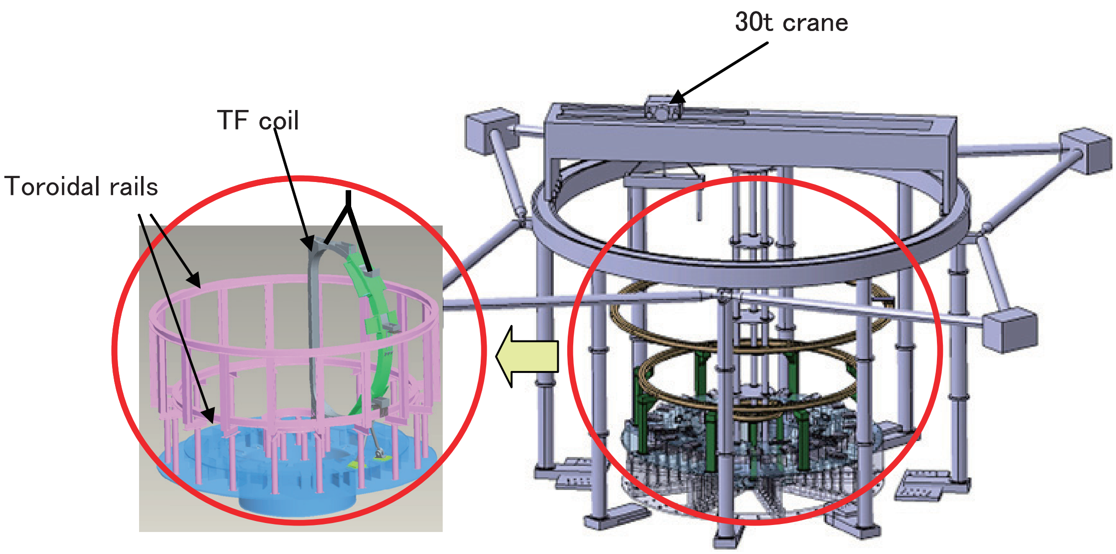

Fig. 10: Assembly frame

2.4.6 Establishment of the Storage site for Disassembled Components

When JT-60 system is disassembled, about 80% of the disassembled radio-activated objects (about 5300 ton excluding reused components) will be stored in the JT-60 Component Storage Building, while about 20% will be retained on the Storage Site 1, after being put in storage vessels. Disassembled parts which are not radio-activated will be stored on the Storage Site 2. The land preparation of the storage sites 1 and 2 has been completed within the premises of Naka Fusion Research Institute (Fig. 11).

Fig. 11: Storage Site 1 (Controlled area: left) and Storage Site 2 (General area: right)

2.4.7 JT-60SA Research Plan

Japan's draft for the JT-60SA Research Plan was prepared. This research plan was planned and suggested mainly by young researchers who will be in charge of JT-60SA experiments, in order to decide how to proceed with experiments and research in each research phase of JT-60SA in accordance with JT-60SA's project mission agreed between Japan and Europe as well as agreed domestically, concerning details on the major six research areas (development of the operation region, MHD stability and its control, transport and confinement, behavior of energetic particles, edge pedestal, and interaction of the divertor / SOL / plasma wall). Then the plan was examined in detail in JT-60SA special taskforce, JT-60 special taskforce, and other meetings and then finalized also integrating proposals from researchers of universities, etc. From now on, the examination activities will be expanded in cooperation with the "Society and Fusion" cluster, Engineerng Cluster, and fusion network. Discussion with Europe will be forwarded in parallel with internal discussions.

2.4.8 Support for the Project Team

Seven specialists were sent to the Project Team, while 130 full-time staffs participated in the Integrated Project Team consisting of staffs from Japan, Europe, and Project Team, as a home team of Japanese side.

While supporting the Project Team, JAEA organized meetings for study of integration of design & fabrication and rationalization of design (three technical coordination meetings, 16 pre-coordination meetings, and four design review meetings), with the Project Team and European Implementing Agency. It also provided support for arrangement of the place of conference and other meeting-related tasks for the Design Review Meeting organized by the Project Committee (Sep. 25) and the 5th Project Committee (Oct. 19), while dispatching 15 commissioners and specialists to the former and five to the latter, respectively.

3. Research & Development of Fusion Plasma

3.1 Research for Achievement of Steady State High Beta Operation

3.1.1 Overview

JAEA participated in the joint experiment of the DIII-D tokamak in US concerning stability and control of high-pressure plasmas, while contributing to 12 cases of inter-machine experiments. Further, experimental data of JT-60 concerning high beta stability, transport characteristics, divertor thermal/particle control characteristics, etc. were analyzed, and 15 research papers and 21 presentations were provided. Through these activities, a guideline for component design of JT-60SA could be obtained which is necessary for realization of steady-state high beta plasmas.

Below, major achievements are described concerning control and understanding of the advanced plasmas of JT-60SA, including i) interaction between energetic particles or ELM and instability in high beta exceeding the free boundary stability limit, ii) extrapolability of the small-amplitude ELM occurrence expected in a high triangularity shape, and iii) transport and accumulation of high-Z impurity.

3.1.2 Inter-Machine Experiments on the Interaction Between Energetic Particle Driven Instability and Resistive Wall Mode

The Energetic particle driven Wall Mode (EWM), which was discovered in JT-60 high-beta plasmas in 2008, induces Resistive Wall Mode (RWM). This EWM is focused in view of better understanding of plasma stability in DEMO reactor regions where the free boundary stability limit is exceeded and many energetic particles exist. This time, a comparative experiment was performed in the DIII-D tokamak concerning the interaction between the EWM and RWM. Just as JAEA did with JT-60, instability which is similar to EWM was observed in DIII-D and data of varied parameters such as plasma rotation, plasma pressure, and NB injection energy were obtained. In this experiment, JAEA took an initiative as a session leader. This experiment revealed that this instability is associated with loss of fast ions and that it exists simultaneously with RWM. Further, a diagnosis was conducted, by applying magnetic perturbation of several kHz.

3.1.3 Change in the ELM Characteristics due to Energetic Particle Driven Instability

The energetic particle driven wall mode (EWM) is driven by energetic ions, causing loss of those fast ions, and then decays. It was found out that, when an EWM occurs, Edge Localized Mode (ELM) is synchronized with EWM (Fig 1). It was also observed that, when the frequency of ELM is increased to about three times as fast at the time of EWM occurrence, the energy release by one ELM crash is reduced to about a half. This is considered as follows; EWM enhanced energetic ion transport temporally increases the pressure of the plasma edge, and thus reaches the pressure limit even before full recovery of pressure without EWM, resulting in trigger of ELM. This result is interesting also in terms of a new scenario for ELM mitigation; however, control of EWM is necessary, because EWM eventually induces the resistive wall mode (RWM), causing desruption and collupses.

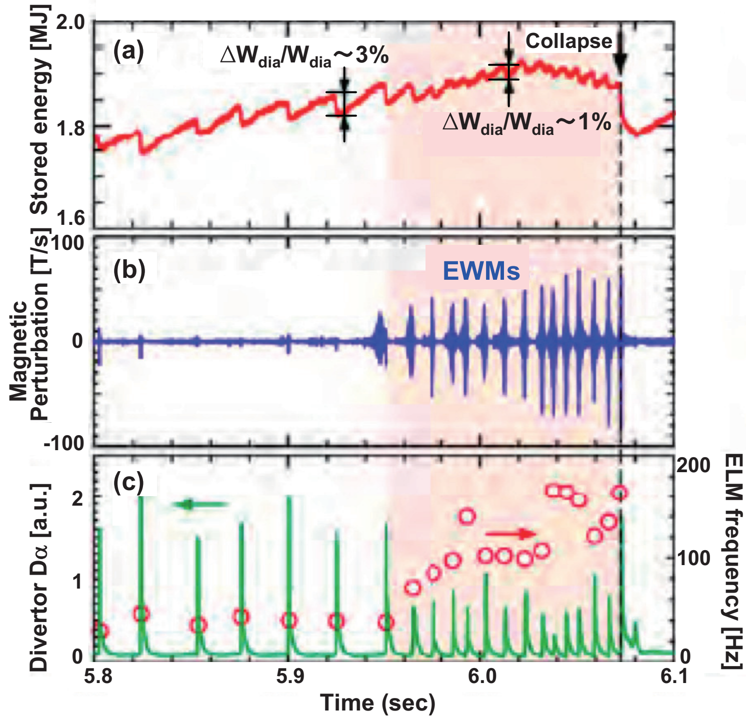

Fig. 1: Comparison of the ELM characteristics between before and after EWM appearance

(a) time evolution of stored energy,
(b) magnetic perturbation and
(c) D_α emission in the divertor area with ELM frequency.

3.1.4 Collisionality Dependence of Grassy ELM Regime

The edge localized mode (ELM) observed in high confinement mode (H-mode) is an ELM with a large amplitude, called "Type I" ELM. As the energy expelled by the ELM is large, it is one of the important issue to be solved for the DEMO reactor to establish a method for reduction of an instantaneous heat load to the divertor target plate. In JT-60, research has been performed in order to extend the operation region of the Grassy ELM, i.e. an ELM with a small amplitude, as a method to solve that issue Since this Grassy ELM has been observed in plasmas with high triangularity of the plasma cross-section, it is expected that the operation with Grassy ELM in JT-60SA or DEMO reactor with high triangularity. In type I ELM regime, on the other hand, a collisionality dependence that the ELM amplitude becomes smaller as the normalized collisionality (ν_e^*) becomes larger has been observed so far and therefore the ELM amplitude in ITER in which ν_e^* is small is a concern. Then, the relation between the amplitude of ELM and ν_e^*, which is an important parameter determining the ELM characteristics, has been investigated As a result, a larger D_α intensity (a measure of divertor heat load) has been observed in plasmas with higher ν_e^*, as shown in Fig. 2. As the ELM amplitude increases, the ELM frequency decreases. Since the observed ν_e^* in the grassy ELM is opposite way to the type I ELM, it was found that the opeartion with grassy ELM is suitable for JT-60SA and other next-step devices expecting low ν_e^* plasmas (ν_e^*<~0.1).

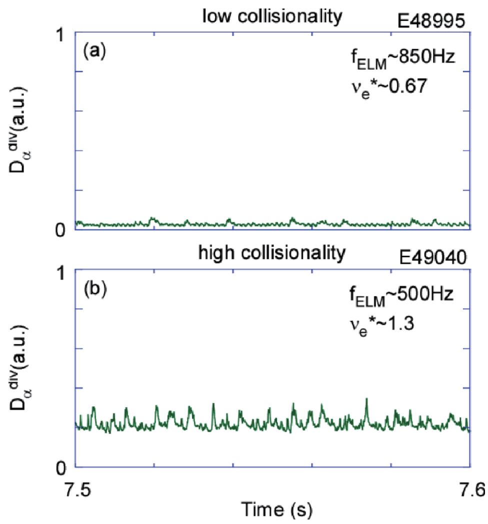

Fig. 2: Comparison of ELM amplitude between discharges with different normalized collisionality. The pressure at the pedestal and that of the whole plasma are similar.

3.1.5 Plasma Rotation Effect on Transport and Accumulation of High-Z Impurity

It had been shown in JT-60 that accumulation of high-Z impurity into the center of the plasma is increased by plasma rotation in the counter direction to the plasma current. The process of tungsten accumulation due to toroidal rotation was recently analyzed further, and a model was developed, in which an inward pinch arises from an atomic process of a high-Z impurity, such as tungsten. The generation mechanism of this inward pinch is as follows; 1) The high-Z impurity ion is accelerated by the friction force nearly to the rotation speed of the background plasma. 2) The orbit of accelerated ion is shifted from the flux surface widely, resulting in change in the electron temperature on the ion orbit. 3) In accordance with the change in the electron temperature, the charge number "Z" of the impurity ion changes, and the magnetic drift speed v_d ($\propto Z^{-1}$) changes along the orbit. Due to the difference of the magnetic drift speed in the upper and lower parts of the poloidal surface, an inward pinch is generated (Fig 3).

It was found out that this is caused when the charge number variation along the particle orbit is large, and that it is an inherent phenomenon of such high-Z impurity which is ionized and recombined easily in the core region. Monte Carlo simulation proved that an inward pinch similar to the one predicted by this analytical mode developed will take place.

It was estimated that the inward pinch due to the radial electric field would be about 1 - 0.1m/s in the toroidal rotation observed in the JT-60 experiment.

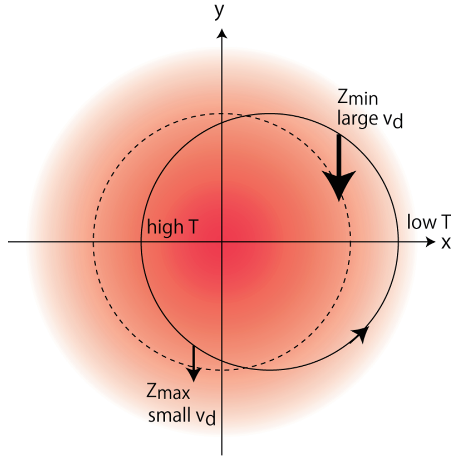

Fig. 3: Generation mechanism of an inward pinch arising from a change in the charge number Z along with the high-Z particle orbit

3.1.6 Deuterium Accumulation Mechanism on the Tungsten Cladding Tiles

Tungsten is a promising candidate material for ITER's divertor plate. If the mechanism of hydrogen accumulation to tungsten can be clarified, precise prediction of the hydrogen (tritium) accumulation amount to ITER's tungsten divertor tiles will become possible. An experiment was conducted in JT-60, with a tungsten-coated tile made of carbon composite fiber material mounted on a part of the outer divertor. Upon completion of the experiment, the tile was taken out and analyzed, demonstrating that no blister was formed on the tungsten coating surface, and that the deuterium accumulation amount in the tungsten-coated tile was about 10^{22} D/m^2. This amount of hydrogen accumulation is one order of magnitude larger than the measurement result in basic experiments using bulk tungsten. In order to identify the cause of the observation, measurement was performed for depth distribution of deuterium, carbon (impurity) and oxygen (impurity) in the tungsten coating (Fig. 4). As a result, the depth distribution of deuterium was similar to that of carbon. This suggests that deuterium atoms may be captured by carbon in the tungsten coating. Carbon in the tungsten coating was mainly accumulated during the plasma discharges. Therefore, it is expected that capture of deuterium atoms by carbon atoms, accumulated during the plasma discharges, are responsible to significant increase in deuterium accumulation.

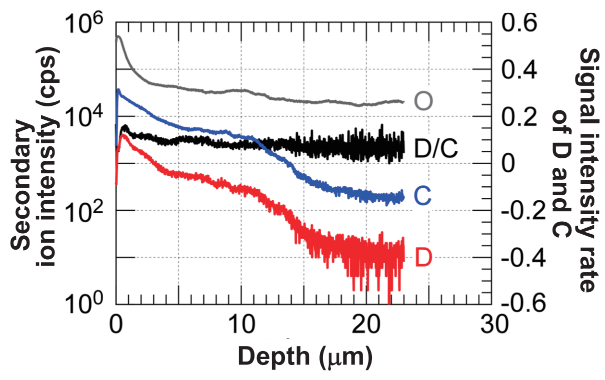

Fig. 4: Depth distribution of deuterium (D), carbon (C) and oxygen (O) in the tungsten layer; and signal intensity rate of D and C

＜Remarks＞

○ Fusion Energy Forum “Masaji Yoshikawa Prize for Fusion Energy” was granted.

3.2 Development of Equipment Technique

3.2.1 Neutral Beam Injector

To enhance a performance of the Negative-ion-based Neutral Beam Injector (N-NBI) onJT-60, voltage holding capability of the negative ion source thas been significantly improved. This succeeded in the acceleration of hydrogen ion beams of 500keV and 3A (Fig. 1). This is the world’s first achievement in acceleration of a beam of 1A or above up to 500keV. This fulfills the beam energy required for the JT-60SA.The improvement of the voltage holding capability can apply to the development of the ITER accelerator that is the same type as the JT-60 negative ion source with an electrostatic multi-stage accelerator.

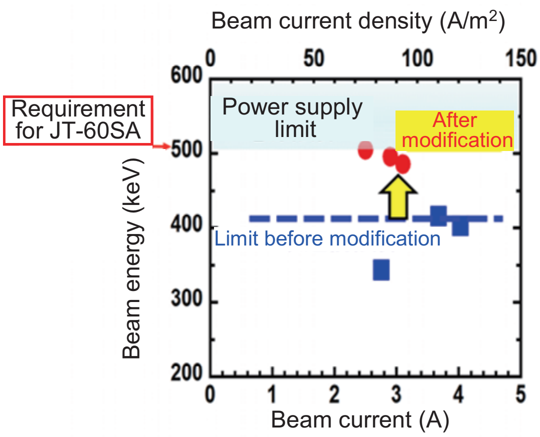

Fig. 1: Beam current and energy before and after the modification

Till now, the beam energy of the JT-60 negative ion source has been limited to about 400keV due to the insufficient withstand voltage between the large acceleration electrodes (dia: 160cm) in vacuum. Therefore, detailed study was made on the vacuum withstand voltage characteristics between large electrodes, which had been an unknown field till now. As a result, it was made known for the first time that large electrodes have significantly different withstand voltage characteristics from small electrodes (with diameter of about 16cm) that have been generally used in the past, and that large electrodes require a insulation distance about six times as large as that of small electrodes in order to secure a same withstand voltage (Fig. 2). Besides, since simple extension of the distance between the electrodes will spread the beam wider due to repulsion among ions, causing a problem of decrease in the injection power due to ions colliding against the electrode, etc. in the ion source, the distance between electrodes was optimized, by calculating the ion beam orbit in detail (Fig. 3). As a result, stable acceleration of ions up to the beam energy level required for JT-60SA (500keV) could be successfully realized.

This achievement has been applied for development of the negative ion source of ITER, which uses the multi-step acceleration system just like the negative ion system of JT-60, making a big contribution to stable acceleration up to 1MeV, the required energy for ITER.

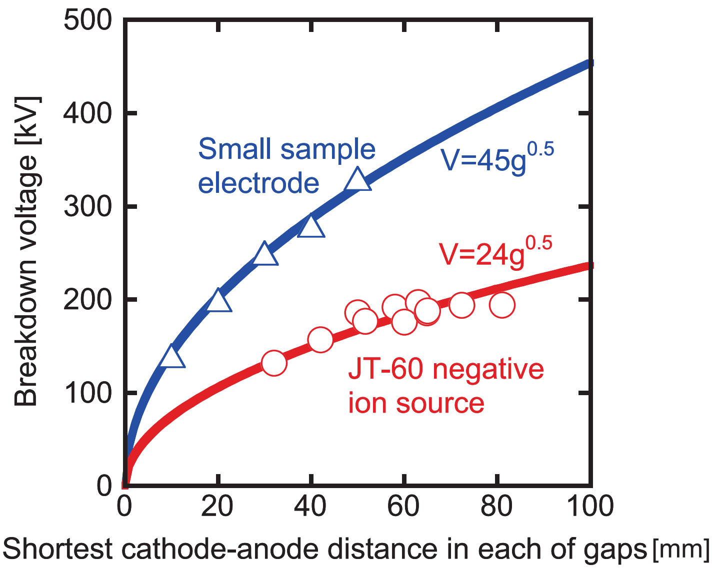

Fig. 2: Withstand voltage characteristics of large electrodes

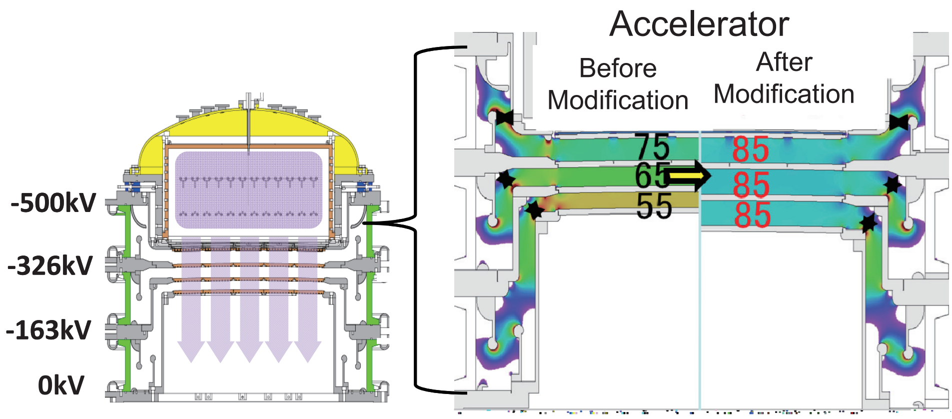

Fig. 3: Schematic diagrams of the JT-60 negative ion source (left) and its accelerators before and after modification.

＜Remarks＞

The Award of The Japan Society of Plasma Science and Nuclear Fusion Research for FY2009 and the 14th Science Incentive Award were granted.

3.2.2 Radio-Frequency Heating System

In development of the radio-frequency heating systems, a large progress was made in power enhancement of the gyrotron, the core component of the electron cyclotron wave heating unit. Due to, above all, development of a new operation method which can enhance the microwave output to 1.5 times as much as the conventional system, the world record of the microwave output was improved from 1MW till now to 1.5MW (four seconds) for the practical output continuation time required for the plasma heating current drive experiment (one second or longer) (Fig. 4) (press release in November).

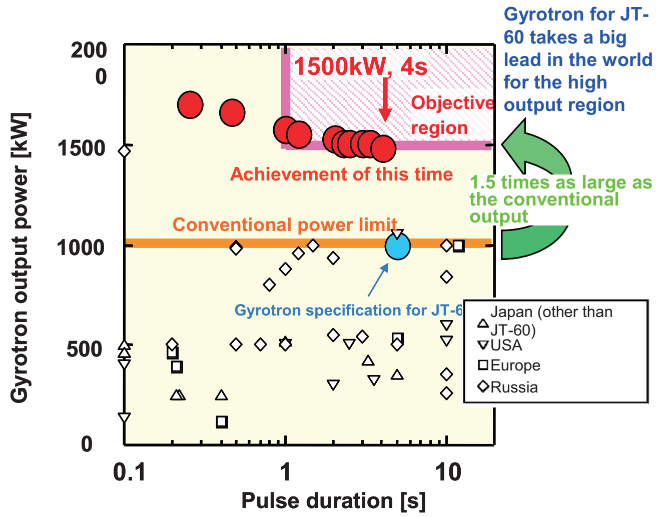

Fig. 4: Achievement of this time, together with records of worldwide gyrotron development

In the gyrotron development for ITER till now, such an operation region has been identified in which kinetic energy of electrons are converted into millimeter waves with high efficiency. However, in order to reach this high efficiency operation region, it was necessary with the conventional method to control the superconductive coil current right after start of oscillation to change the magnetic field strength, and it took a few tens of seconds to shift to the high efficiency operation. Instead of this method, a new method was developed in FY 2009, focusing attention on the "electric field intensity" which gives influence on the electron beam orbit as well as the magnetic field intensity but can be controlled more speedily. As a result, such a new operation system (Fig. 5) could be developed successfully which enables a shift to high efficiency operation in about 0.1 second (1/100 compared to the conventional system), by slightly changing the anode voltage which extracts the electron beam. Through this, microwave output 1.5 times as large as the conventional system could be realized, because a margin can be secured in the temperature of the collector till the shift to the "high-efficiency operation".

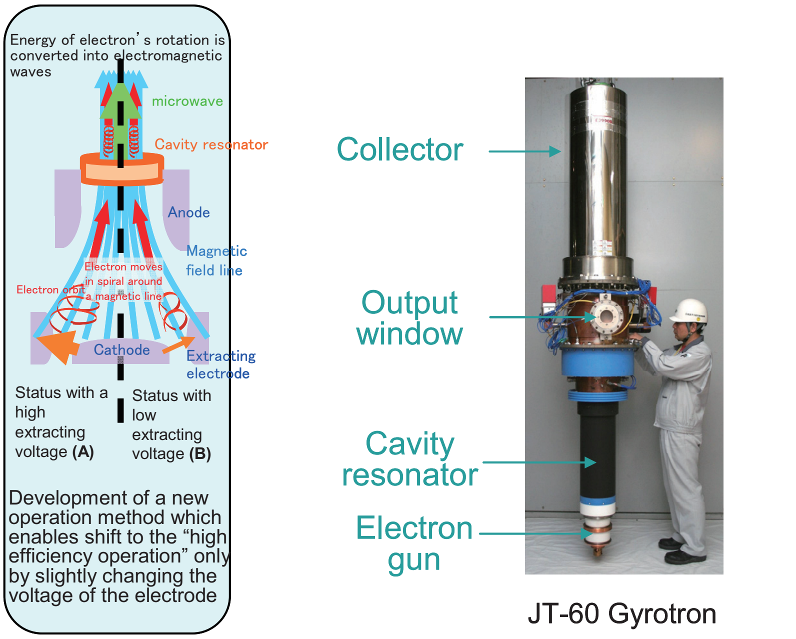

Fig. 5: Schematic plan of the new method to shift to the high efficiency operation & appearance of the gyrotron

On the other hand, development for realization of continuous oscillation of 100 seconds was also conducted in parallel to development for enhancement of the output. An output test was conducted using a mode convertor which had been modified for enhanced efficiency. In the test, temperature increase of the DC brake section cooling water was successfully reduced to the half (Fig. 6), while the collector temperature was also maintained within the permissible range with high efficiency of 50%; thus a good prospect could be obtained for achievement of continuous oscillation for 100 seconds. Though the modified tube requires more time for conditioning operation to reduce the gas discharge, the oscillation duration with the output of 1MW could be successfully extended in this fiscal year from five seconds before modification to 14.7 seconds.

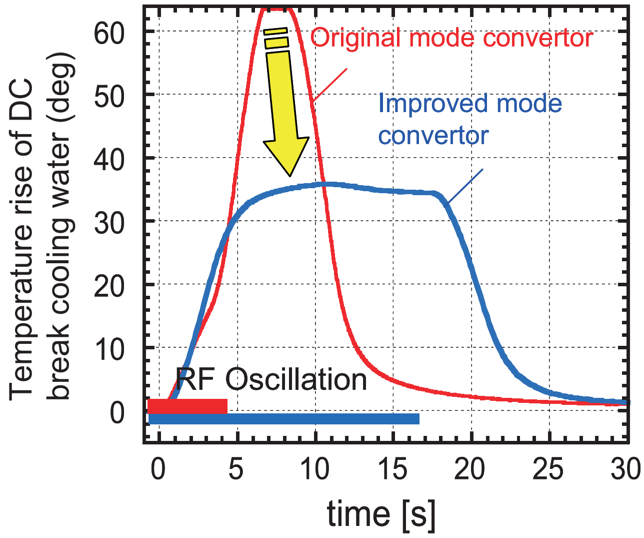

Fig. 6: Thermal loads to the DC brake has been reduced significantly by modification of the mode convertor

＜Remarks＞

○ In development of the negative-ion-source based neutral-beam heating system and radio-frequency heating system, much bigger achievement than originally expected could be obtained (press release in November and December).

○ For achievements in development & research activities on JT-60, "1st Establishment of the Nuclear Power History Award" was granted by the Atomic Energy Society of Japan in April 2009, as a recognition of fusion energy development activities in JT-60 over the past quarter a century.

○ Being highly evaluated as large-scaled electric equipment which made contribution to mutual development in the field of electric technology and paved a road to sustainable application of fusion reactions and power reactor, JT-60 received the "3rd Foundation Stone Award" by the Institute of Electrical Engineers of Japan in February 2010.

3.3 Code Development

For integrated simulation of the fusion plasmas, integration of different models, including magnetofluid stability model, nuclear burning model, and edge pedestal model, was performed based on the core plasma transport code. Besides, another integration, i.e. integration of impurity transport model and neutral particles transport model in the divertor region and plasma edge region (SOL region), was carried forward based on the divertor plasma transport code. For FY2009 as the last fiscal year of this midterm project, these two integrated codes were combined to perform integration of all the plasma regions.

For transport in the divertor region, the particle flux and heat flux from the core are determined as boundary conditions with the core plasma. On the other hand, backflow and commingling of neutral particles and impurities from the divertor to the core give influence on core plasma confinement properties. Therefore, such an integrated code that can calculate the core plasma confinement properties and divertor properties self-consistently has been developed in the following way; data on the particle flux and heat flux which flow out to the SOL region are passed from the Core Plasma Transport Code to the Divertor Code, while data on the backflow of the neutral particles and impurities to the reactor plasma and data on the cooling effect are given from the Divertor Code side (Fig. 1). In this way, a simulation method could be realized which examines the divertor plasma transport characteristics and core plasma confinement characteristics of JT-60SA, ITER, and other systems without any inconsistency.

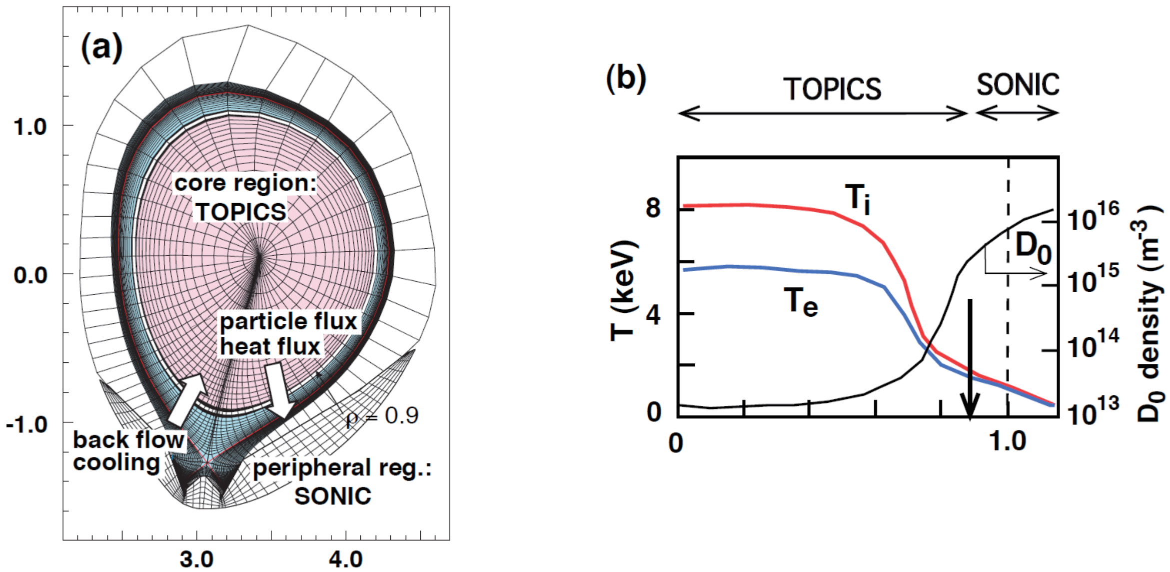

Fig. 1 (a) Relation between the region of the core plasma transport code TOPICS (red region) and the edge region consisting of the plasma / neutral particles / impurities transport codes (blue region)
(b) Temperature distribution according to the plasma minor radius. The solutions are connected on the surface of $\rho = 0.9$

＜Remarks＞

○ The 14th Science Incentive Award was granted by the Japan Society of Plasma Science and Nuclear Fusion Research related to the model integration.

3.4 Collaboration with Universities and Fostering of Human Resources

In cooperation and collaboration with universities, etc. the following organizations were established and organized: Fusion Plasma Joint Planning Committee, JT-60 Special Committee, JT-60SA Special Committee, and Theory & Simulation Special Committee.

As for joint research on JT-60 in the form of open-application system, “Joint Research Activities on National Centralized Tokamak in Japan” which covers JT-60 and JT-60SA have been started, as the operation of JT-60 had been completed in August 2008 and the phase of full-swing design and construction work of JT-60SA has come. As a result, 30 open-application type joint research projects (26 in the previous year) could be conducted, including new joint research on design and construction of JT-60SA, such as NBI heating technology, plasma measurement & diagnosis technology, and radiation safety evaluation technology, without impairing continuity from “Joint research related to experiments and analysis of JT-60” which continued till 2008. Here, as more than a half of 139 participants (Fig. 1) in this research project were assistant professors and graduate students, a big contribution could be made through this also from the viewpoint of human resource development (Fig. 2). For 12 joint research themes that have been completed in FY 2008, a debrief session was held.

Beside the above open-application type joint research, three design examination works which were regarded as necessary for execution of JT-60SA plan, were performed in a form of an open-application type R&D task.

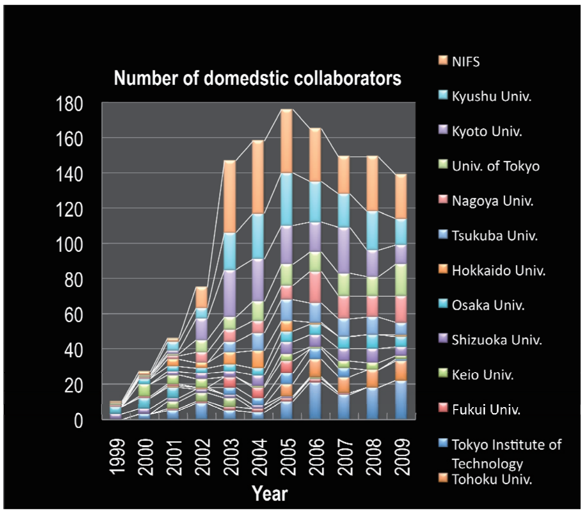

Fig. 1: Number of co-researchers on JT-60 in Japan

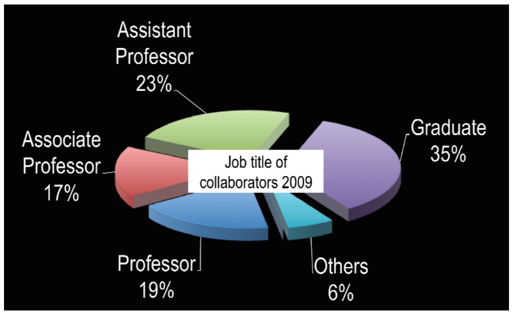

Fig. 2: Breakdown of co-researchers

3.5 Theory & Simulation Studies

In this midterm plan, theories and calculation methods related to hydromagnetic behavior of the fusion plasma were expanded based on the variational principle, so as to enable handling of MHD stability matters, including toroidal rotation effects, as well as of the resistive wall mode. Besides, a highly conservative, high-precision turbulent transport code was developed using a Vlasov model (which regards it as continuous media in the topological space) as an alternative to the conventional particle method. Based on these, the following achievement could be obtained as fruits of the final year of the midterm plan.

Development of the magneto-hydro dynamic (MHD) stability analysis code, covering the plasma rotation in the toroidal direction, has been completed, and with this code it was demonstrated that plasma rotation has an destabilizing effect on the MHD mode, one of the cause of the Edge Localized Mode (ELM). Concerning a physical mechanism of this destabilization, importance of the effect of the plasma sheared rotation on the short wavelength (high toroidal mode number) mode was clarified (Fig 1), providing a theoretical guideline which may lead to control of the ELM stability by plasma rotation.

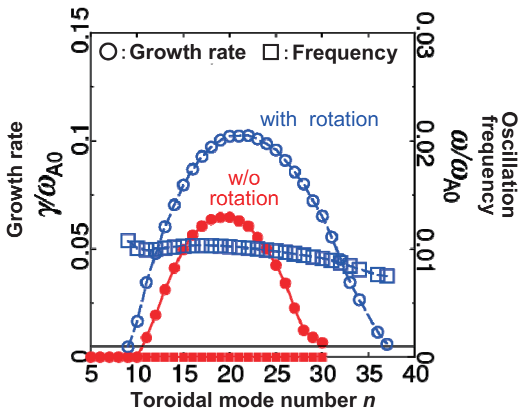

Fig. 1: Comparison of the linear growth rate of the MHD mode between the cases with and without plasma sheared rotation.

Development of the toroiodal turbulent transport code of the ion system turbulence has been completed, by incorporating the particle collision effects into gyrokinetic Vlasov model, and simulation was performed concerning formation of the ion temperature- and plasma rotation distribution, successfully reproducing the experiment results qualitatively. The physical mechanism of the ion thermal transport which brings about this distribution formation was analyzed to reveal that rigidity of the temperature distribution (which constrains the distribution near the critical temperature gradient, regardless of the increase in the heating power) is brought about by an avalanche-like non-localized thermal transport phenomenon. Thus a theoretic guideline was obtained for control of confinement.

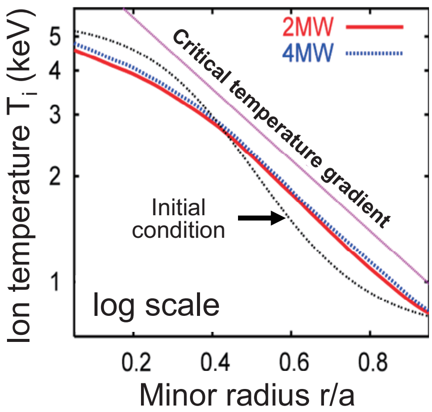

Fig. 2: Temperature distribution observed in ion system turbulence simulation. The distribution is constrained near the critical temperature gradient, regardless of the heating power.

4. Research & Development in Fusion Engineering

4.1 Research & Development of Breeding Blankets

Based on the plan of the performance tests concerning thermal-, flow-, mechanical, and neutronic characteristics of the breeding blanket as well as concerning tritium recovery, engineering-scale performance tests were conducted; the following results were achieved, clarifying basic requirements of the ITER test blanket module (TBM) and attaining the objectives of the midterm plan.

4.1.1 Development of the TBM

As for design- and fabrication technology development for the TBM, TBM assembly fabrication test of the full-scale first wall and side wall by means of electron beam welding was performed successfully using a mockup made of F82H steel plate which has the same size and shape as the actual first wall and side wall of the TBM. Fig 1 shows the photo of the outer appearance of the full-scale TBM mockup, for which the first wall and side wall sections were fabricated separately and successfully assembled. The biggest problem in the welding in assembly of separately fabricated parts, i.e. deformation of the housing, was properly controlled by the fixing jigs, and precision of +/- 1mm from the target value could be achieved for the final outer dimension. Though, in a liquid penetration test, an undercut was detected at four points of the welding section between the first and side walls, it was confirmed that its depth was within 0.55mm and reparable. Besides, a thermomechanical test was conducted using a mockup as shown in Fig 1 (D), in which it was demonstrated that no abnormal deformation or crack is generated at the welding section between the first wall and side wall, proving the adequacy of the fabrication- and design methods. This achievement clarified basic requirements of welding conditions to be applied for manufacturing of the actual TBM, including the processing precision of the welding groove, fixing technology, etc. Further, as a performance evaluation test of the TBM full-scale side wall mockup, a cooling-water flow test was conducted with water of room temperature (total flow rate of 60L/min), clarifying the flow distribution in cooling channels of the side wall mockup. It was revealed that decrease in the flow rate was 15% of the average flow at a maximum and that this flow distribution does not affect heat-removing performance, given the heat emission amount at the side wall; thus it demonstrated adequacy of the structure design of the side wall in terms of heat removal. Besides, individual safety evaluations of the water-cooled solid breeding TBM were summarized and submitted to the ITER Organization, clarifying the basic requirement for securing safety of the TBM and auxiliary system. The above mentioned achievements together with the fabrication and test results of the full-scale mockup of the first wall and side wall in the previous years have clarified the basic requirements of manufacturing and design of the TBM structure.

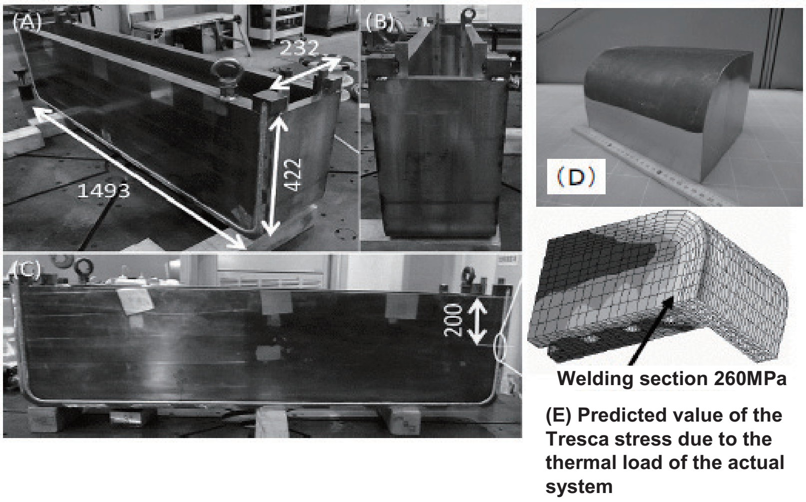

Fig. 1: Full-scale mockup of the first wall and side wall made of F82H steel plate which have been separately fabricated and then successfully assembled.
(A) Appearance (B) Top side (C) Lateral side (D) Mockup for a thermomechanical test
(E) Predicted Tresca stress value of the actual system

4.1.2 Development of Tritium Recovery Technologies

For development of technologies for recovering tritium from the blanket, R&D activities were made concerning the tritium water treatment system. For the polymer electrolytic cell, one of the major components of the tritium water treatment system, radiation resistance property (ion conductivity and water permeability) data were obtained. In addition, basic data for development of a hydrophobic catalyst (which oxidizes tritium to water at the room temperature) were obtained for enhancement of the detritiation technology. As shown in Fig. 2, it was observed that hydrophobic alumina catalyst has significantly higher oxidation performance around the room temperature compared to general alumina-platinum catalyst. Basic data on a tritium analysis method for the breeding blanket were obtained, such as hydrogen isotope analysis microgas chromatograph data.

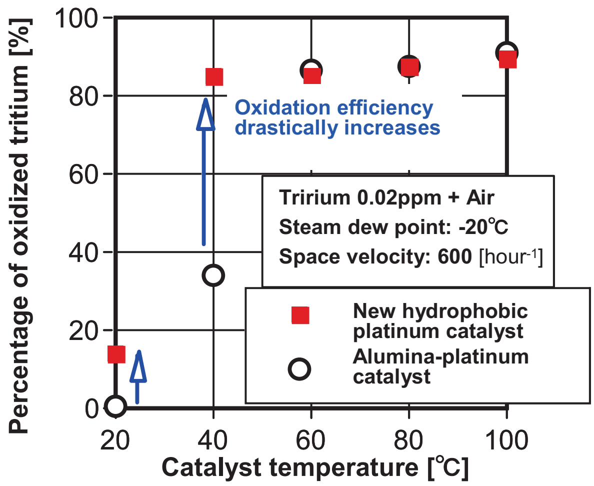

Fig. 2: Temperature dependency of the tritium oxidation performance of alumina-platinum catalyst and hydrophobic catalyst

A “blanket simulation container” (Fig.3) was developed newly, which enables high-energy neutron irradiation experiments in the same environment as the actual nuclear reactor using the Fusion Neutronics Source (FNS). A tritium recovery performance test was conducted, by packing that container with the same tritium breeding pebbles as the actual system and irradiating high-energy neutrons of 14MeV (the same energy as a fusion reactor). As a result, it was confirmed for the first time in the world that a tritium recovery rate of almost 100% can be obtained.

Fig. 3: Newly developed blanket simulation container

4.1.3 Development of the Advanced Tritium Breeder

As development of an advanced tritium breeder, a method for synthesis of Li_2TiO_3 with added Li was developed, which enhanced structure stability against Li burn-up and Li evaporation at high temperatures, by increasing the lithium (Li) content beforehand. It was demonstrated that this material can be synthesized by using lithium hydroxide ($LiOH \cdot H_2O$) and metatitanic acid (H_2TiO_3) as the starting materials and turning mixtures into a gel at the room temperature. Further, it was also made known that chemically stable Li_2TiO_3 with added Li in single phase $Li_{2+x}TiO_{3+y}$ structure can be synthesized, when the molar ratio of Li/Ti is within the range of 2.0 – 2.2, as shown in Fig. 4. Concerning the ^{6}Li enrichment technology, a preliminary isotope separation test was initiated using a new separation membrane with a high isotope separation coefficient. For development of irradiation technologies, trial production of a tritium baking system was performed based on the examination result of the tritium recovery conditions.

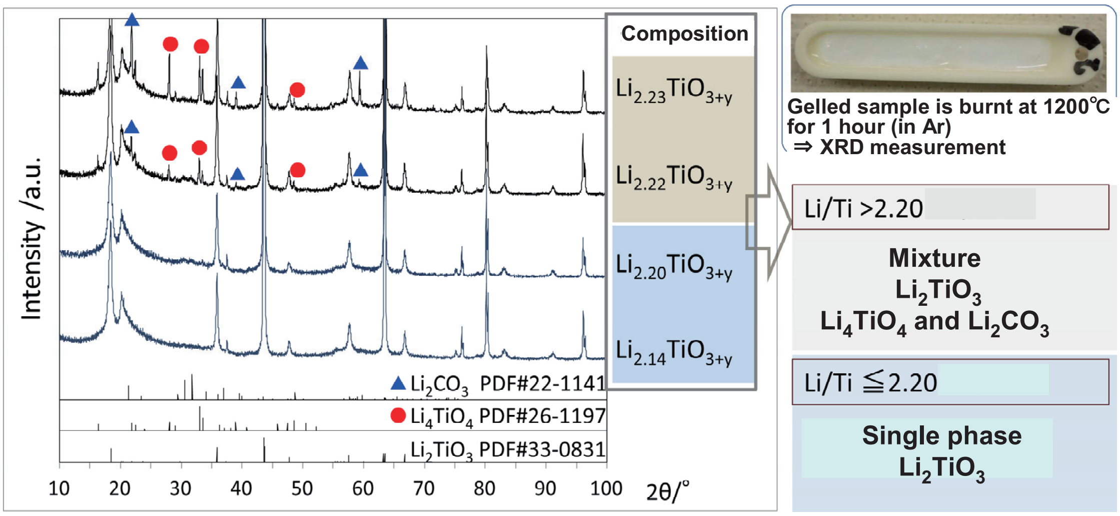

Fig. 4: XRD measurement results of the Li-added Li_2TiO_3 with different Li/Ti composition ratios

4.1.4 Study on the Nuclear Characteristics

For study of the nuclear characteristics, re-examination was conducted in order to identify the cause of the precision deterioration in the blanket tritium production rate evaluation for cases where a reflector exists in the system, while a review was made on the data of the 2003 experiments, in which the problem of this time was discovered (Fig. 5 & 6). As a result, it was found out that the claimed precision deterioration in the tritium production rate evaluation was due to some errors in the data of 2003, and that the tritium production rate can be estimated as about 10%, even if a reflector exists. A good prospect could be obtained for application of a multi-foil activation foil method as a nuclear performance measurement method for the ITER test blanket module. Besides, an analysis tool for 3D nuclear analysis of the ITER test blanket module was enhanced further.

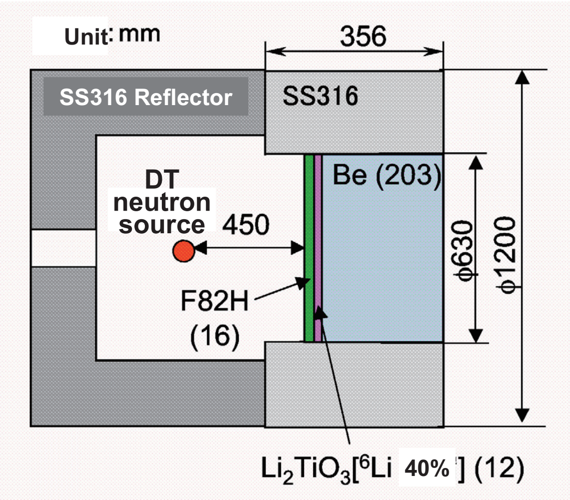

Fig. 5: Experiment system

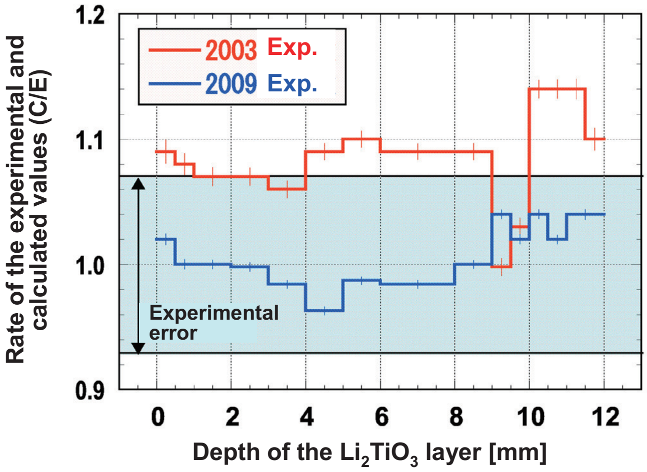

Fig. 6: Ratio of the calculated value / experimental value of the tritium production rate

＜Remarks＞

○ For the achievement in heat conductivity research of the plasma facing component and development of the equipment, “Miya – Abdou Award” was granted at the 9th International Symposium of Fusion Nuclear Technology (award winner: Koichiro Esato)

○ For development of a synthesis method of Li-added Li_2TiO_3, “Attainment in Research and Development” award was granted as prize-giving by the Director-General for 2009.

4.2 Research & Development of Structural Materials

The neutron irradiation test of the reduced-activation ferritic steel was continued using the HFIR reactor, achieving irradiation up to 35dpa.

The irradiation test of the reduced-activation ferritic/martensitic steel was continued, and it was demonstrated that the post-irradiation fracture toughness of F82H after 20dpa irradiation could be improved by Ta concentration increase or optimized heat treatment condition (Fig. 7). It was demonstrated that the brittle-ductile transition temperature (T_0) shift was suppressed by increasing Ta addition （F82H-MOD3:Fe-8Cr-2W-0.2V-0.1Ta）, and its T_0 remains in the same level of that of F82H-IEA heat irradiated up to 7dpa, while that of F82H-IEA heat rises up to near 100℃.

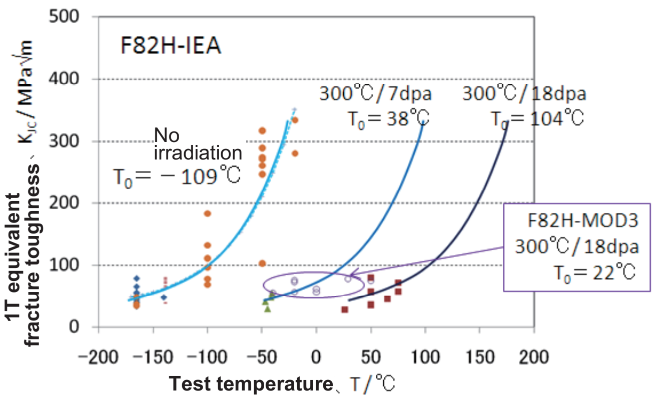

Fig. 7: Toughness data of F82H and toughness-improved material at 300℃ and 20dpa level

F82H water corrosion database were expanded, and corrosion data of 300℃ and 320℃ up to 2500 hours were obtained. As a result, tendency was identified under the TBM cooling water condition as follow: the higher corrosion rate was observed as the dissolved oxygen concentration become lower; the corrosion speed of different heat and weld varies approximately in factor of two. In addition, erosion & corrosion test equipment was upgraded based using joint research fund.

4.3 Enhancement of Fusion Engineering Technologies

4.3.1 Vacuum Technology

In research for enhancement of the vacuum technology, a long-term durability test was conducted for evaluation of the insulation deterioration property of the insulation washer (with an alumina thermal spray coating) for the vacuum vessel, demonstrating that it resists 78,096 hours' operation in total. As a part of the vacuum characteristics evaluation research for the wall materials, three joint research activities were performed concerning the hydrogen-storage property of tungsten and reduced-activation steel as well as concerning material damage due to ELM quasi-thermal load, etc.

4.3.2 Advanced Superconductivity Technologies

Since a superconductor is formed when high-temperature superconductive strands for a fusion reactor incorporate oxygen in annealing atmosphere into the strands, securing oxygen concentration during heat treatment has been a task to achieve in the advanced superconductive technology. As a part of the research for enhancement of the advanced superconductivity technology, a method has been innovated in which heat treatment is implemented while oxygen is supplied from outside. A small-scale conductor was produced on a trial base, using this method, where high-temperature superconductive strands were encapsulated into a metal pipe and then subjected to thermal treatment. Evaluation of characteristics of these strands revealed that critical current density of 930A/mm2, i.e. 1.5 times as high as that of the conventional type, can be obtained in high magnetic field of 16T (temperature: 10K).

4.3.3 Tritium Safety Engineering

In the field of tritium safety engineering, a basic database was established concerning the interaction of tritium and materials, which is important for safe confinement of tritium. Basic data were obtained concerning permeation of tritium water vapor through pure ion and F82H as well as metal corrosion due to tritium penetration. Though normally, a passive-state film is formed on a metal surface due to oxidation, such a phenomenon was observed, as Fig. 8 shows, in which formation of the film is considered to be impaired due to existence of tritium. In joint research with universities and other institutes, basic data were obtained concerning; i) tritium decontamination from concrete, ii) behaviors of tritium permeation into stainless steel and release from the metal surface, iii) development of a monitoring method for tritium chemical species using a gas permeation membrane (especially for separation of organic tritium).

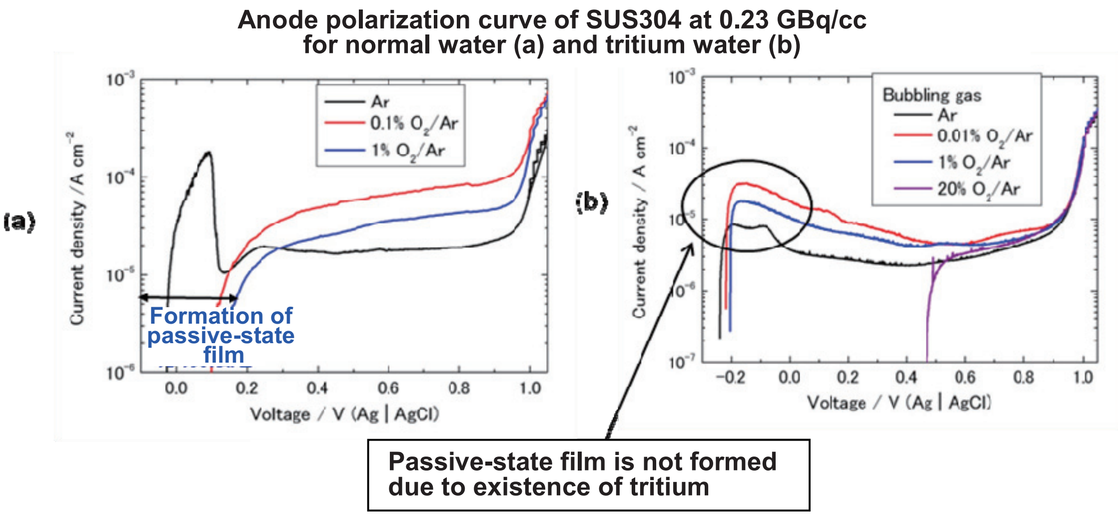

Fig. 8: Metal corrosion behavior of high-concentration tritium

4.3.4 Neutronics

In the field of neutronics, analysis of various benchmark experiments conducted by FNS was performed using the β version library for the purpose of revision of Fusion Evaluated Nuclear Data Library (FENDL), which is maintained under the leadership of IAEA, and Japanese Evaluated Nuclear Data Library (JENDL), in parallel with an integral experiment for lead nuclear data verification. For new experiments of nuclear data verification, a DT neutron beam hole was installed. As an R&D task from the ITER Organization, evaluation of the radiation shielding and activation of the ITER NB system has been started.

4.3.5 Beam Engineering

In research for enhancement of the beam engineering, evaluation of the withstand voltage characteristics of accelerator with the gap length up to 500 mm, which is five times as long as that for JT-60, was conducted, in order to clarify the withstand voltage characteristics of electrode grid with much longer gap length than the accelerator for JT-60, also in view of the accelerator for the DEMO reactor. As a result, it was demonstrated for the first time that the existing accelerator systems have the withstand voltage of about a half of the conventional small-sized electrode, as shown in Fig. 9. Based on this result, a large-bore ceramic column and other components for the ITER NBI were designed. This represents a big contribution to various achievements, including success of sustaining 240kV (120% of the rated value of the ITER NBI for one stage) for one hour.

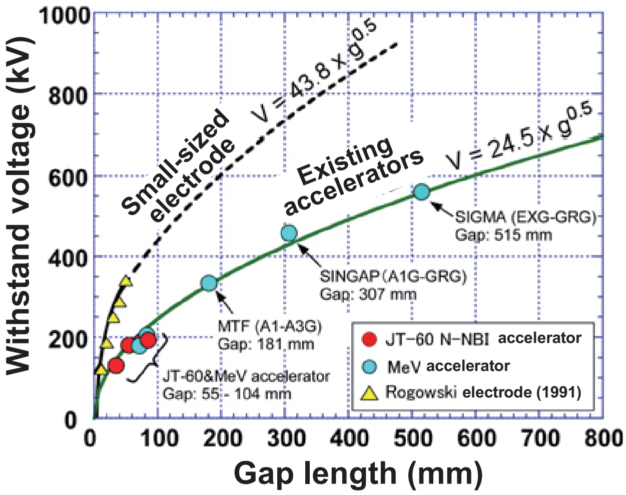

Fig. 9: Withstand voltage characteristics of the existing accelerator systems

4.3.6 Radio-Frequency Engineering

As research for enhancement of the radio-frequency engineering, research was made to increase the high-power millimeter-wave transmission efficiency. The main cause of decrease in the transmission efficiency of high-power millimeter-waves is high-order mode excitation which occurs when the gyrotron output is coupled to the transmission system; in order to restrict this excitation, a world's first mirror system with a remote & precision control mechanism using a ultrasonic motor was developed for the quasi-optical RF coupling circuit system (MOU), enabling mirror angle adjustment during output of radio-frequency waves. As a result, a world's first transmission system with propagating mode (HE11 mode) components of 95% has been successfully realized. Besides, gyrotron output of about 92% was transmitted over long distance, and it was confirmed that its radiation pattern was a gauss-type radio-frequency beam, as designed. The technology developed this time is applicable to all transmission systems for ECH, including the DEMO reactor for the future. Based on this result, Japan was assigned to procurement of MOU for ITER at the end of 2009, which was originally assigned to the USA.

＜Remarks＞

○ For the research on high-power millimeter wave radiation, the “Highest Award” was granted in the workshop of young researches in 2009 in Kita-Kanto branch of the Atomic Energy Society of Japan.

4.4 Study on Reactor Systems

Based on nuclear heat analysis, thermal hydraulic analysis and electromagnetic stress analysis, a concept of water-cooled solid breeder blanket with engineering feasibility has been explored for the SlimCS DEMO reactoe (Fig. 1). It was indicated that TBR’s design target of 1.05 would be satisfied by optimizing the detailed inside structure of each blanket module in accordance with the neutron wall load distribution in the poloidal direction. In addition, energy multiplication by the blanket was estimated, demonstrating that the thermal output is 3.84GW compared to the fusion output of 3 GW (multiplication rate of 1.28).

In order to make the reactor structure consistent with the blanket concept, a torus configuration of DEMO was considered in terms of tie-in with other in-vessel components, supporting structure, cooling pipe routing, and maintainability (Fig. 2).

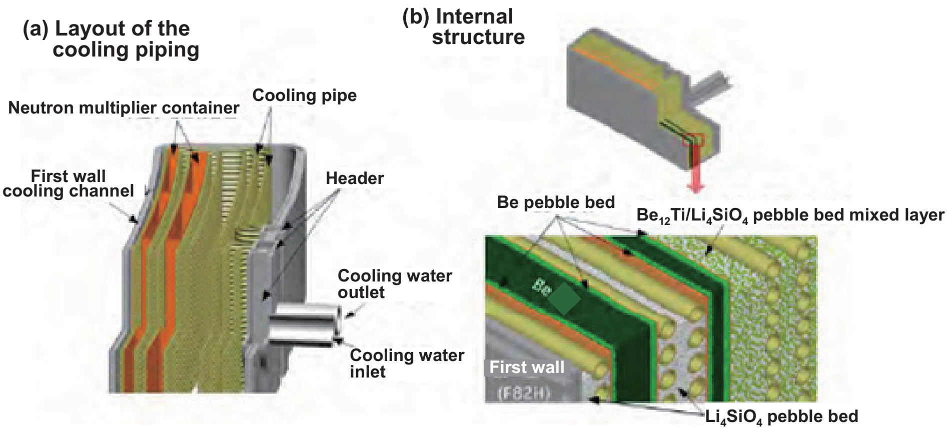

Fig. 1: Conceptual view of the water-cooled solid breeding blanket

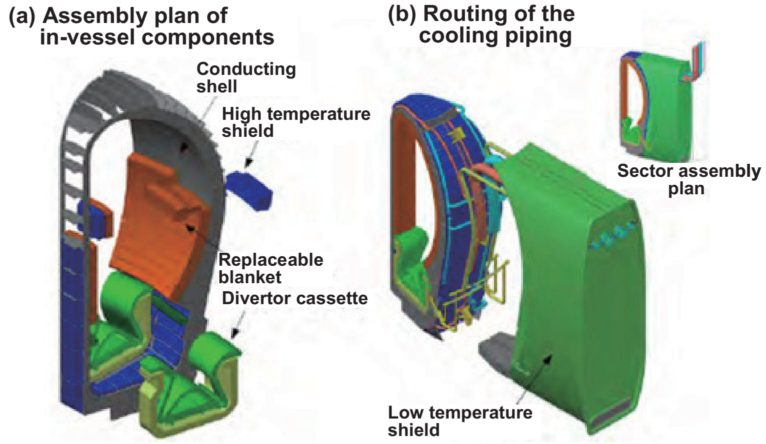

Fig. 2: Conceptual drawing of the reactor structure including the blanket

Appendix

A.1 Publication List (April 2009 – March 2010)

A.1.1 List of JAEA Report

1) (Eds.) Tanigawa, H., Enoeda, M., "Proceedings of the Fifteenth International Workshop on Ceramic Breeder Blanket Interactions - Sapporo, 3-4, September, 2009 -," JAEA-Conf 2009-006 (2010).

2) (Eds.) Tanigawa, H., Nozawa, T., Ando, M., "Summary Report of Joint Research in Japan on BA DEMO R&D Activity 2008 (Joint Research)," JAEA-Review 2009-053 (2010) (in Japanese).

3) Asakawa, S., Tsuchiya, K., Kuramochi, M., et al., "Structure Design of the Central Solenoid in JT-60SA," JAEA-Technology 2009-044 (2009) (in Japanese).

4) Division of Fusion Energy Technology, "Report on the Cooperating Researches Utilizing Fusion Engineering Facilities Completed in the Fiscal Year 2008 (Joint Research)," JAEA-Review 2009-032 (2009) (in Japanese).

5) Ohmori, J., Koizumi, N., Shimizu, T., et al., "Analytical Study of Cover Plate Welding Deformation of the Radial Plate of the ITER Toroidal Field Coil," JAEA-Technology 2009-046 (2009).

6) Taniguchi, M., Kashiwagi, M., Umeda, N., et al., "Comparative SINGAP-MAMuG Test for the ITER Neutral Beam Injector," JAEA-Research 2008-121 (2009) (in Japanese).

7) The JT-60 Team, "Review of JT-60U Experimental Results in 2007 and 2008," JAEA-Review 2009-045 (2010).

8) Totsuka, T., Sakata, S., "Conceptual Design of a New Supervisory Control System for JT-60SA," JAEA-Technology 2009-006 (2009) (in Japanese).

9) Uehara, K., "Momentum Transfer During Landau Damping and Radio Frequency Current Drive," JAEA-Research 2009-049 (2010).

10) Yoshikawa, A., Tanigawa, H., Seki, Y., et al., "Characteristics of Water Flow Distribution in TBM Side Wall," JAEA-Technology 2009-077 (2010) (in Japanese).

A.1.2 List of Papers Published in Journals

1) Agostini, P., Ida, M., Miccichè, G., et al., "Approach to the Lifetime Assessment of the Bayonet Back Plate for IFMIF Target," Fusion, Eng. Des., **84** 364 (2009).

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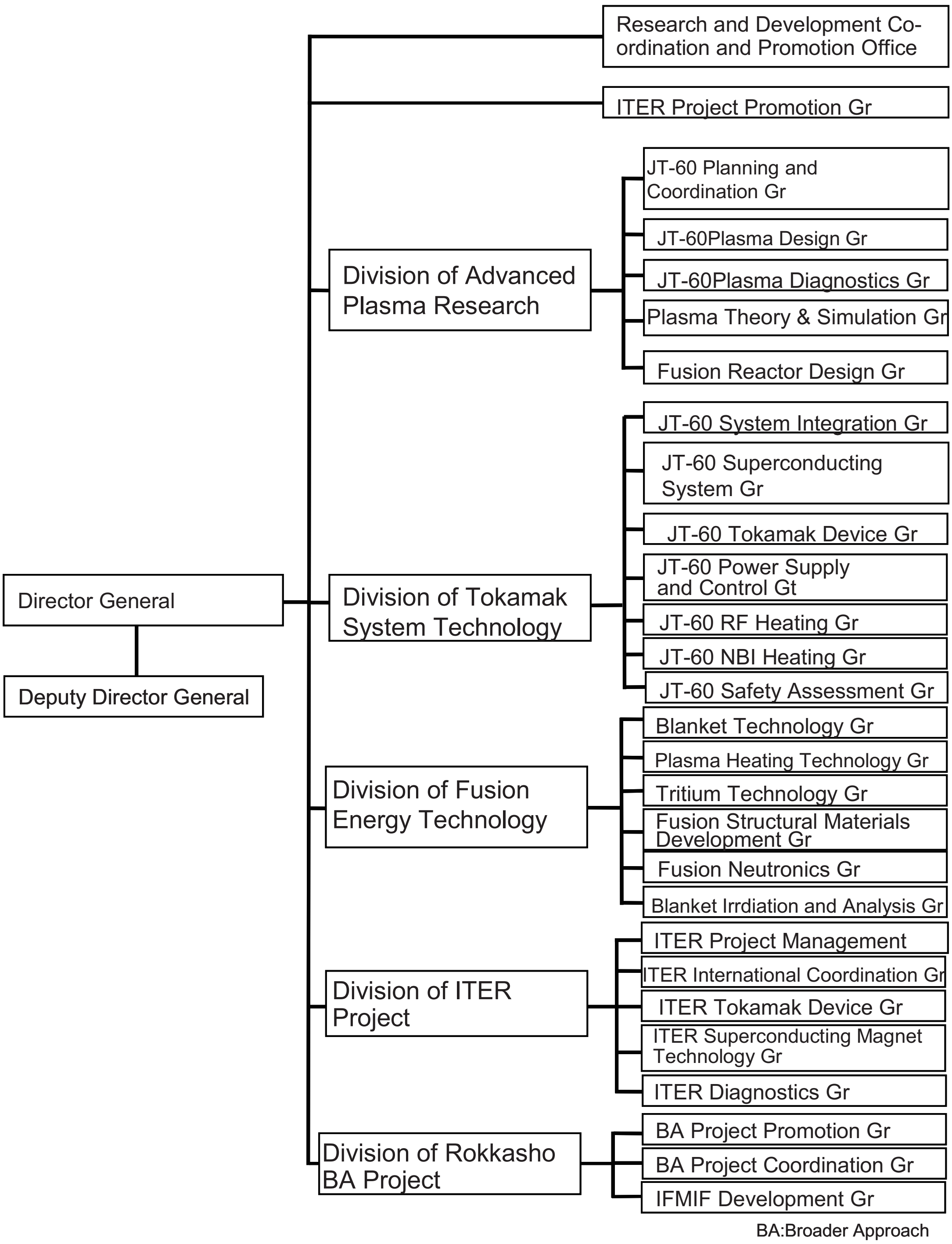
A.2 Organization of Fusion Research and Development Directorate



A.3 Personnel Data

A.3.1 Staff in Fusion Research and Development Directorate of JAEA [at 2010.3.31]

Fusion Research and Development Directorate

NINOMIYA Hiromasa	(Director General)
OKUMURA Yoshikazu	(Deputy Director General)
TAJIMA Yasuhide	(Deputy Director General)
TAKATSU Hideyuki	(Deputy Director General)
NISHI Masataka	(Deputy Director General)
KIKUCHI Mitsuru	(Supreme Researcher)
YOSHIDA Hidetoshi	(Principal Researcher)
NAGAMI Masayuki (*1)	
TSUNEMATSU Toshihide	(Invited Researcher)
SEKI Masahiro	(Invited Researcher)
SEKI Shogo	(Invited Researcher)
SHIMOMURA Yasuo	(Invited Researcher)
MATSUI Hideki	(Invited Researcher)
KOHYAMA Akira	(Invited Researcher)
IDA Katsumi	(Invited Researcher)
KISHIMOTO Yasuaki	(Invited Researcher)
KONOSHI Satoshi	(Invited Researcher)
HORIIKE Hiroshi	(Invited Researcher)
MATSUDA Shinzaburo	(Invited Researcher)
YAGI Masatoshi	(Invited Researcher)

Research and Development Co-ordination and Promotion Office

USHIGUSA Kenkichi	(General Manager)	
IIZUKA Koji	(Deputy General Manager)	
KASUGAI Atsushi	ISEI Nobuaki	KIMURA Shoko
KOYANAGI Daisaku	MATSUMOTO Hiroyuki	MORITA Hisao
NEMOTO Tetsuo	ONOZAKI Kazutoyo	SATO Yu
TSUCHIDA Tatsuro	MOCHIDA Kazumi	TANAKA Fumiyo
SATO Masaomi		

ITER Project Promotion Group

SHIRAI Hiroshi	(Group Leader)
OGAWA Toshihide	

Division of Advanced Plasma Research

MORI Masahiro	(Unit Manager)
OZEKI Takahisa	(Senior Principal Researcher)
TSUKAHARA Yoshimitsu	

JT-60 Planning and Coodination Group

KAMADA Yutaka	(Group Leader)	
KOIDE Yoshihiko	(Deputy Group Leader)	
OYAMA Naoyuki	HIGASHIJIMA Satoru	KIYONO Kimihiro

MATSUZAWA Yukihiro (*24)	SUZUKI Takashi (*25)	SEIMIYA Munetaka (*1)

JT-60 Plasma Design Group

OZEKI Takahisa	(Group Leader)	
IDE Shunske	SHIMIZU Katsuhiro	HAMAMATSU Kiyotaka
SUZUKI Takahiro	HAYASHI Nobuhiko	URANO Hajime
KAMATA Isao (*27)	SUZUKI Mitsuhiro (*33)	HONDA Mitsuru (*28)
HOSHINO Kazuo (*26)	TAKIZUKA Tomonori (*1)	

JT-60 Plasma Diagnostics Group

ITAMI Kiyoshi	(Group Leader)	
HATAE Takaki	KAMIYA Kensaku	SHINOHARA Kouji
SUNAOSHI Hidenori	KITAMURA Shigeru	CHIBA Shinichi
NAKANO Tomohide	YOSHIDA Maiko	MIYAMOTO Atsushi (*24)
NUMATA Hiroyuki (*25)	SAKUMA Takeshi (*25)	KOKUSEN Shigeharu (*24)
HAMANO Takashi (*25)	UEHARA Kazuya (*1)	HIRANO Yoichi (*1)
SAEKI Hisashi(*24)	FUKUMOTO Masakatsu (*26)	TOJO Hiroshi (*26)

Plasma Theory & Simulation Group

TOKUDA Shinji	(Group Leader)	
IDOMURA Yasuhiro	ISHII Yasutomo	MIYATO Naoaki
AIBA Nobuyuki (*28)	HIROTA Makoto (*28)	SHIRAISHI Junya (*26)
JOLLIET Sébastien(*26)		

Fusion Reactor Design Group

TOBITA Kenji	(Group Leader)	
ASAKURA Nobuyuki	NISHIO Satoshi	KURITA Gen-ichi
YOSHIDA Toru(*19)	LIU Changle(*12)	UTO Hiroyasu(*26)

Division of Tokamak System Technology

MORI Masahiro	(Unit Manager)
KURIHARA Kenichi	(Senior Principal Researcher)
IKEDA Yoshitaka	(Senior Principal Researcher)

JT-60 System Integration Group

SHIBANUMA Kiyoshi	(Group Leader)	
KUBO Hirotaka	(Deputy Group Leader)	
HOSHINO Katsumichi	KAWASHIMA Hisato	ARAI Takashi
OKANO Fuminori	NISHIYAMA Tomokazu	HOSHI Ryo (*6)
KOBAYASHI Kaoru (*6)	SATO Yoji (*24)	SAWAI Hiroaki(*32)

JT-60 Superconducting System Group

YOSHIDA Kiyoshi	(Group Leader)	
TSUCHIYA Katsuhiko	KIZU Kaname	KASHIWA Yoshitoshi
HONDA Atsushi	MURAKAMI Haruyuki	ASAKAWA Shuji (*3)
TAKENOUCHI Tadashi (*31)	KURAMOCHI Masaya (*33)	ICHIGE Toshikatsu (*33)
KAMIYA Koji (*28)	KOMEDA Masao(*21)	

JT-60 Tokamak Device Group

SAKASAI Akira	(Group Leader)	
MASAKI Kei	SAKURAI Shinji	TAKECHI Manabu
ICHIGE Hisashi	YAGYU Jun-ichi	MIYO Yasuhiko
KAMINAGA Atsushi	SASAJIMA Tadayuki	SHIBAMA Yusuke
HAYASHI Takao	MATSUNAGA Go	ISHIGE Youichi (*25)
MATSUMURA Hiroshi (*8)	MUROFUSHI Akira (*19)	KOMURO Kenichi (*24)
SUZUKI Hiroaki (*24)	OZAKI Hidetsugu (*22)	SHIMIZU Koichi(*24)
KATAYAMA Masahiro(*32)	MASUO Hiroshige（*22）	

JT-60 Power Supply and Control Group

MATSUKAWA Makoto	(Group Leader)	
NAITO Osamu	(Deputy Group Leader)	
TERAKADO Tsunehisa	OHMORI Yoshikazu	SHIMADA Katsuhiro
YAMAUCHI Kunihito	OKANO Jun	SHIBATA Kazuyuki (*25)
WADA Kazuhiko (*25)	KAMIKAWA Masaaki (*17)	SUZUKI Hiroshi (*24)
KAWAMATA Youichi	TOTSUKA Toshiyuki	AKASAKA Hiromi
SAKATA Shinya	SATO Minoru	SUEOKA Michiharu
SUGIMURA Toru (*30)	YAMAGUCHI Taiji (*14)	KOMINATO Toshiharu (*2)

JT-60 RF Heating Group

MORIYAMA Shinichi	(Group Leader)	
YOKOKURA Kenji	ISAYAMA Akihiko	SHIMONO Mitsugu
HASEGAWA Koichi	SAWAHATA Masayuki	SUZUKI Sadaaki
TERAKADO Masayuki	HIRANAI Shinichi	IGARASHI Koichi (*24)
SATO Fumiaki (*24)	WADA Kenji (*24)	SHIBAYAMA Minoru (*24)
KOBAYASHI Takayuki (*28)	HINATA Jun(*13)	

JT-60 NBI Heating Group

HANADA Masaya	(Group Leader)	
KAWAI Mikito	(Deputy Group Leader)	
OOASA Kazumi	AKINO Noboru	KAZAWA Minoru
KOMATA Masao	USUI Katsutomi	MOGAKI Kazuhiko
SASAKI Shunichi	KIKUCHI Katsumi (*25)	OSHIMA Katsumi (*24)
SEKI Norikatsu(*25)	SHIMIZU Tastuo (*24)	NEMOTO Shuji (*24)
ENDO Yasuei (*24)	KOJIMA Atsushi (*28)	TANAKA Yutaka(*26)
KUBO Naoya (*24)		

JT-60 Safety Assessment Group

MIYA Naoyuki	(Group Leader)
SUKEGAWA Atsuhiko	OIKAWA Akira (*1)

Division of Fusion Energy Technology

AKIBA Masato	(Unit Manager)
NISHITANI Takeo	(Senior Principal Researcher)

Blanket Technology Group

ENOEDA Mikio	(Group Leader)	
HOMMA Takashi (*1)	SUZUKI Satoshi	TANZAWA Sadamitsu
NISHI Hiroshi	SEKI Yohji	HIROSE Takanori
TANIGAWA Hisashi	TSURU Daigo	EZATO Koichiro
YOKOYAMA Kenji	YOSHIKAWA Akira (*26)	

Plasma Heating Group

SAKAMOTO Keishi	(Group Leader)	
INOUE Takashi	(Deputy Group Leader)	
WATANABE Kazuhiro	TANIGUCHI Masaki	YAMANAKA Haruhiko
KASHIWAGI Mieko	DAIRAKU Masayuki	UMEDA Naotaka
YAMAMOTO Masanori (*6)	TAKEMOTO Junpei (*17)	TOBARI Hiroyuki (*28)
TAKAHASHI Koji	IKEDA Yukiharu	NARUI Norio (*24)
HAYASHI Kazuo (*24)	KOMORI Shinji (*25)	KAJIWARA Ken (*28)
ODA Yasuhisa (*26)		

Tritium Technology Group

YAMANISHI Toshihiko	(Group Leader)	
HAYASHI Takumi	KAWAMURA Yoshinori	NAKAMURA Hirofumi
YAMADA Masayuki	SUZUKI Takumi	KOBAYASHI Kazuhiro
ISOBE Kanetsugu	IWAI Yasunori	HOSHI Shuichi (*25)
INOMIYA Hiroshi(*25)	ALIMOV Vladimir (*11)	SATO Katsumi (*24)
OYAIZU Makoto (*26)		

Fusion Structural Materials Development Group

TANIGAWA Hiroyasu	(Group Leader)	
ANDO Masami	NOZAWA Takashi	SAWAHATA Atsushi (*9)

Fusion Neutronics Group

KONNO Chikara	(Group Leader))	
SATO Satoshi	TANAKA Shigeru	OCHIAI Kentaro
ABE Yuichi	KUTSUKAKE Chuzo(*1)	KAWABE Masaru (*25)
OGINUMA Yoshikazu (*25)	TAKAKURA Kosuke (*24)	OHNISHI Seiki (*28)
KONDO Keitaro (*26)		

Blanket Irradiation and Analysis Group

NISHITANI Takeo	(Group Leader)	
NAKAMICHI Masaru	HOSHINO Tsuyoshi	HASEGAWA Teiji (*25)
OHTA Hiroyuki (*16)	OIKAWA Fumiaki (*16)	YONEHARA Kazuo (*16)

Division of ITER Project

YOSHINO Ryuji	(Unit Manager)
KOIZUMI Koichi	(Senior Principal Researcher)
OKUNO Kiyoshi	(Senior Principal Researcher)

ITER Project Management Group

SUGIMOTO Makoto	(Group Leader)	
NEYATANI Yuzuru	(Deputy Group Leader)	
KITAZAWA Siniti	OOHARA Hiroshi	YAGUCHI Eiji (*19)
Tod Tollefson (*24)	TAKAHASHI Go (*33)	SATO Koichi (*33)
IWAMA Yasushi (*24)	WAKEBE Takashi (*4)	

ITER International Coordination Group

SUGIMOTO Makoto	(Group Leader)	
ANDO Toshiro	(Deputy Group Leader)	
UENO Kenichi		

ITER Tokamak Device Group

KAKUDATE Satoshi	(Group Leader)	
TAKEDA Nobukazu	ABURADANI Atsushi	MATSUMOTO Yasuhiro (*32)
KOZAKA Hiroshi (*24)	NEGISHI Yusuke (*2)	

ITER Superconducting Magnet Technology Group

NAKAJIMA Hideo	(Group Leader)	
KOIZUMI Norikiyo	(Deputy Group Leader)	
TAKAHASHI Yoshikazu	ISONO Takaaki	KAWANO Katsumi
NUNOYA Yoshihiko	HAMADA Kazuya	MATSUI Kunihiro
NABARA Yoshihiro	HEMMI TSUTOMU	OSHIKIRI Masayuki (*25)
TAKANO Katsutoshi (*25)	TSUTSUMI Fumiaki (*33)	SHIMANE Hideo (*19)
CHIDA Yutaka(*18)	SHIMIZU Tatuya (*19)	YOSHIKAWA Masatoshi(*15)

ITER Diagnostics Group

KUSAMA Yoshinori	(Group Leader)	
OGAWA Hiroaki	SUGIE Tatsuo	KAWANO Yasunori
KONDOH Takashi	SATO Kazuyoshi	ISHIKAWA Masao (*28)
IWAMAE Atsushi (*28)	HAYASHI Toshimitsu (*23)	ONO Takehiro (*24)
YAMAMOTO Tsuyoshi (*14)	MIYAMOTO Seiji (*28)	TOSHIMITSU Shin-ichi (*1)
YATSUKA Eiichi (*26)		

Division of Rokkasho BA Project

KIMURA Haruyuki	(Unit Manager)

BA Project Promotion Group

YOSHIDA Hiroshi	(Group Leader)

BA Project Coordination Group

OHIRA Shigeru	(Group Leader)

IFMIF Development Group

KIMURA Haruyuki	(Group Leader)	
NAKAMURA Hiroo	(Deputy Group Leader)	
IDA Mizuho (*10)	MAEBARA Sunao	KIKUCHI Takayuki

KOJIMA Toshiyuki(*24)
YONEMOTO Kazuhiro(*17)
TSUTSUMI Kazumasa (*24)
KOGAWARA Takafumi (*5)
KUBO Takashi (*20)
SHINTO Katsuhiro(*28)
KONDO Hiroo
KASUYA Kenichi (*24)
MIYASHITA Makoto (*32)
TAKAHASHI Hiroki
NARITA Takahiro (*24)

A.3.2 Staff in ITER Organization and Project Teams of the Broader Approach Activities

ITER Organization

Office of Director-General

MATSUMOTO Hiroshi	(Head)

Office for Central Integration and Engineering

TADA Eisuke	(Head)
NAKAHIRA Masataka	

Department for Fusion Science & Technology

SHIMADA Michiya
OIKAWA Toshihiro

Department for Central Engineering & Plant Support

MARUYAMA So
SHU Wataru

Department for CODAC & IT, Heating & CD, Diagnostics

KIZAWA Shoko

Project Teams of the Broader Approach Activities

International Fusion Energy Research Center

ARAKI Masanori	(Project Leader)
HAYASHI Kimio	SAKAMOTO Yoshiteru

Satellite Tokamak Programme

ISHIDA Shinichi	(Project Leader)	
FUJITA Takaaki	SEKI Masami	OSHIMA Takayuki
SATO Masayasu	KAWASHIMA Hisato	

IFMIF EVEDA

SUGIMOTO Masayoshi	(Deputy Project Leader)	
NAKAMURA Kazuyuki	ASAHARA Hiroo (*24)	
OHTANI Keiji (*27)	YAMAMOTO Michiyoshi (*7)	UMENO Hideki (*4)
NISHIYAMA Koichi (*29)	FUJISHIRO Kouji (*28)	SHIDARA Hiroyuki (*28)
TAKEUCHI Hiroshi (*1)		

A.3.3 Collaborating Laboratories

Tokai Research and Development Center

Nuclear Science and Engineering Directorate

Irradiation Field Materials Research Group

JITSUKAWA Shiro	(Group Leader)	
FUJII Kimio	OKUBO Nariaki	TANIFUJI Takaaki
WAKAI Eiichi	YAMAKI Daiju	

Research Group for Corrosion Damage Mechanism

MIWA Yukio

Quantum Beam Science Directorate

Nanomaterials Synthesis Group

TAGUCHI Tomitsugu

Oarai Research and Development Center

Technology Development Department

MIYAKE Osamu (Director)

Advanced Liquid Metal Technology Experiment Section

HAYASHI Kenji (General Manager)

FURUKAWA Tomohiro

HIRAKAWA Yasushi

Advanced Nuclear System Research and Development Directorate

Innovative Technology Group

ARA Kuniaski (Group Leader)

OTAKE Masahiko

*1 Contract Staff
*2 Customer System Co., Ltd.
*3 Fuji Electric Co., Ltd.
*4 General Engineering Co. Ltd.
*5 GIC Corporation
*6 Hitachi, Ltd.
*7 Hitachi Automotive Systems, Ltd.
*8 Hitachi Engineering & Services Co., Ltd.
*9 Ibaraki University
*10 Ishikawajima-Harima Heavy Industries Co., Ltd.
*11 Institute of Physical Chemistry and Electrochemistry of the Russian Academy of Sciences
*12 Institute of Plasma Physics, Chinese Academy of Science
*13 Japan Advanced Systems, Inc.
*14 Japan EXpert Clone Corp.
*15 Japan Superconductor Technology Inc.
*16 KAKEN Co., Ltd.
*17 Kandenko Co., Ltd.
*18 Kawasaki Heavy Industries, Ltd.
*19 KCS Corporation
*20 Kumagai Gumi Co., Ltd.
*21 MAYEKAWA MFG. CO., LTD
*22 Metal Technology Co. Ltd.
*23 NEC Corporation
*24 Nippon Advanced Technology Co., Ltd.
*25 Nuclear Engineering Co., Ltd.
*26 Post-Doctoral Fellow
*27 Research Organization for Information Science & Technology
*28 Senior Post-Doctoral Fellow
*29 Shinsei High Tech Co. Ltd
*30 Systems Co., Ltd.
*31 Tomoe Shokai Co., Ltd.
*32 Toshiba Corporation
*33 Total Support Systems

国際単位系（SI）

表１．SI 基本単位

基本量	SI 基本単位	
	名称	記号
長さ	メートル	m
質量	キログラム	kg
時間	秒	s
電流	アンペア	A
熱力学温度	ケルビン	K
物質量	モル	mol
光度	カンデラ	cd

表２．基本単位を用いて表されるSI組立単位の例

組立量	SI 基本単位	
	名称	記号
面積	平方メートル	m^2
体積	立法メートル	m^3
速さ，速度	メートル毎秒	m/s
加速度	メートル毎秒毎秒	m/s^2
波数	毎メートル	m^{-1}
密度，質量密度	キログラム毎立方メートル	kg/m^3
面積密度	キログラム毎平方メートル	kg/m^2
比体積	立方メートル毎キログラム	m^3/kg
電流密度	アンペア毎平方メートル	A/m^2
磁界の強さ	アンペア毎メートル	A/m
量濃度(a)，濃度	モル毎立方メートル	mol/m^3
質量濃度	キログラム毎立法メートル	kg/m^3
輝度	カンデラ毎平方メートル	cd/m^2
屈折率(b)	（数字の）　1	1
比透磁率(b)	（数字の）　1	1

(a) 量濃度（amount concentration）は臨床化学の分野では物質濃度（substance concentration）ともよばれる。
(b) これらは無次元量あるいは次元１をもつ量であるが、そのことを表す単位記号である数字の１は通常は表記しない。

表３．固有の名称と記号で表されるSI組立単位

組立量	SI 組立単位			
	名称	記号	他のSI単位による表し方	SI基本単位による表し方
平面角	ラジアン(b)	rad	1 (b)	m/m
立体角	ステラジアン(b)	sr(c)	1 (b)	m^2/m^2
周波数	ヘルツ(d)	Hz		s^{-1}
力	ニュートン	N		m kg s^{-2}
圧力，応力	パスカル	Pa	N/m^2	m^{-1} kg s^{-2}
エネルギー，仕事，熱量	ジュール	J	N m	m^2 kg s^{-2}
仕事率，工率，放射束	ワット	W	J/s	m^2 kg s^{-3}
電荷，電気量	クーロン	C		s A
電位差（電圧），起電力	ボルト	V	W/A	m^2 kg s^{-3} A^{-1}
静電容量	ファラド	F	C/V	m^{-2} kg^{-1} s^4 A^2
電気抵抗	オーム	Ω	V/A	m^2 kg s^{-3} A^{-2}
コンダクタンス	ジーメンス	S	A/V	m^{-2} kg^{-1} s^3 A^2
磁束	ウエーバ	Wb	Vs	m^2 kg s^{-2} A^{-1}
磁束密度	テスラ	T	Wb/m^2	kg s^{-2} A^{-1}
インダクタンス	ヘンリー	H	Wb/A	m^2 kg s^{-2} A^{-2}
セルシウス温度	セルシウス度(e)	℃		K
光束	ルーメン	lm	cd sr(c)	cd
照度	ルクス	lx	lm/m^2	m^{-2} cd
放射性核種の放射能(f)	ベクレル(d)	Bq		s^{-1}
吸収線量, 比エネルギー分与, カーマ	グレイ	Gy	J/kg	m^2 s^{-2}
線量当量, 周辺線量当量, 方向性線量当量, 個人線量当量	シーベルト(g)	Sv	J/kg	m^2 s^{-2}
酸素活性	カタール	kat		s^{-1} mol

(a)SI接頭語は固有の名称と記号を持つ組立単位と組み合わせても使用できる。しかし接頭語を付した単位はもはやコヒーレントではない。
(b)ラジアンとステラジアンは数字の１に対する単位の特別な名称で、量についての情報をつたえるために使われる。実際には、使用する時には記号rad及びsrが用いられるが、習慣として組立単位としての記号である数字の１は明示されない。
(c)測光学ではステラジアンという名称と記号srを単位の表し方の中に、そのまま維持している。
(d)ヘルツは周期現象についてのみ、ベクレルは放射性核種の統計的過程についてのみ使用される。
(e)セルシウス度はケルビンの特別な名称で、セルシウス温度を表すために使用される。セルシウス度とケルビンの単位の大きさは同一である。したがって、温度差や温度間隔を表す数値はどちらの単位で表しても同じである。
(f)放射性核種の放射能（activity referred to a radionuclide）は、しばしば誤った用語で"radioactivity"と記される。
(g)単位シーベルト（PV,2002,70,205）についてはCIPM勧告2（CI-2002）を参照。

表４．単位の中に固有の名称と記号を含むSI組立単位の例

組立量	SI 組立単位		
	名称	記号	SI 基本単位による表し方
粘度	パスカル秒	Pa s	m^{-1} kg s^{-1}
力のモーメント	ニュートンメートル	N m	m^2 kg s^{-2}
表面張力	ニュートン毎メートル	N/m	kg s^{-2}
角速度	ラジアン毎秒	rad/s	m m^{-1} s^{-1}=s^{-1}
角加速度	ラジアン毎秒毎秒	rad/s^2	m m^{-1} s^{-2}=s^{-2}
熱流密度，放射照度	ワット毎平方メートル	W/m^2	kg s^{-3}
熱容量，エントロピー	ジュール毎ケルビン	J/K	m^2 kg s^{-2} K^{-1}
比熱容量，比エントロピー	ジュール毎キログラム毎ケルビン	J/(kg K)	m^2 s^{-2} K^{-1}
比エネルギー	ジュール毎キログラム	J/kg	m^2 s^{-2}
熱伝導率	ワット毎メートル毎ケルビン	W/(m K)	m kg s^{-3} K^{-1}
体積エネルギー	ジュール毎立方メートル	J/m^3	m^{-1} kg s^{-2}
電界の強さ	ボルト毎メートル	V/m	m kg s^{-3} A^{-1}
電荷密度	クーロン毎立方メートル	C/m^3	m^{-3} sA
表面電荷	クーロン毎平方メートル	C/m^2	m^{-2} sA
電束密度，電気変位	クーロン毎平方メートル	C/m^2	m^{-2} sA
誘電率	ファラド毎メートル	F/m	m^{-3} kg^{-1} s^4 A^2
透磁率	ヘンリー毎メートル	H/m	m kg s^{-2} A^{-2}
モルエネルギー	ジュール毎モル	J/mol	m^2 kg s^{-2} mol^{-1}
モルエントロピー, モル熱容量	ジュール毎モル毎ケルビン	J/(mol K)	m^2 kg s^{-2} K^{-1} mol^{-1}
照射線量（Ｘ線及びγ線）	クーロン毎キログラム	C/kg	kg^{-1} sA
吸収線量率	グレイ毎秒	Gy/s	m^2 s^{-3}
放射強度	ワット毎ステラジアン	W/sr	m^4 m^{-2} kg s^{-3}=m^2 kg s^{-3}
放射輝度	ワット毎平方メートル毎ステラジアン	W/(m^2 sr)	m^2 m^{-2} kg s^{-3}=kg s^{-3}
酵素活性濃度	カタール毎立方メートル	kat/m^3	m^{-3} s^{-1} mol

表５．SI 接頭語

乗数	接頭語	記号	乗数	接頭語	記号
10^{24}	ヨタ	Y	10^{-1}	デシ	d
10^{21}	ゼタ	Z	10^{-2}	センチ	c
10^{18}	エクサ	E	10^{-3}	ミリ	m
10^{15}	ペタ	P	10^{-6}	マイクロ	µ
10^{12}	テラ	T	10^{-9}	ナノ	n
10^{9}	ギガ	G	10^{-12}	ピコ	p
10^{6}	メガ	M	10^{-15}	フェムト	f
10^{3}	キロ	k	10^{-18}	アト	a
10^{2}	ヘクト	h	10^{-21}	ゼプト	z
10^{1}	デカ	da	10^{-24}	ヨクト	y

表６．SIに属さないが、SIと併用される単位

名称	記号	SI 単位による値
分	min	1 min=60s
時	h	1h =60 min=3600 s
日	d	1 d=24 h=86 400 s
度	°	1°=(π/180) rad
分	’	1’=(1/60)°=(π/10800) rad
秒	”	1”=(1/60)’=(π/648000) rad
ヘクタール	ha	1ha=1hm^2=10^{4}m^2
リットル	L，l	1L=1l=1dm^3=10^{3}cm^3=10^{-3}m^3
トン	t	1t=10^3 kg

表７．SIに属さないが、SIと併用される単位で、SI単位で表される数値が実験的に得られるもの

名称	記号	SI 単位で表される数値
電子ボルト	eV	1eV=1.602 176 53(14)×10^{-19}J
ダルトン	Da	1Da=1.660 538 86(28)×10^{-27}kg
統一原子質量単位	u	1u=1 Da
天文単位	ua	1ua=1.495 978 706 91(6)×10^{11}m

表８．SIに属さないが、SIと併用されるその他の単位

名称	記号	SI 単位で表される数値
バール	bar	1 bar=0.1MPa=100kPa=10^{5}Pa
水銀柱ミリメートル	mmHg	1mmHg=133.322Pa
オングストローム	Å	1 Å=0.1nm=100pm=10^{-10}m
海里	M	1 M=1852m
バーン	b	1 b=100fm^2=(10^{-12}cm)2=10^{-28}m^2
ノット	kn	1 kn=(1852/3600)m/s
ネーパ	Np	SI単位との数値的な関係は、対数量の定義に依存。
ベル	B	
デジベル	dB	

表９．固有の名称をもつCGS組立単位

名称	記号	SI 単位で表される数値
エルグ	erg	1 erg=10^{-7} J
ダイン	dyn	1 dyn=10^{-5}N
ポアズ	P	1 P=1 dyn s cm^{-2}=0.1Pa s
ストークス	St	1 St =1cm^2 s^{-1}=10^{-4}m^2 s^{-1}
スチルブ	sb	1 sb =1cd cm^{-2}=10^{4}cd m^{-2}
フォト	ph	1 ph=1cd sr cm^{-2} 10^{4}lx
ガル	Gal	1 Gal =1cm s^{-2}=10^{-2}ms^{-2}
マクスウェル	Mx	1 Mx = 1G cm^2=10^{-8}Wb
ガウス	G	1 G =1Mx cm^{-2} =10^{-4}T
エルステッド(c)	Oe	1 Oe ≙ (10^3/4π)A m^{-1}

(c) ３元系のCGS単位系とSIでは直接比較できないため、等号「 ≙ 」は対応関係を示すものである。

表10．SIに属さないその他の単位の例

名称	記号	SI 単位で表される数値
キュリー	Ci	1 Ci=3.7×10^{10}Bq
レントゲン	R	1 R = 2.58×10^{-4}C/kg
ラド	rad	1 rad=1cGy=10^{-2}Gy
レム	rem	1 rem=1 cSv=10^{-2}Sv
ガンマ	γ	1 γ =1 nT=10-9T
フェルミ		1フェルミ=1 fm=10-15m
メートル系カラット		1メートル系カラット = 200 mg = 2×10-4kg
トル	Torr	1 Torr = (101 325/760) Pa
標準大気圧	atm	1 atm = 101 325 Pa
カロリー	cal	1cal=4.1858J（｢15℃｣カロリー），4.1868J（｢IT｣カロリー）4.184J（｢熱化学｣カロリー）
ミクロン	µ	1 µ =1µm=10^{-6}m

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