National Institutes of Natural Sciences

National Institute for Fusion Science

Peer Review Reports for FY2017

March, 2018

National Institute for Fusion Science

Advisory Committee External Peer Review Committee

Contents

Chapter 1 Background

The National Institute for Fusion Science (below as NIFS) was established in 1989 as an inter-university research institute, and utilizes the Large Helical Device (below as LHD) as the principal device to advance fusion research in universities in Japan.

The LHD, which was planned by bearing the support and the expectations of the fusion community, has the special characteristic of producing the heliotron-type magnetic field, which is an idea unique to Japan. In addition to generating high-performance helical-type plasma through high-power heating, NIFS is advancing with experimental research that aims to clarify physical and technological issues for realizing the magnetic field confinement fusion reactor. On the other hand, parallel with this, in analyses of fusion plasmas having fundamental complexities, theoretical research that uses large-scale simulations is essential. For that reason, a supercomputer for exclusive use was introduced at NIFS. We are advancing with leading-edge research by making this supercomputer at NIFS available for use to fusion theory researchers in Japan through collaborative research. Moreover, since 2010, in order to further strengthen the centripetal power of NIFS as a Center of Excellence (below as COE) in the field of plasma fusion research we have organized three research projects, these being LHD, theory and simulation, and reactor engineering.

Further, looking toward achieving the fusion reactor, we have initiated research project that will integrate these research results. In addition to having revised the research structure within NIFS and having placed all research staff in one research department, by establishing a research system that enables participation by free will in research projects and has enabled easier cooperation in the three projects of LHD, theory and simulation, and reactor engineering than in the past, we are increasingly able to respond resourcefully to new topics.

In this period, there have been changes to the structure of the domestic academic research system. Since 2004, NIFS has been a research institute under the Inter-University Research Institute Corporation National Institutes of Natural Sciences (below as NINS). Upon becoming an inter-university research institute corporation, a system for mid-term goals and mid-term planning spanning six years was introduced, and a system of annual evaluations regarding the progress, too, was introduced. This annual evaluation focuses primarily upon administrative management. However, at NIFS it has been determined that receiving external evaluations of research results is important. Under the NIFS Advisory Committee, each year an External Peer Review Committee is organized and the members evaluate the research. The topics of evaluation are determined by the Advisory

Committee. The evaluation is undertaken by the members of the External Peer Review Committee, which is composed of experts who are external members of the Advisory Committee and external experts who are appropriate for evaluating the topics. The External Evaluation Committee submits its evaluation results to the Advisory Committee. Then, NIFS, together with making the results public by uploading that information to the NIFS homepage, utilizes this information to improve research activities in the following years.

The topics for evaluation for the External Peer Review Committee are discussed and decided upon by the Advisory Committee, and those topics for evaluation differ each year. Most recently, in 2014 the Deuterium Experiment Implementation Planning, in 2015 the Numerical Simulation Reactor Research Project, and in 2016 Collaborative Research were topics evaluated by external reviewers. This year, 2017, the "Fusion Engineering Research Project" was selected and reviewed by the external examiners.

As external members of the External Peer Review Committee there were ten external members from the Advisory Committee and three members from foreign countries. Further, here were three experts from outside NIFS and one expert from abroad. Thus was the External Peer Review Committee composed, and thereby the evaluation was undertaken

The first meeting of the External Peer Review Committee including the Experts' Committee was convened on October 20, 2017. The Committee discussed the process for moving forward with this fiscal year's external peer review, and decided upon the perspective of the evaluation. On December 2, 2017, the second meeting of the External Peer Review Committee and the Experts' Committee was held. From NIFS was provided a detailed explanation that utilized documents from the material of viewgraphs and reports based on the perspectives (see the documents section). A question-and-answer section also was held. Subsequently, the third meeting of the External Peer Review Committee and the Experts' Committee was held on February 2, 2018. Together with holding another question and answer session with NIFS, evaluation work based on the topics of the evaluation and the coordination of the evaluation work were undertaken. We compiled the external peer review report (draft) based upon the discussion to this point and further discussions were held by electronic mail. Upon confirmation and examination by the External Peer Review Committee and the Experts' Committee, we compiled the final report. Please see Reference Material 4 for the meeting schedule of the External Peer Review Committee and the Experts' Committee.

Moreover, the perspectives for the evaluation of "Fusion Engineering Research Project," which is the title of this year's topic, are considered indispensable in the evaluation of the "Fusion Engineering Research Project" promoted by NIFS which NINS decided upon in the mid-term planning. These perspectives are the basis of the evaluation of achievements and the evaluation of the level of research.

Further, based upon the proposal that was implemented in the External Peer Review Report of "Fusion Engineering Research Project" in 2013, we have consulted the following points in the evaluation.

1. In fulfilling the role as a Center of Excellence (COE) in basic technology development in the field of fusion engineering, is there a deepening of the academic systemization of leading-edge technologies developed there as engineering?
2. Aiming at developing young researchers who will lead the world, is NIFS constructing frameworks that will extend human resources and realize improvement in quality with universities and research institutes?
3. Is NIFS advancing effective management by the introduction of large-scale equipment and test facilities, the maintenance of the research environment based upon the arrangement of staff and increase in staff, and the construction of maintenance and management systems?
4. Is NIFS contributing to the construction of fusion specifications and standards by integrating and making databases of results and knowledge?

The perspectives for the "Fusion Engineering Research Project" evaluation are as below.

1. Design Study on the Helical Fusion Reactor

(1) Whether or not the Fusion Engineering Research Project (below as FERP) has shown continued progress on upgrading and refinement of the helical reactor design study (From the second mid-term plan)

(2) Whether or not the FERP has summarized the conceptual design study of the helical fusion reactor and embodied the numerical targets for each development issue (From the third mid-term plan)

(3) Whether or not the design study of the helical fusion reactor and the R&D activities of the major components are closely related to each other (From the third mid-term plan)

2. R&D Study on the Fusion Technology Basis

(1) Whether or not the FERP has served as a COE dedicated for the fusion technology development (From the second mid-term plan)
(2) Whether or not the FERP is enhancing interdisciplinary researches to strengthen the basis of the fusion engineering study (From the second mid-term plan)
(3) Whether or not the FERP is improving the facilities for the fusion engineering study and enhancing the joint-use and collaboration (From the second and third mid-term plans)
(4) Whether or not the FERP is enhancing the collaboration research by utilizing the frameworks of “Bilateral Collaboration Research” and “LHD Project Collaboration Research” (From the second mid-term plan)
(5) Whether or not the FERP has served as a COE to contribute to the international activities including ITER and BA, jointly with universities (From the second mid-term plan)
(6) Whether or not the FERP is providing distinctive education in the field of fusion engineering research, taking advantage of the function as an inter-university research institute (From the second mid-term plan)
(7) Whether or not the FERP has been closely cooperating with foreign institutions by enhancing researcher exchange and collaboration based on the international agreements (From the second mid-term plan)
(8) Whether or not FERP has contributed to creating research results from universities (From the third mid-term plan)

Chapter 2 Summary of the Evaluation, and Proposals

Based upon the opinions and the discussions at the meetings of the External Peer Review Committee and Experts' Committee, we summarize the important points of the evaluation, and we report in writing the proposal regarding promotion of the Fusion Engineering Research Project.

[1] Summary of the Evaluation

1. Design Study on the Helical Fusion Reactor

(1) Whether or not the FERP has shown continued progress on upgrading and refinement of the helical reactor design study

Maintenance and cost evaluations, as well as analyses that employed simulations, have been continuously undertaken. Not only are improvements and refinement of the helical-type fusion reactor design being planned, so too are settings of challenging issues being undertaken, and these are highly evaluated. Further, that reactor designs are consolidated to a couple of designs by presenting fundamental structural conditions and usage conditions can be evaluated.

On the other hand, regarding the method of separating Basic and Challenging, some appreciation may be anticipated. However, it is necessary to clarify the full image through consideration of feasibility and priority. Clearly expressing the engineering feasibility of the fundamental designs based on the academic and engineering knowledge that has been achieved to date, further it is sought to identify challenging issues. Moreover, it will be necessary from now to identify differences in the consideration level, overlapping issues with, and different issues from DEMO reactor designs that are being advanced through current tokamak devices.

(2) Whether or not the FERP has summarized the conceptual design study of the helical fusion reactor and embodied the numerical targets for each development issue

That the development goals for each component are being quantified to the extent possible is useful for grasping conditions in the advancement of research, and is highly evaluated.

On the other hand, the meaning of the numerical goals, the degree of importance of this topic, the complementary relevance across research topics, the prioritization, and the characterization are not clear. From now, strategic endeavors are anticipated. Linked to conceptual designs, the refinement of each topic should be considered further. And for the above reason, it is necessary that there be a revision of the understanding of Basic and Challenging and of numerical goals. In addition, it is anticipated that there will be a clarification of the approach to "As an overall design, how will optimal integration be achieved?" Regarding the degree of the possibility of achieving the numerical goal and the overall balance, a semi-quantitative evaluation also is believed to be necessary.

(3) Whether or not the design study of the helical fusion reactor and the R&D activities of the major components are closely related to each other

Centered on the development of the high-temperature superconductor coils, the blanket, and divertor, well-balanced interlocking between design and developmental research is highly evaluated. Further, the topics of development research issues related to ambitious designs, too, are being treated. That results are visible can be evaluated.

On the other hand, in the helical fusion reactor design, not only Challenging issues, but also issues to be developed that have high commonalities with the tokamak and should be breakthrough topics being strongly linked to the Action Plan remain. For that reason, paying attention to research development in Basic topics it is important to indicate the strategy in which importance of research development including numerical goals should be clarified and the competitiveness of priorities in the development research should be indicated. Further, it also is important to indicate the relationship between the goals expressed by the reactor design and R&D items, and to express feedback to the reactor design. Further, it is necessary to raise the strategic roadmap which includes the development of devices and "the time schedule."

2. R&D Study on the Fusion Technology Basis

(1) Whether or not the FERP has served as a COE dedicated for the fusion technology development

Research concerning important fundamental technologies in the fusion engineering field is being conducted organically in effective collaborative relationships with universities, and NIFS, as a COE focused on this field, is satisfactorily fulfilling its roles.

Further, that NIFS is utilizing hardware actively as a common resource of the fusion community can be evaluated extremely highly. Further, as a hub for exchanging information with domestic and international research organizations by reporting domestic and international meeting results and by hosting IAEA meetings, NIFS is accumulating a superlative result.

On the other hand, in addition to technology related to the helical reactor, we anticipate NIFS' roles as a basic technology development COE in broad aspects of fusion engineering including other reactor types, being based upon the action plan issued by the MEXT. Also, it is hoped that there will be appeals for advancement by indicating overall development strategies for each of the principal engineering technology fields or for each of the instruments to be developed. Moreover, we also wish NIFS to examine numerical data regarding how each instrument is utilized and how many academic articles are published by each researcher that include open journals.

(2) Whether or not the FERP is enhancing interdisciplinary researches to strengthen the basis of the fusion engineering study

Expanding research horizontally in the interdisciplinary field, and achieving important results, NIFS is highly evaluated. Further, providing the superlative facilities and equipment that have been obtained and prepared as an inter-university research institute as platforms for broad-ranging engineering research, and promoting development of collaborative research with companies under the idea of "revolutionary energy circulation engineering," NIFS can be evaluated.

On the other hand, from the point of view of the expansion of research in interdisciplinary fields, there are limits. In the future, we hope that NIFS aims at generalizing toward the engineering basis founded upon technical advances and making contribution to academic systemization at the research level that will lead other fields. Further, in order to advance further in research expansion in interdisciplinary fields, in the future, we anticipate endeavors that will utilize the delivery of information toward outside research fields and that utilize the URA system. Further, regarding how interdisciplinary research is conducted, as it does not necessarily move in a direction of academic creation, it may be thought beneficial to examine approaches for pioneering transdisciplinary fields based upon the requests of society.

(3) Whether or not the FERP is improving the facilities for the fusion engineering study and enhancing the joint-use and collaboration

As preparation and expansion of the engineering experiment equipment, we can highly evaluate that the introduction of transmission electron microscope, of the high-heat flux electron beam irradiation experimental device ACT 2, and of the superconductor coil experimental devices is being affixed to the NIFS experimental device, and these are being utilized for joint use and collaborative research, and that research results are steadily being achieved. One example of this at NIFS is the JT-60SA superconductor center solenoid coils experiment.

On the other hand, so as to not increase the burden upon NIFS researchers, and to improve further the convenience to researchers through maintenance and management of such equipment, it is essential to ensure the technical staff who manage the equipment. Further, in the future, if there are plans for the enhancement of related machinery and long-term management of machinery, upon setting goals and targets it is hoped that there will be examination of the machinery plan including the appointment of staff. For that reason, discussion based upon each machine's usage conditions and data regarding research results will be expected. Together, as the core of the next engineering device development which aims towards the future fusion reactor, in order for more effective management of collaborative use and collaborative research by use of leading-edge equipment, further information disseminated to the research community is anticipated.

(4) Whether or not the FERP is enhancing the collaboration research by utilizing the frameworks of "Bilateral Collaboration Research" and "LHD Project Collaboration Research"

Through bilateral collaboration research, with links to Toyama University, University of Tsukuba, Kyushu University, and other universities, the collaborative research base regarding reactor research has been expanded. With links to generating results, we can highly evaluate the contributions that will surely strengthen the functions of universities such as utilization of distinctive equipment and facility at research institution of core universities. Further, regarding LHD Project Collaboration Research, the temperature-elevated desorption spectrum diagnostic device, plasma irradiation device development, advanced materials testing research, evaluation of tritium's effects upon the living human body, blanket, divertor, and other topics in fusion engineering are implemented as collaborative research, and results are emerging. Together with Bilateral Collaboration Research and LHD Project Collaboration Research, through promotion of linkages with laboratories at universities for the reactor engineering field endeavoring to expand collaborative research is highly evaluated. From now, further expansion of Bilateral Collaboration Research such as the re-introduction of university-affiliated research centers that is to become the research basis is expected. The established policy for collaborative research themes that reflects the characteristics of the fusion reactor research project and of each center, and how the research results evolve from the collaborative research system, too, should be considered.

(5) Whether or not the FERP has served as a COE to contribute to the international activities including ITER and BA, jointly with universities

As contributions to international projects under the coordination and cooperation system with universities, the projects such as the superconductor coil test experiments conducted on ITER and on JT-60SA, the collaborative research on ITER for the low temperature systems and the neutral particle injection device, the BA activities on JT-60SA, the DEMO development research at IFERC, the collaborative research on IFMIF-EVEDA, heating device development, enhancement of database on plasma-facing materials and atoms and molecules, are numerous, and this is highly evaluated. Further, in deciding the action plan regarding DEMO reactor design by the joint-core team, implementing important contributions under cooperation with universities by participating as a COE for this field is highly evaluated.

Further, the contribution to the ITER and BA activities is a matter of course, and in composing the action plan aiming toward the tokamak DEMO reactor NIFS is anticipated to show the strategy, that is, in what direction is fusion research at universities in Japan being guided, from a higher perspective as a COE including also NIFS' organizational contributions.

(6) Whether or not the FERP is providing distinctive education in the field of fusion engineering research, taking advantage of the function as an inter-university research institute

Utilizing NIFS' facilities for fusion research under collaborative use and collaborative research with universities, we can highly evaluate that excellent educational opportunities are being provided at universities for the purpose of advancing education and real-world education, and these results are linked to numerous academic papers and theses of graduate students, leading to producing results. Further, at Sokendai (The Graduate University for Advanced Studies), NIFS is advancing with the development of doctoral course graduate students, and through enrolling graduate students entrusted from universities as an inter-university research institute, enhancing coordinated graduate schools and summer school programs, NIFS contributes to the distinctive education in the plasma and fusion fields.

On the other hand, the number of doctoral degrees issued is not many. Further, it cannot be said that a unique education in the field of fusion reactor engineering is being undertaken in an organized style. In the future, together with links to universities and other facilities, we anticipate a leading role that NIFS can do precisely to be fulfilled. For that reason, it is necessary to advance our efforts in the participation of students in research utilizing leading-edge devices, in relationships and linkages between Sokendai and other universities, and in securing excellent human resources.

(7) Whether or not the FERP has been closely cooperating with foreign institutions by enhancing researcher exchange and collaboration based on the international agreements

Based upon international cooperation agreements, the Japan-United States cooperative program projects such as TITAN and PHENIX, and Japan-China and Japan-Republic of Korea programs such as the Post-CUP and the A3 Foresight programs have been implemented. Further, functioning as a core institute for collaborative research under the international coordination such as the IEA-sponsored stellarator/heliotron agreement and the PWI agreement, and the research projects and workshops coordinated by IAEA, NIFS is advancing close collaborative research linkages with overseas researchers. This is highly evaluated. Further, NIFS is fulfilling functions as a COE that manages and implements international collaborative research. In the future, we anticipate consideration on future programs, the clarification of these programs being all-Japan programs, and the further progress of international collaborative research.

(8) Whether or not FERP has contributed to creating research results from universities

Through Bilateral Collaboration Research, LHD Project Collaboration Research, General Collaboration Research, collaborative use of fusion reactor engineering equipment, and cooperative research activities with foreign countries such as the Japan-US cooperation program, numerous articles by university researchers have been published. And international articles and awards have been published and received, respectively, on plasma engineering and fusion reactor engineering research. Further, research funding related to this research is not only contributing significantly to the research results from universities but also to education. These are highly evaluated.

On the other hand, even after the enhancement of the engineering experimental equipment, the number of related research articles changed little. Further, there is concern that the number of doctoral degrees at universities is fewer. In addition, because the contributions towards strengthening the functions of universities from an inter-university research institute will become all the more significant, it will be necessary to continuously and systematically collect high-quality verifiable data objectively regarding this issue. At that time, not only factual data, we anticipate that the strategy and standing as the inter-university research institute will be clarified further.

[2] Proposals

In the current evaluation, we discussed the Fusion Engineering Research Project at NIFS. Based upon the contents of that discussion, below we offer our proposal regarding the future direction of the Fusion Engineering Research Project.

(1) Regarding the improvement and the refinement of the helical-type fusion reactor design, we anticipate clarification of the full image that will consider the realization and the priority of the methods, and also clarification of the comparison with the DEMO reactor design of the tokamak-type being forwarded.

(2) While strongly linking the conceptual design and the developmental research for the core devices and instruments, the meaning of the numerical goals, the significance of the topics, the complementary relationships among topics, and the degree of priority and standing should be clarified and a still more strategic effort is anticipated.

(3) In the enhancement and expansion of the fusion reactor engineering experimental equipment, for developing the Fusion Engineering Research Project and the collaborative research, as well as for increasing accessibility to users including graduate students, the enhancement plans that include staffing as well as the goals should be made concrete.

(4) We anticipate the construction of an education system that leads to graduate education and creation of career paths based upon cross-cutting and interdisciplinary links to universities and research institutes, for aiming at nurturing human resources for a future in fusion reactor development research in addition to assisting continuously with producing research results from universities, through collaborative use and collaborative research beginning with Bilateral Collaboration Research and LHD Project Collaboration Research.

(5) We anticipate that displaying views of the direction and the strategy from a higher perspective regarding fusion research in Japanese universities as an inter-university research institute, NIFS plays the role of a COE for basic technology development in the entire field of fusion engineering including other types such as ITER and BA activities, the Action Plan of MEXT that aims toward the DEMO reactor.

Chapter 3 In Closing

In order to strengthen further the centripetal force of the COE in the Plasma-Nuclear Fusion field, at NIFS from 2010 (Heisei 22), we constructed the three projects of LHD, theory and simulation, and fusion engineering aiming at realizing the fusion reactor, we have initiated research planning by unifying these results. Moreover, the research structure at NIFS was reorganized and all academic researchers have now been placed in one research department. They may now participate in any or all of the three research projects by free will. Due to this, we anticipate the promotion of links with LHD, theory and simulation, and fusion engineering, and we anticipate being able to respond resourcefully to new topics.

In the NIFS External Peer Review Committee review, in 2014 (Heisei 26) the implementation of the LHD deuterium experiment, in 2015 (Heisei 27) the Numerical Simulation Reactor Research Project, and in 2016 (Heisei 28) the Collaborative Research, were evaluated. Thus, in this current year of 2018 (Heisei 30) the Advisory Committee undertook an external evaluation that focused on “The Fusion Engineering Research Project.” The External Peer Review Committee was composed of ten members of the Advisory Committee outside of NIFS and three members from abroad, further, three members outside of NIFS, and one member from abroad as the Experts’ Committee. The points below were evaluated.

1. Design Study on the Helical Fusion Reactor

(1) Whether or not the FERP has shown continued progress on upgrading and refinement of the helical reactor design study (From the second mid-term plan)

(2) Whether or not the FERP has summarized the conceptual design study of the helical fusion reactor and embodied the numerical targets for each development issue (From the third mid-term plan)

(3) Whether or not the design study of the helical fusion reactor and the R&D activities of the major components are closely related to each other (From the third mid-term plan)

2. R&D Study on the Fusion Technology Basis

(1) Whether or not the FERP has served as a COE dedicated for the fusion technology development (From the second mid-term plan)

(2) Whether or not the FERP is enhancing interdisciplinary researches to strengthen the basis of the fusion engineering study (From the second mid-term plan)

(3) Whether or not the FERP is improving the facilities for the fusion engineering study and enhancing the joint-use and collaboration (From the second and third mid-term plans)
(4) Whether or not the FERP is enhancing the collaboration research by utilizing the frameworks of “Bilateral Collaboration Research” and “LHD Project Collaboration Research” (From the second mid-term plan)
(5) Whether or not the FERP has served as a COE to contribute to the international activities including ITER and BA, jointly with universities (From the second mid-term plan)
(6) Whether or not the FERP is providing distinctive education in the field of fusion engineering research, taking advantage of the function as an inter-university research institute (From the second mid-term plan)
(7) Whether or not the FERP has been closely cooperating with foreign institutions by enhancing researcher exchange and collaboration based on the international agreements (From the second mid-term plan)
(8) Whether or not FERP has contributed to creating research results from universities (From the third mid-term plan)

The External Peer Review Committee was convened four times from October 2017 through February 2018 including e-mail discussion committee. Detailed explanations of the evaluation topics provided from NIFS and active discussions were held. The External Peer Review Committee members summarize evaluation results and submit this report.

As the result of the external evaluation of the “Fusion Engineering Research Project,” in general, a recommendation of a high evaluation was received. Further, regarding the evaluation points above, the points of playing the role of COE in basic technology development in the fusion engineering field, the points of advancing and expanding cooperative research through utilizing effectively the system of Bilateral Collaboration Research, LHD Project Collaboration Research, and the points of advancing cooperation through collaborative research and exchange of researchers with overseas research bases, are highly evaluated, and in the future, still further development is anticipated. Regarding sophistication and refinement of the helical-type fusion reactor design and fundamental research on fusion engineering, in general these are evaluated highly. However, regarding targeting the numerical goals of development topics, and the interlocking between reactor design research and fusion engineering basic research, additional efforts are required. Further, organic linkages are anticipated regarding the ITER and BA activities, and the

Action Plan of MEXT toward the DEMO reactor. The strengthening of linkages with developmental research beginning with ITER may be greatly anticipated to contribute toward academic systemization of the base of fusion engineering and expanding the broad areas of engineering fields. On the other hand, high-level collaborative use and collaborative research which utilized engineering experiment equipment expanded broadly in Heisei 24 (2012) was promoted. The strengthening of the hardware can be highly evaluated. However, regarding the software such as generalization and systemization of technological developments based upon the hardware toward interdisciplinary engineering research utilization for high-level specialized education, and further aiming at creating research results coordinated with universities, further activation is required in the future. However, for promoting this type of research and education it is crucial that not only NIFS but also the fusion engineering community including universities should advance as an integrated manner.

In conclusion, the proposal for future advancement of the NIFS Fusion Engineering Research Project is provided below.

(1) Regarding the improvement and the refinement of the helical-type fusion reactor design, we anticipate clarification of the full image that will consider the realization and the priority of the methods, and also clarification of the comparison with the DEMO reactor design of the tokamak-type being forwarded.

(2) While strongly linking the conceptual design and the developmental research for the core devices and instruments, the meaning of the numerical goals, the significance of the topics, the complementary relationships among topics, and the degree of priority and standing should be clarified and a still more strategic effort is anticipated.

(3) In the enhancement and expansion of the fusion reactor engineering experimental equipment, for developing the Fusion Engineering Research Project and the collaborative research, as well as for increasing accessibility to users including graduate students, the enhancement plans that include staffing as well as the goals should be made concrete.

(4) We anticipate the construction of an education system that leads to graduate education and creation of career paths based upon cross-cutting and interdisciplinary links to universities and research institutes, for aiming at nurturing human resources for a

future in fusion reactor development research in addition to assisting continuously with producing research results from universities, through collaborative use and collaborative research beginning with Bilateral Collaboration Research and LHD Project Collaboration Research.

(5) We anticipate that displaying views of the direction and the strategy from a higher perspective regarding fusion research in Japanese universities as an inter-university research institute, NIFS plays the role of a COE for basic technology development in the entire field of fusion reactor engineering including other types such as ITER and BA activities, the Action Plan of MEXT that aims toward the DEMO reactor.

Documents

1. 2017 External Peer Review Presentation Materials

2017 NIFS External Review (Nagoya, Dec. 2, 2017)

Fusion Engineering Research Project in NIFS

FY2013 - 2017

Prof. Takeo MUROGA

Executive Director of FERP (on Science)

Prof. Nagato YANAGI

Executive Director of FERP (on Device)

National Institute for Fusion Science

Evaluation Points for FERP

The External Peer Review Committee presented *three evaluation points for*

1. Design Study on the Helical Fusion Reactor

ヘリカル型核融合炉の設計研究

and eight evaluation points for

2. R&D Study on the Fusion Technology Basis

工学基盤構築に向けた研究

according to the 2nd and 3rd mid-term plans of NIFS,

and

Suggestions from the last external review (2013)

are considered as a reference for the evaluation

1. Design Study on the Helical Fusion Reactor

ヘリカル型核融合炉の設計研究

(1) Whether or not the FERP has shown continued progress on upgrading and refinement of the helical reactor design study (from the 2nd mid-term plan)

ヘリカル型核融合炉設計の高度化・精密化を継続的に進めているか（第二期中期計画より）

(2) Whether or not the FERP has summarized the conceptual design of the helical fusion reactor and has embodied the numerical targets for each development issue (from the 3rd mid-term plan)

ヘリカル型核融合炉の概念設計をまとめ、各開発課題の数値目標を具体化しているか（第三期中期計画より）

(3) Whether or not the helical fusion reactor design study and the R&D activities on major components are closely related with each other (from the 3rd mid-term plan)

ヘリカル型核融合炉設計と基幹機器の開発研究とが連動しているか（第三期中期計画より）

2. R&D Study to Develop the Fusion Technology Bases

工学基盤構築に向けた研究

(1) Whether or not the FERP has served as a COE dedicated for fusion technology development

核融合工学分野における基盤技術開発のCOEとしての役割を果たしているか

(2) Whether or not the FERP is enhancing interdisciplinary researches to strengthen the basis of the fusion engineering study (from the 2nd mid-term plan)

工学研究の基礎となる学際領域の研究拡充を図っているか（第二期中期計画より）

(3) Whether or not the FERP is improving the facilities for the engineering study and enhancing the joint-use and collaboration (from the 2nd and 3rd mid-term plans)

工学実験設備の更なる拡充と高度な共同利用・共同研究を進めているか（第二期、第三期中期計画より）

(4) Whether or not the FERP is enhancing the collaboration research by utilizing the frameworks of "Bilateral Collaboration Research" and "LHD Project Collaboration Research" (from the 2nd mid-term plan)

双方向型共同研究、LHD計画共同研究などの制度を有効に利用し共同研究の拡充を図っているか（第二期中期計画より）

2. R&D Study to Develop the Fusion Technology Bases (contd.)

工学基盤構築に向けた研究

(5) Whether or not the FERP has served as a COE to contribute to the international activities including ITER and BA, jointly with universities (from the 2nd mid-term plan)

国際熱核融合実験炉及び「幅広いアプローチ」等の国際事業に対して、卓越した研究拠点として大学とともに連携協力を図っているか（第二期中期計画より）

(6) Whether or not the FERP is providing distinctive education in the field of fusion engineering research, taking advantage of the function as an Inter-University Research Institute (from the 2nd mid-term plan)

大学共同利用機関としての機能を生かして、核融合工学分野での特色ある教育を実施しているか（第二期中期計画より）

(7) Whether or not the FERP has been closely working with foreign institutions by enhancing researcher exchange and collaboration, based on the international agreements (from the 2nd mid-term plan)

国際交流協定などに基づき、海外の研究拠点との研究者交流、共同研究により連携を進めているか（第二期中期計画より）

(8) Whether or not the FERP has contributed to creating the research results from universities (from the 3rd mid-term plan)

大学からの研究成果創出に資しているか（第三期中期計画より）

Suggestion from the last external review (2013)

1. Whether or not the FERP is serving as a COE dedicated for the fusion technology development so that the resultant technologies could be utilized as an engineering knowledge basis

   核融合工学分野における基盤技術開発の COE としての役割を果たし、そこで開発された最先端 技術を工学として学術的な体系化へ深化させているか

2. Whether or not the FERP has come up with a strategy jointly with universities and other institutions to foster human resources, in particular young scientists who could take the lead on their fields of research

   世界をリードする若手研究者の育成に向けて、人的基盤の拡充と質的向上を実現する新しい人 材育成の枠組みを、大学や研究機関と連携して構築しているか

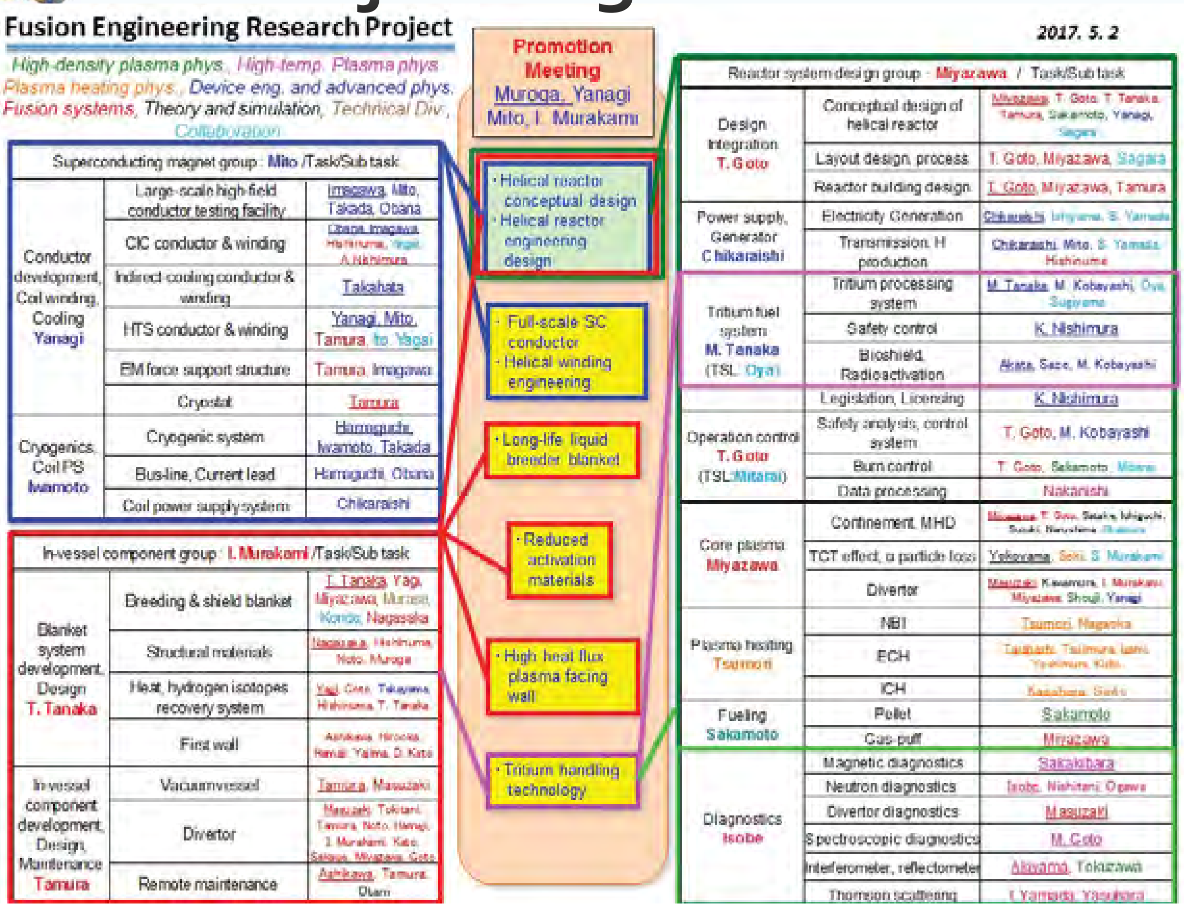
3. Whether or not the FERP has been operated efficiently in introducing large-scale test facilities and providing necessary staff to establish the desirable research environment

   大型機器や試験設備の導入と、そのための人的配置や増員をも踏まえた研究環境の整備、維 持・管理体制の構築をはかり、効率的な運用を進めているか

4. Whether or not the FERP has contributed to setting the standard for fusion energy development via making a database out of the research results

   成果や知見の集積化・データベース化により核融合の規格・基準構築に寄与しているか

Project Organization



1. Design Study on the Helical Fusion Reactor

ヘリカル型核融合炉の設計研究

1. Design Study on the Helical Fusion Reactor

ヘリカル型核融合炉の設計研究

(1) Whether or not the FERP has shown continued progress on upgrading and refinement of the helical reactor design study (from the 2nd mid-term plan)

The helical reactor design study is largely progressing.

- Detailed simulation for plasma operation and startup
- Innovative options for engineering design
  - ✓ High-Tc conductor and joint winding
  - ✓ Liquid-metal divertor in support of helical divertor
  - ✓ Molten-salt blanket with good maintainability
- Cost analysis
- Exploration of smaller and sub-ignition concepts

Design study on the helical fusion reactor FFHR-d1 has been intensively carried out

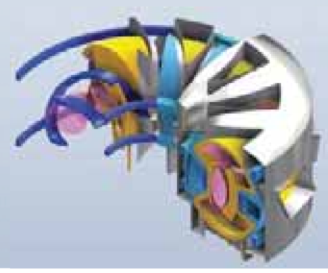
FY2010 – FY2013

- 1st round:
  - ✓ Basic device parameters
- 2nd round:
  - ✓ 3D design components
  - ✓ Physics analysis on the core plasma

FY2014 – FY2017

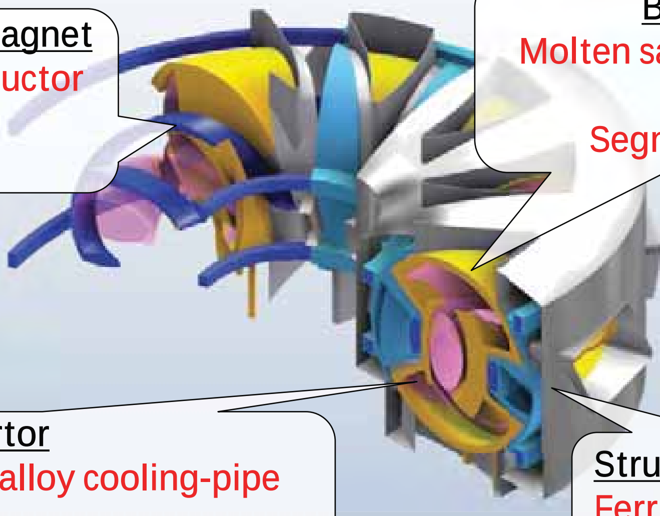
- 3rd round:
  - ✓ Construction of 3D structure
  - ✓ Maintenance method of in-vessel components
- Multipath strategy
  - ✓ Detailed physics analysis for operation and startup scenario
  - ✓ Cost model
  - ✓ d1A, d1B, d1C, and c1

	LHD	FFHR-d1
R [m]	3.9 m	15.6 m
B [T]	3 T	5.1 T
V [m^3]	30 m^3	1900 m^3
Magnetic Energy	0.9 GJ	170 GJ
Fusion Power	—	3 GW



Engineering Design of FFHR-d1

Innovative ideas have been integrated
(1) to overcome difficulties with 3D structure
(2) to enhance passive safety
(3) to improve plant efficiency



Superconducting magnet
High-Tc Superconductor
+
Joint Winding

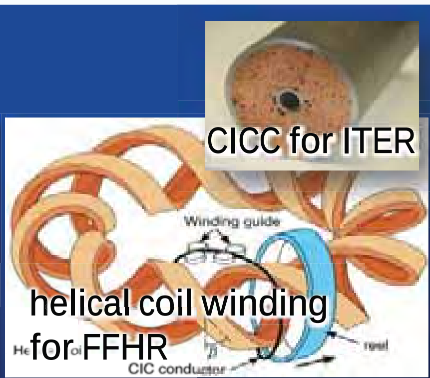
Blanket
Molten salt + Ti powder
+
Segmentation

Divertor
W-monoblock + Cu-alloy cooling-pipe
+
Liquid metal (Sn) shower

Structural materials
Ferritic steel + ODS,
V-alloy

Superconducting Magnet

Basic

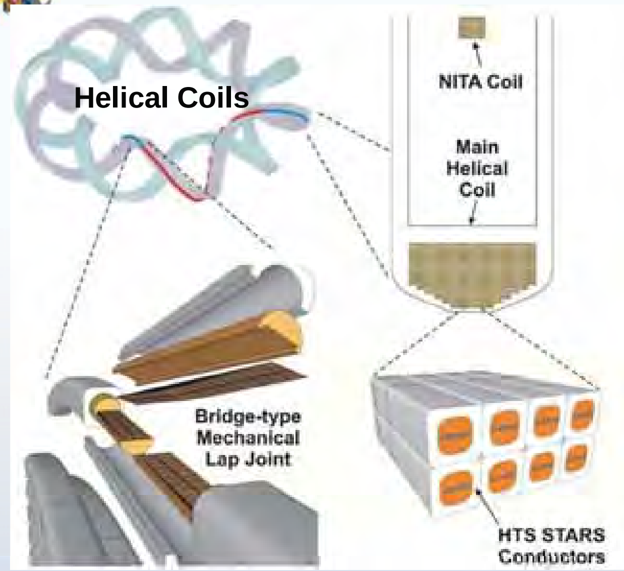


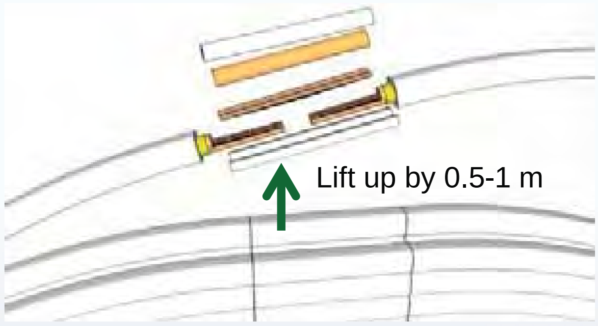
- Cable in Conduit Conductor (CICC) of Nb_3Sn as ITER (or Nb_3Al)
- Continuous winding of helical coil using a winding machine as LHD
- SC coil is directly cooled by liquid He

Challenging

- High Temperature Superconductor (HTS) of ReBCO (YBCO, GdBCO...)
- Joint winding of helical coil based on the lap joint technique
- SC coil is indirectly cooled by He gas

"Joint-Winding" of FFHR-d1 Helical Coils

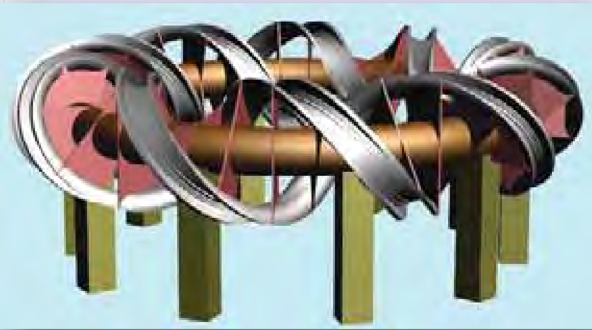




- Gas helium cooling (20 K)
- Welding between turns
- No need for VPI

390 turns × 5 segments × 2 coils
= 3,900 joints

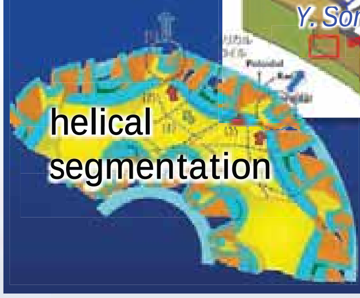
if 1 day / joint
(for 2 coils & 2 directions)
➔ 3,900 / 4 = 2.7 years



Setup of the coil casing

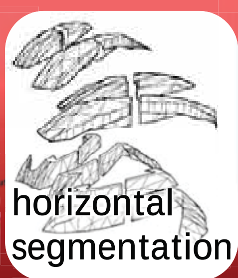
Breeding and Shielding Blankets

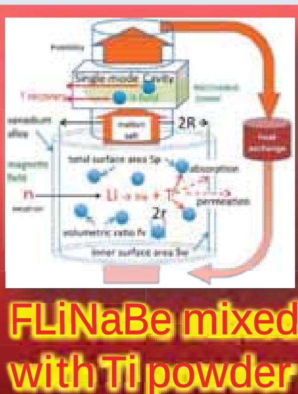
Basic



- The 1st option of the Japanese tokamak DEMO and Japanese ITER TBM
- Cooling by highly pressurized hot water of > 200 atm and > 600 K

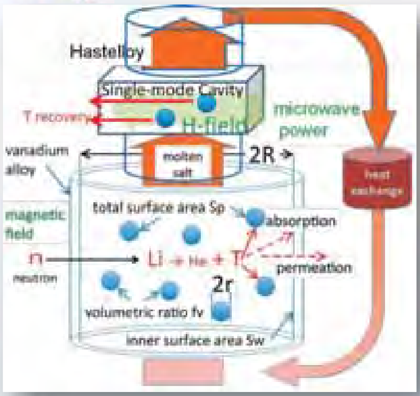
Challenging

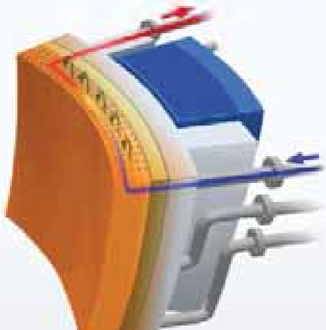




- Use FLiNaBe (T_m ~ 600 K) at a low pressure of a few atm
- Powders (~µm) of hydrogen storage metal (e.g., Ti) are mixed
- Toroidal / horizontal segmentation of the blanket module

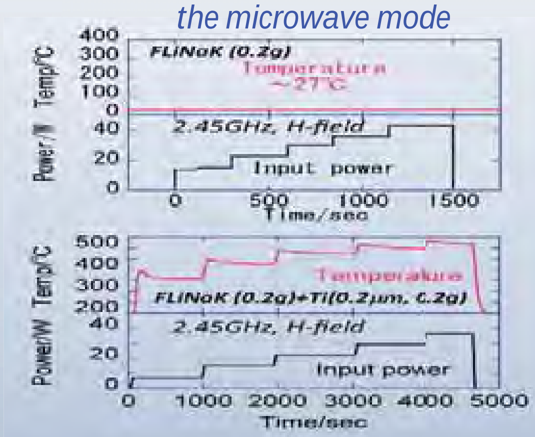
FLiNaBe is the New Candidate





Liquid Blanket
- High safety
- High efficiency
- Molten-salt or Liquid metal

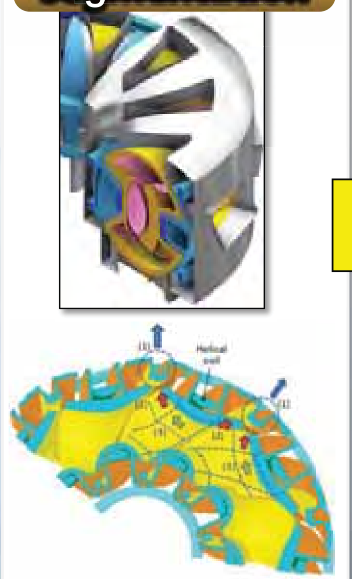
Selective heating of the metal power is possible by optimizing the microwave mode



- The melting temperature of FLiNaBe is as low as ~300℃
  - Lower than FLiBe of m.p. ~360℃
  - Thermal efficiency improves and material choice becomes wider
- Metal powder (e.g. Ti) is introduced to increase hydrogen solubility
  - Microwave for hydrogen recovery

Toroidally Segmented Blanket Could be a Possibility for Easy Maintenance

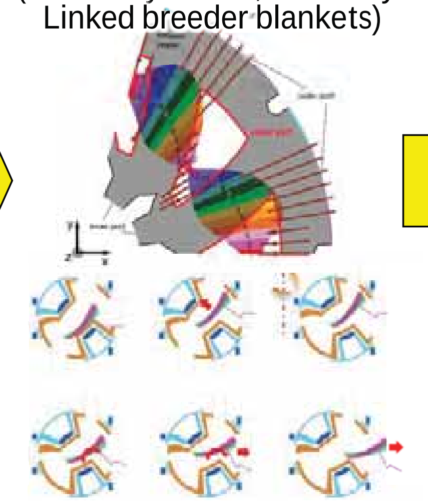
Helical segmentation



Remote maintenance in high-radiation environment is an issue

T-SHELL Blanket

(Toroidally-Sliced, HELically-Linked breeder blankets)

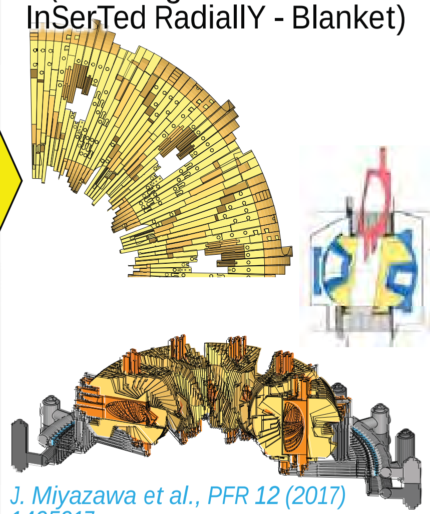


T. Goto et al., PFR 11 (2016) 2405047

First proposal of the toroidally segmented tritium Breeding Blanket (BB)

CARDISTRY-B

(CARtridges Divided and InSerTed RadiallY - Blanket)

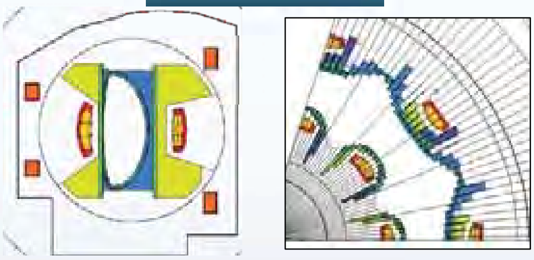


J. Miyazawa et al., PFR 12 (2017) 1405017

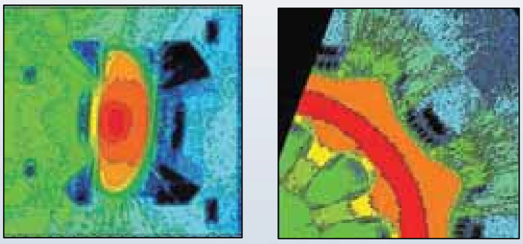
Cartridge-type blankets for both BB and neutron Shielding Blanket (SB)

Neutronics and Thermofluid Analyses

Neutronics



Simulation by the MCNP code

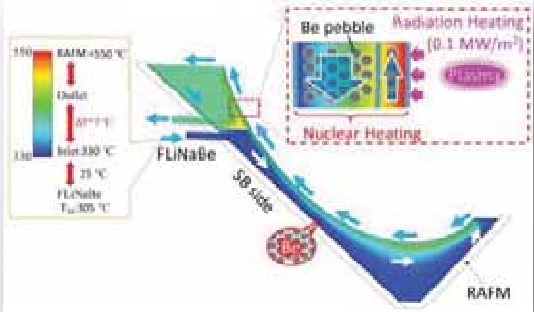


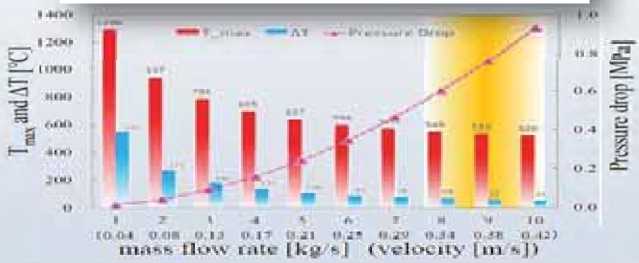
Calculated fast neutron profiles

- Streaming and neutron absorption by the side wall are taken into account
- TBR > 1.10 will be achievable with FLiNaBe

T. Tanaka et al., ISFNT-13, Kyoto (2017)

Thermofluid



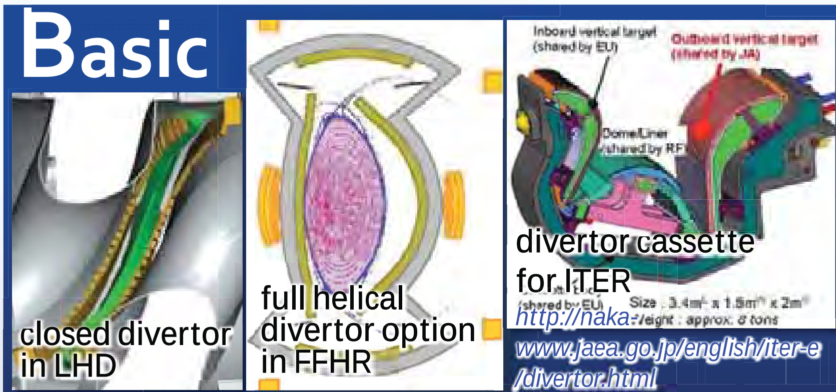


- It will be possible to keep the temperature of the structure materials below 550 ℃, if the magnetic field is not very high
- Deterioration of thermal conductivity at high B is a concern

T. Murase et al., ISFNT-13, Kyoto (2017)

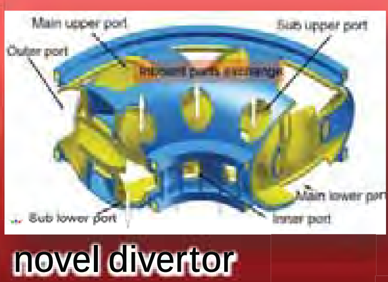
Divertor

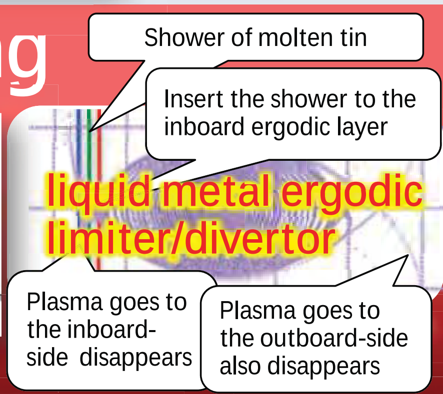
Basic



- Developed for ITER and the 1st option of Japanese tokamak DEMO
- Cooling by pressurized water
- Permissible heat load is below 10 MW/m²
- Maintenance is difficult
- A lot of radioactive wastes

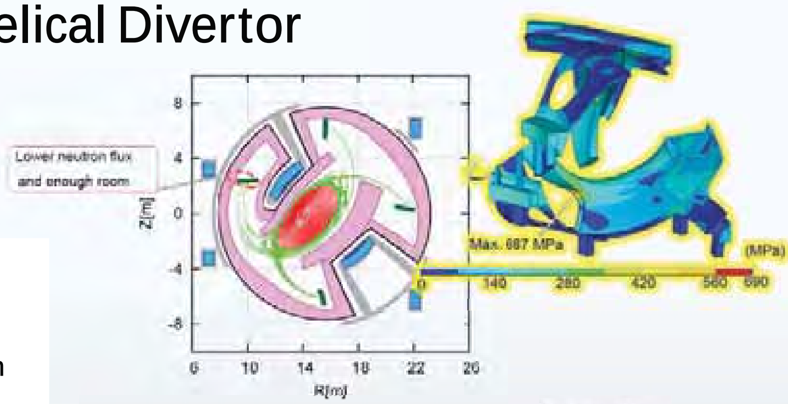
Challenging





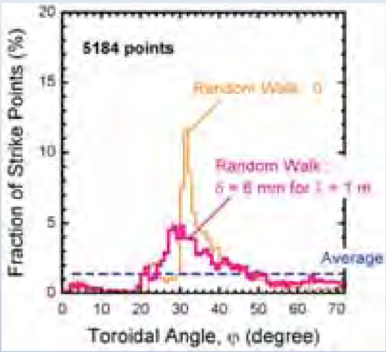
- Proposed recently for FFHR-d1 and c1
- Use molten tin (Tm ~ 500 K) shower of a few m/s of flow speed as an "ergodic limiter/divertor"
- Adopt the "novel divertor" structure for easy maintenance

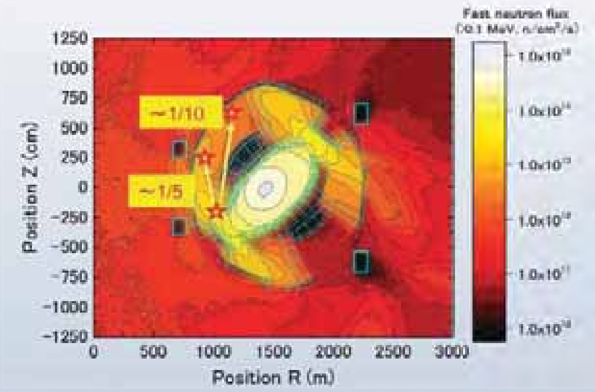
Helical Divertor



Helical Divertor

- Good exp. results in LHD
- Heat flux tolerable with a slight radiation dispersion
- Cu-alloy pipes applicable with low neutron flux
- *Maintenance by remote handling is an issue*





Max. heat flux is estimated at ~25 MW/m^2 without radiation dispersion (or detachment)

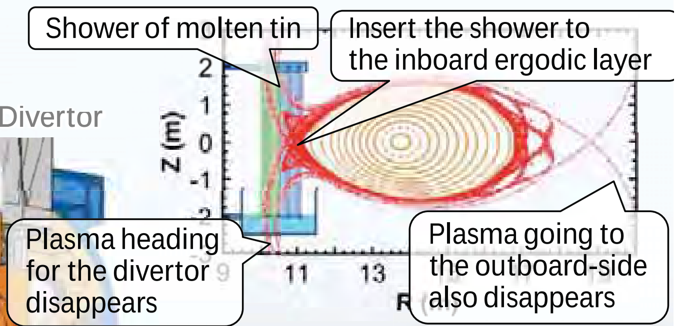
Neutron flux is reduced to 1/10 in "Novel Divertor" with a cut in the supporting-arms of helical coils

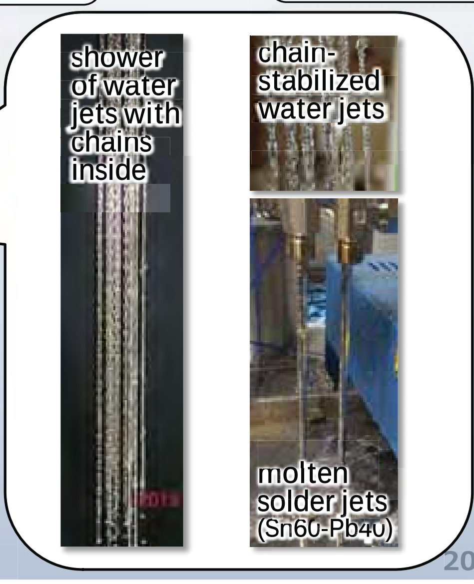
Liquid Tin Shower Divertor

REVOLVER-D

Reactor-oriented Effectively VOLumetric VERtical Divertor

- High permissible heat load
- High pumping efficiency
- High maintainability
- Low cost
- Low amount of radioactive wastes
- High Safety

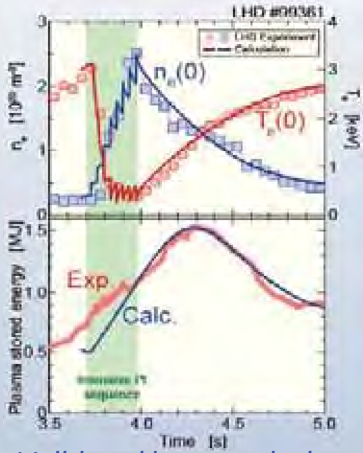




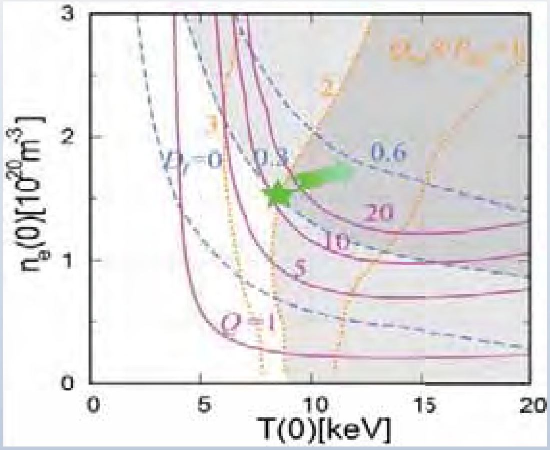
Core Plasma Simulation

T. Goto et al., FED ***89*** *(2014) 2451*
T. Goto et al., 25th IAEA-FEC (2014)
T. Goto et al., 26th IAEA-FEC (2016)

- Basis of a real-time simulation of plasma operation control scenario was developed
- A self-consistent solution of Q ~ 10 on the FFHR-d1 has been found by a systems code "HELIOSCOPE" based on "Direct Profile Extrapolation (DPE)"
  - ✓ Consistent with MHD equilibrium/stability, neoclassical transport, α particle confinement, He ash contamination, and bootstrap current



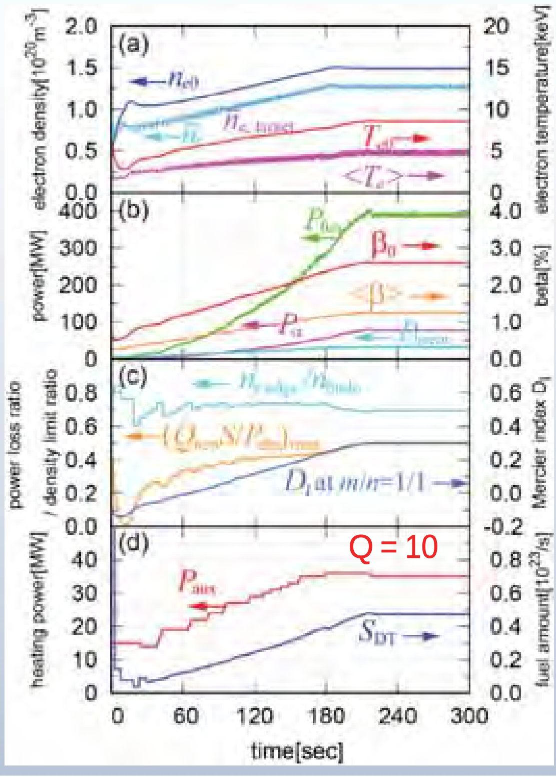
Validated by reproducing experimental data of LHD



POPCON plot achieving Q = 10 in the FFHR-d1

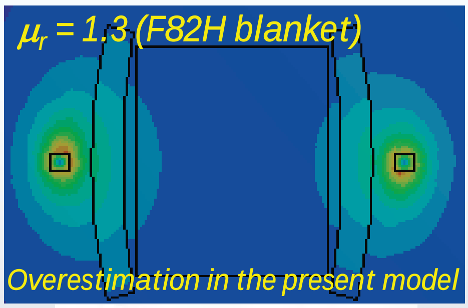
Simulations

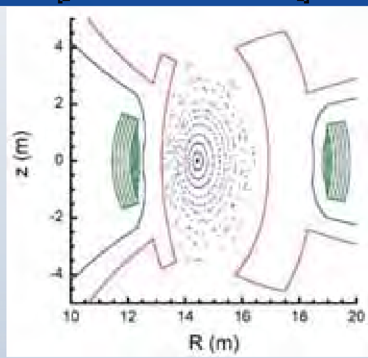
Plasma startup scenario for FFHR-d1



Investigation of magnetic field distortion by ferritic steel blanket

(Collaboration with ASIPP)





Slight expansion of magnetic surfaces (adjustable by sub-helical coils)

1. Design Study on the Helical Fusion Reactor

ヘリカル型核融合炉の設計研究

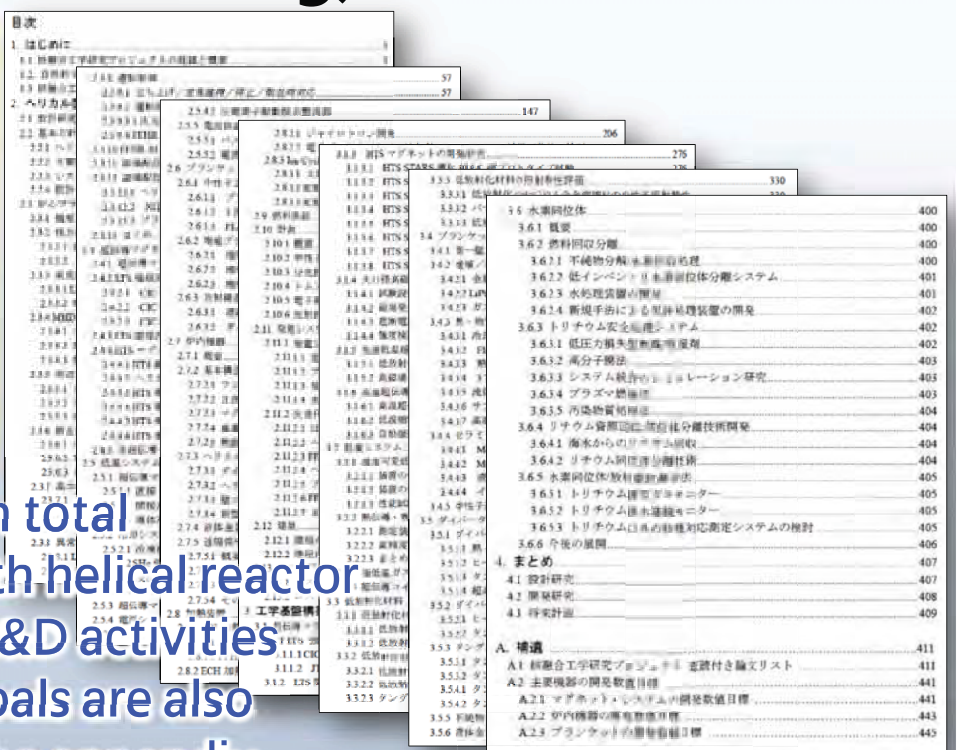
(1) Whether or not the FERP has shown continued progress on upgrading and refinement of the helical reactor design study (from the 2nd mid-term plan)

ヘリカル型核融合炉設計の高度化・精密化を継続的に進めているか（第二期中期計画より）

(2) Whether or not the FERP has summarized the conceptual design of the helical fusion reactor and has embodied the numerical targets for each development issue (from the 3rd mid-term plan)

The conceptual design report of the FFHR-d1 has been published and concrete numerical targets for each issue are listed.

The Entire Report of FERP (FY2010-FY2015) has been Issued



- ≈450 pages in total
- Including both helical reactor design and R&D activities
- Numerical goals are also included in the appendix

Numerical Targets are Summarized

Numerical Targets for the Magnet System

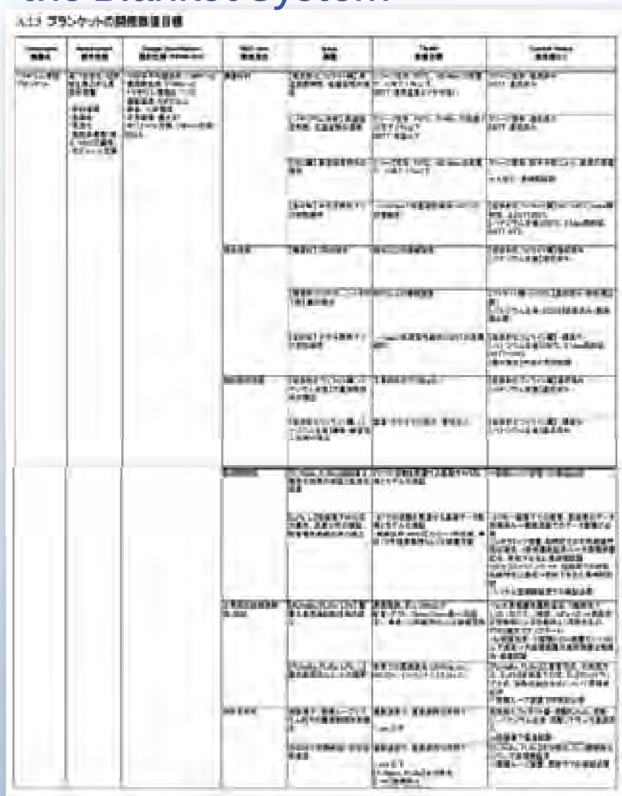
	Target 数値目標	Current Status 達成値など
	運転電流値 100 kA @13 T	ITER用に 68 kA級導体の技術確立
		短尺サンプルで 20 kA 達成
		短尺サンプルで 100 kA 達成 100 kA 級短尺サンプル接続抵抗 ：1.8 nΩ
	巻線作業期間 < 5 y	LHD の実績、ITER の実績がベース
		LHD の実績、加速器用マグネットの実績がベース
	製作精度 2000分の1	LHD の実績がベース
		LHD の実績とITER の設計がベース
	励磁時間 < 12 h	LHD の実績、ITER の設計がベース
		LHD の実績、ITER の設計がベース

- Numerical targets for the magnet system, in-vessel components, and blanket system have been summarized

Numerical Targets are Summarized

Numerical Targets for the In-vessel Components

Numerical Targets for the Blanket System



1. Design Study on the Helical Fusion Reactor

ヘリカル型核融合炉の設計研究

(1) Whether or not the FERP has shown continued

R&D studies closely linked with the helical reactor design are intensively progressing.

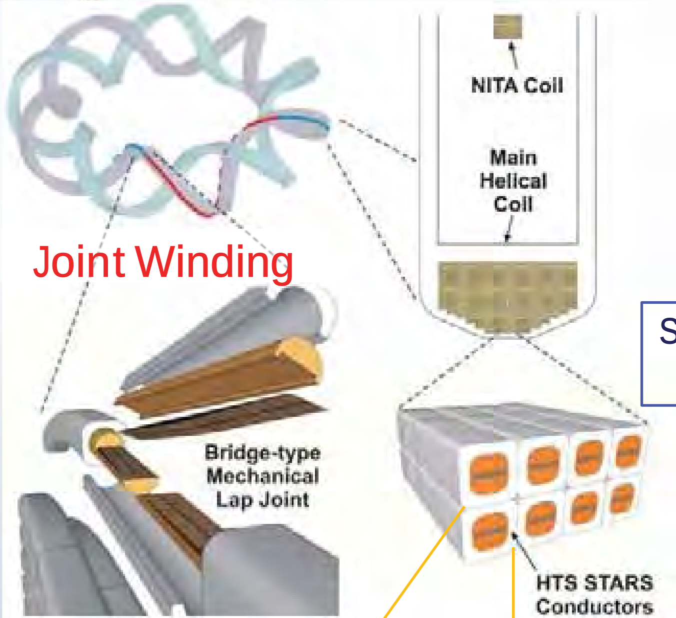
- HTS magnet
- Molten-salt blanket (metal powder, neutron irradiation, HF, Oroshhi-2)
- Liquid metal divertor

ヘリカル型核融合炉の概念設計をまとめ、各開発課題の数値目標を具体化しているか（第三期中期計画より）

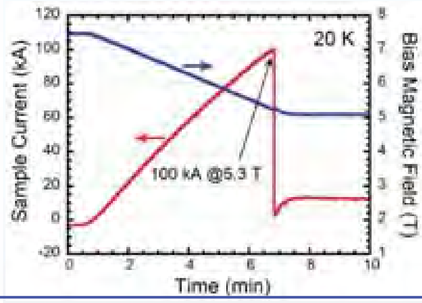
(3) Whether or not the helical fusion reactor design study and the R&D activities on major components are closely related with each other (from the 3rd mid-term plan)

ヘリカル型核融合炉設計と基幹機器の開発研究とが連動しているか（第三期中期計画より）

High-Temperature Superconductor



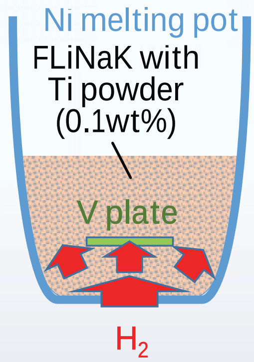
Segmented conductors (~30 m unit length)



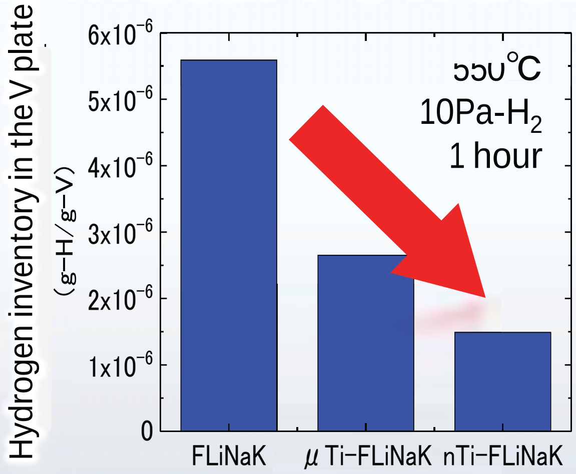
Short-sample test successfully achieved 100 kA @5 T, 20 K with 0.3 m length

Coiled sample test planned to examine 50 kA @13 T, 20 K with 6 m length

Molten Salt with Metal Powder



Schematic of the experimental setup



- Molten salt generally shows low hydrogen retention
- Hydrogen easily permeates to the material or outside

→ Micro or Nano size powder of Hydrogen storage metal is added to increase the hydrogen retention (new idea proposed by Prof. Sagara)

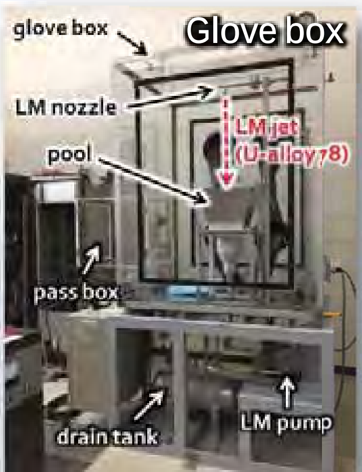
✓ Hydrogen inventory in the V plate after 1 hour H_2 exposure decreases when the Ti powder is added

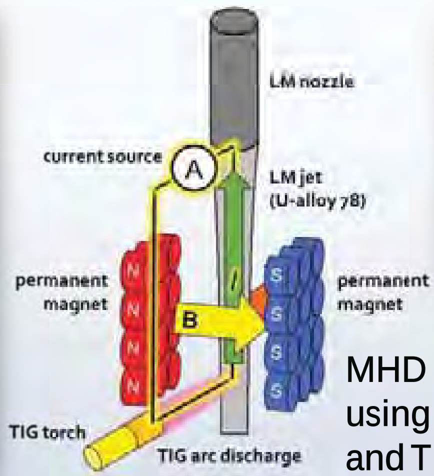
→ Hydrogen is successfully retained in the Ti power

✓ μ and n denote the size of Ti powder

A. Sagara et al., FED 89 (2014) 2114
J. Yagi et al., 29th SOFT (2016)

Experiments using Liquid Metal Jets are Ready to Go





MHD exp. using PM and TIG arc

- Glove box (Ar atmosphere)
  - ✓ LM jet of ~1 m length (w/ U-alloy 78 at ~100 ℃)
  - ✓ MHD experiment
- Vacuum chamber
  - ✓ LM jet of ~0.1 m length (w/ Tin at ~300 ℃)
  - ✓ high heat load experiment

Ohgo, SOKENDAI D1 (2017)

2. R&D Study on the Fusion Technology Basis

工学基盤構築に向けた研究

2. R&D Study on the Fusion Technology Basis

工学基盤構築に向けた研究

(1) Whether or not the FERP has served as a COE dedicated for fusion technology development
核融合工学分野における基盤技術開発のCOEとしての役割を果たしているか

(2) Whether or not the FERP is enhancing interdisciplinary researches to strengthen the basis of the fusion engineering study (from the 2nd mid-term plan)
工学研究の基礎となる学際領域の研究拡充を図っているか（第二期中期計画より）

(3) Whether or not the FERP is improving the facilities for the engineering study and enhancing the joint-use and collaboration (from the 2nd and 3rd mid-term plans)
工学実験設備の更なる拡充と高度な共同利用・共同研究を進めているか（第二期、第三期中期計画より）

(4) Whether or not the FERP is enhancing the collaboration research by utilizing the frameworks of "Bilateral Collaboration Research" and "LHD Project Collaboration Research" (from the 2nd mid-term plan)
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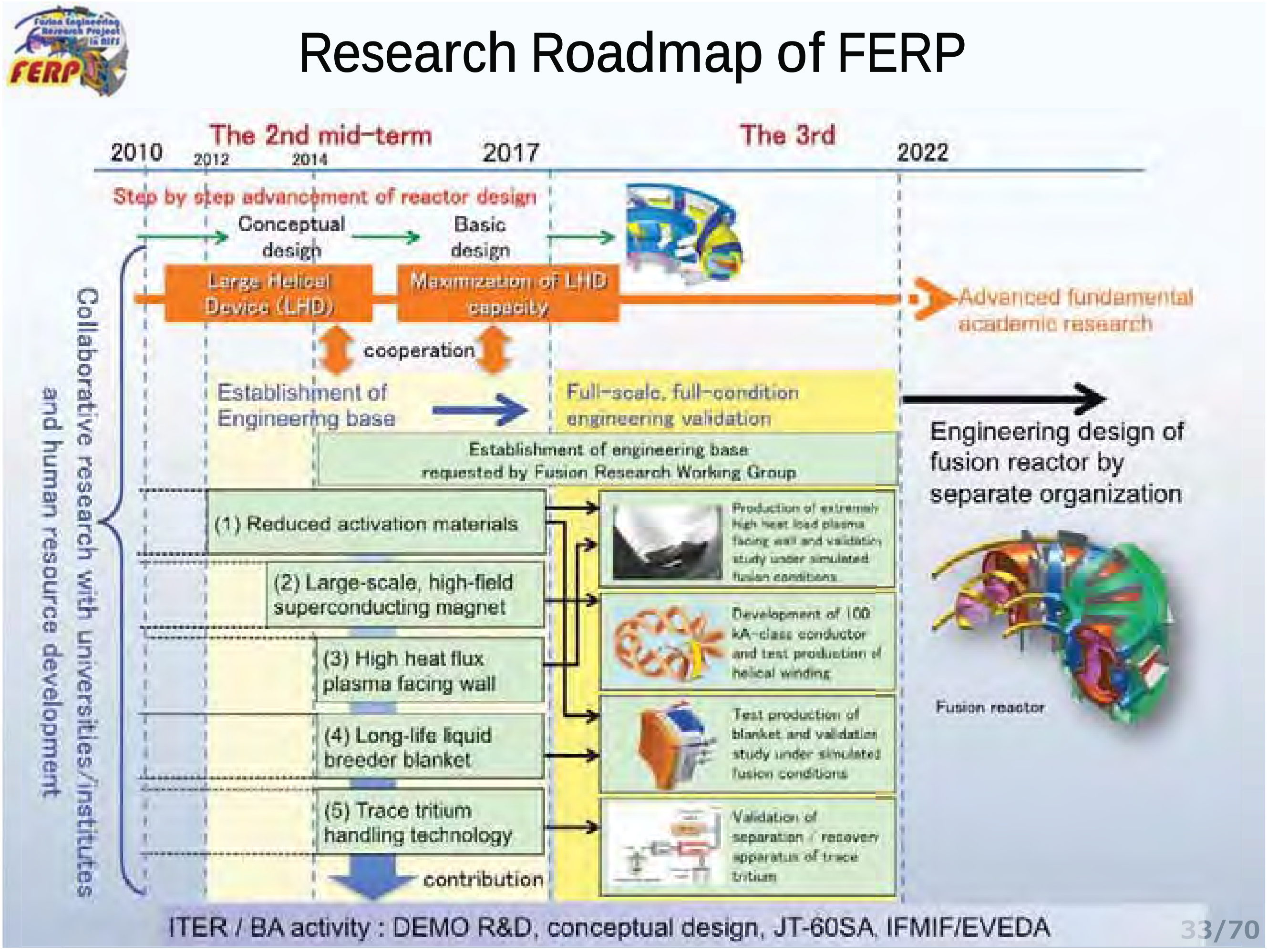
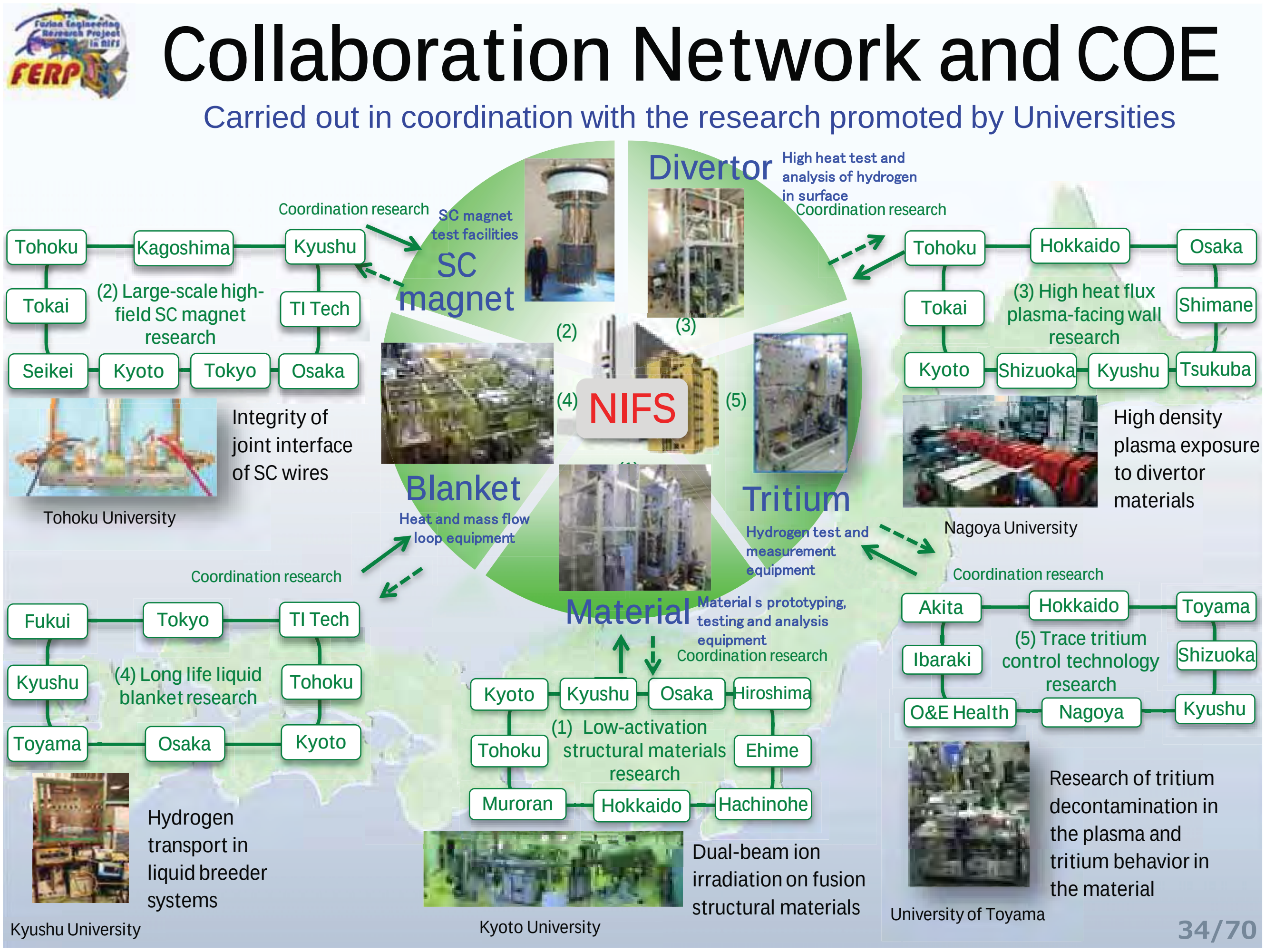


Research Roadmap of FERP
2010
The 2nd mid-term
2012
2014
2017
The 3rd
2022
Step by step advancement of reactor design
Conceptual design
Basic design
Large Helical Device (LHD)
Maximization of LHD capacity
Advanced fundamental academic research
cooperation
Establishment of Engineering base
Full-scale, full-condition engineering validation
Engineering design of fusion reactor by separate organization
Establishment of engineering base requested by Fusion Research Working Group
Collaborative research with universities/institutes and human resource development
(1) Reduced activation materials
(2) Large-scale, high-field superconducting magnet
(3) High heat flux plasma facing wall
(4) Long-life liquid breeder blanket
(5) Trace tritium handling technology
Production of extremely high heat load plasma facing wall and validation study under simulated fusion conditions
Development of 100 kA-class conductor and test production of helical winding
Test production of blanket and validation study under simulated fusion conditions
Validation of separation / recovery apparatus of trace tritium
Fusion reactor
contribution
ITER / BA activity : DEMO R&D, conceptual design, JT-60SA, IFMIF/EVEDA
33/70



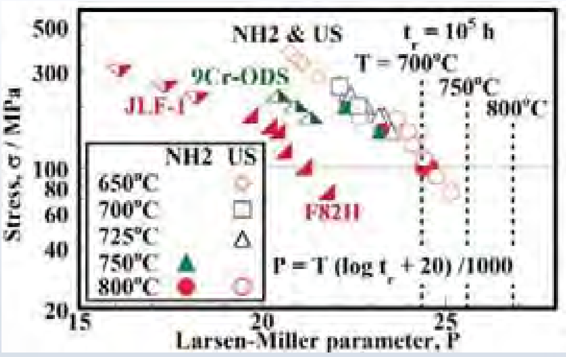
Collaboration Network and COE
Carried out in coordination with the research promoted by Universities
Divertor
High heat test and analysis of hydrogen in surface
Coordination research
SC magnet test facilities
SC magnet
(2)
(3)
(4)
NIFS
(5)
Blanket
Heat and mass flow loop equipment
Tritium
Hydrogen test and measurement equipment
Material
Materials prototyping, testing and analysis equipment
Coordination research
Tohoku
Kagoshima
Kyushu
Tokai
(2) Large-scale high-field SC magnet research
TI Tech
Seikei
Kyoto
Tokyo
Osaka
Integrity of joint interface of SC wires
Tohoku University
Coordination research
Tohoku
Hokkaido
Osaka
Tokai
(3) High heat flux plasma-facing wall research
Shimane
Kyoto
Shizuoka
Kyushu
Tsukuba
High density plasma exposure to divertor materials
Nagoya University
Coordination research
Fukui
Tokyo
TI Tech
Kyushu
(4) Long life liquid blanket research
Tohoku
Toyama
Osaka
Kyoto
Hydrogen transport in liquid breeder systems
Kyushu University
Coordination research
Akita
Hokkaido
Toyama
Ibaraki
(5) Trace tritium control technology research
Shizuoka
O&E Health
Nagoya
Kyushu
Research of tritium decontamination in the plasma and tritium behavior in the material
University of Toyama
Coordination research
Kyoto
Kyushu
Osaka
Hiroshima
Tohoku
(1) Low-activation structural materials research
Ehime
Muroran
Hokkaido
Hachinohe
Dual-beam ion irradiation on fusion structural materials
Kyoto University
34/70

Research highlights

(1) Reduced Activation Materials

Structural materials for advanced blankets of helical reactors

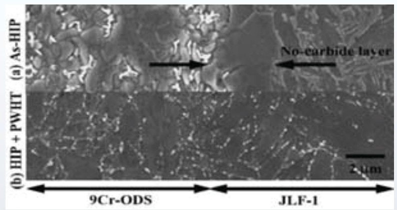
Thermal creep of high purity V-4Cr-4Ti alloys

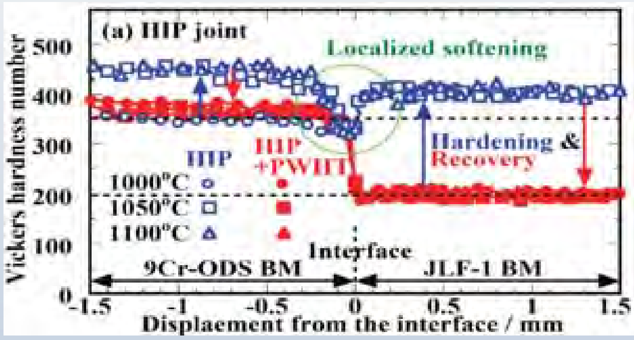


NH2 : NIFS-HEAT-2 High purity V-4Cr-4Ti
US : US-DOE HEAT medium purity V-4Cr-4Ti
F82, JLF-1 : Reduced activation ferritic steel （RAFM)
9Cr-ODS : Oxide Dispersion Strengthened 9Cr steel

High purity V-4Cr-4Ti high had higher ductility but lower strength.
However, the creep strength was shown to be comparable with medium purity V-4Cr-4Ti

HIP joining of RAFM and 9Cr-ODS





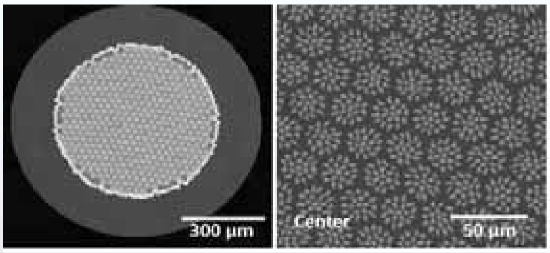
HIP joining caused matrix hardening and interface softening.
Post-Weld Heat Treatment recovered to the original hardness profile

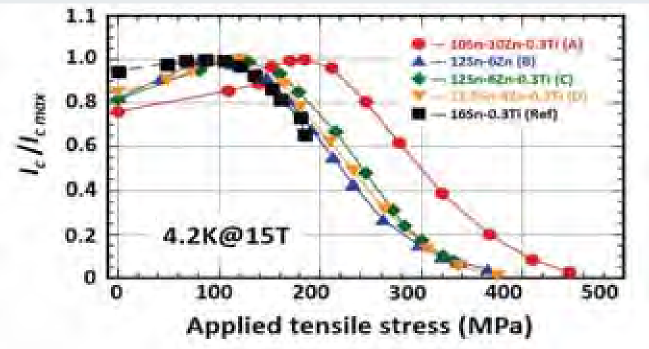
Research highlights

(2) Superconducting Magnet

LTC options for magnet systems of helical reactors

Development of high-strength Nb3Sn strand





- ✓ Yield strength increases by Cu-Zn matrix
- ✓ Tensile stress at which max. Ic obtained increases to 200 MPa

Development of indirect-cooling large-current Nb3Sn conductor

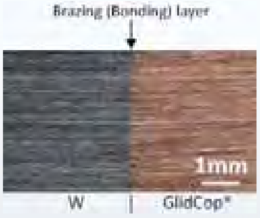
- ✓ Al-alloy jacket with Friction Stir Welding
- ✓ A 20-kA coiled sample ready to be tested in 13-T, ϕ700-mm magnet
- ✓ Strengthened strand by Cu-Nb matrix

Research highlights

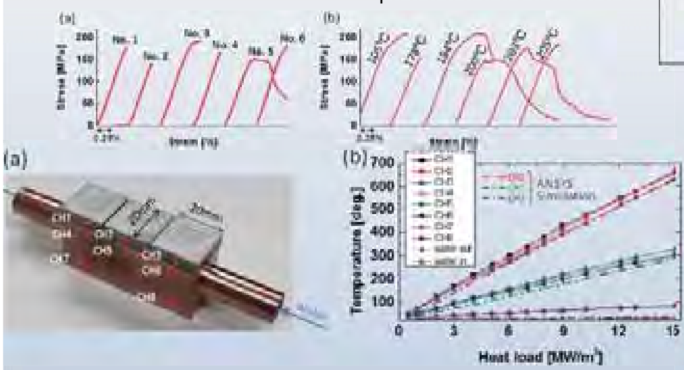
(3) High heat flux plasma facing wall

Advancement of solid helical divertors for helical reactors

Optimization of brazing technology

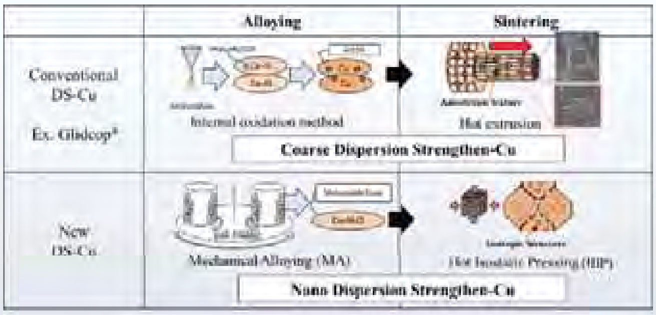


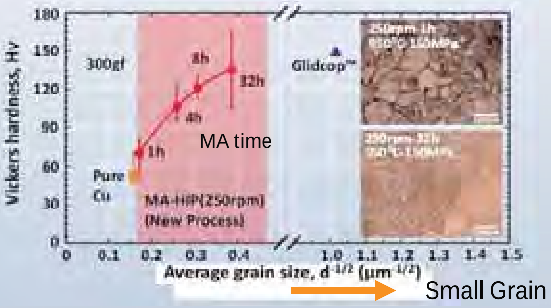
W/BNi-6/GlidCop®.



The new divertor test sample fabricated by W/BNi-6/GlidCop joining showed heat flux resistance to 15 MW/m^2

High strength Cu-alloys by MA and HIP





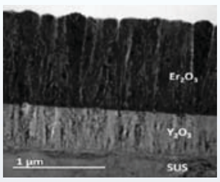
Increase in MA time resulted in fine structure and high strength of Cu-1Al. High radiation resistance is expected.

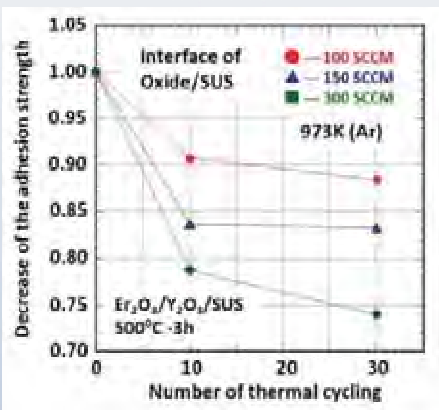
Research highlights

(4) Long-life liquid breeder blanket

Advanced liquid blanket and materials characterization technology for helical reactors

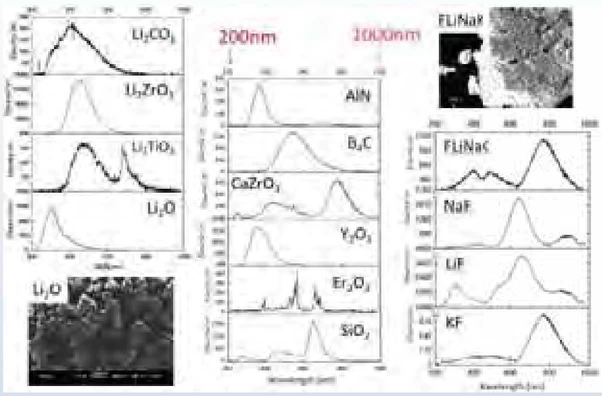
Tritium permeation barrier/electrical insulation coating by MOCVD

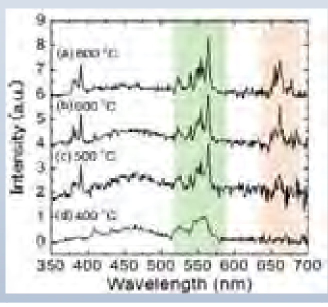




Scratch tests showed degradation by thermal cycling can be controlled by selecting CVD gas flow rate

Cathodolimonescence (CL) of blanket materials for non-destructive structural characterization

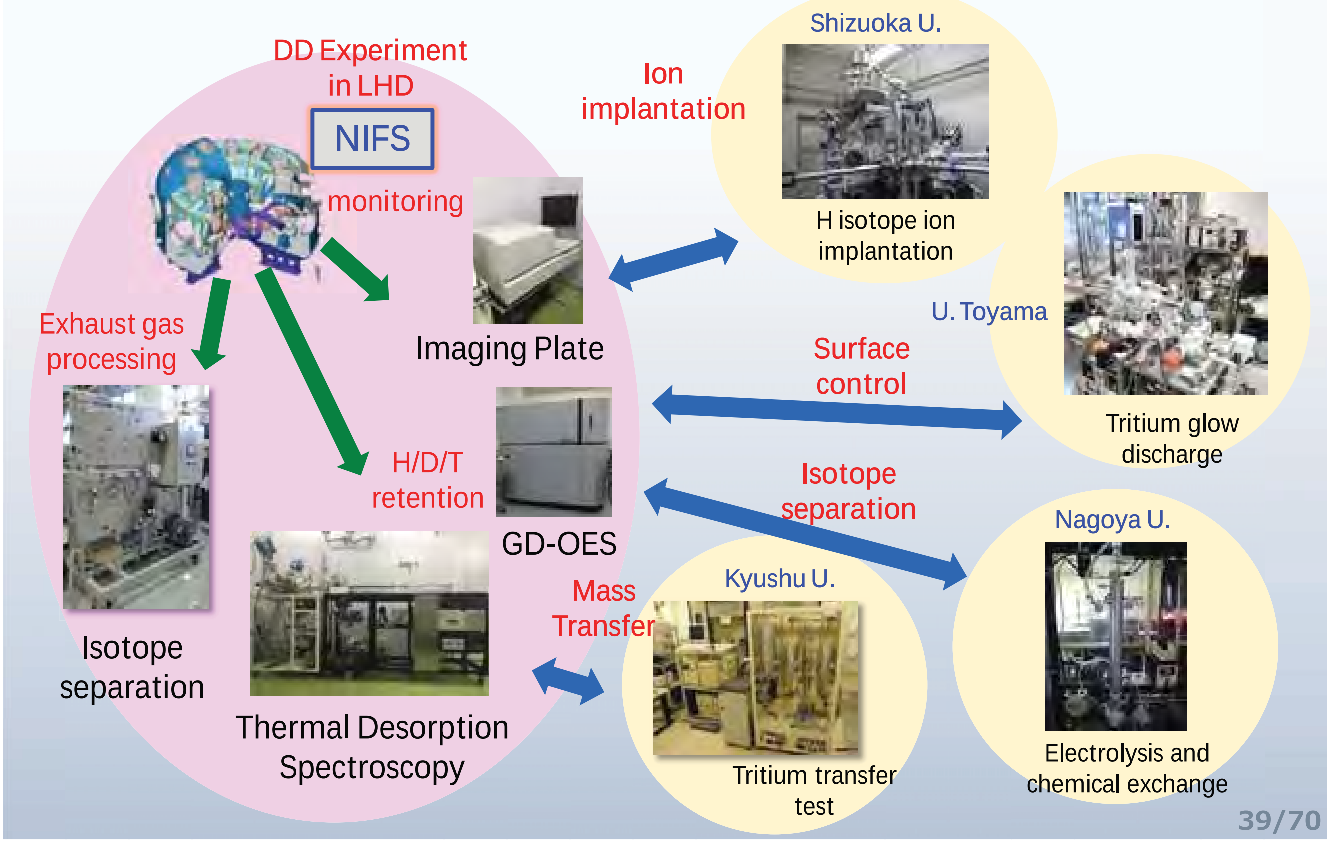




CL spectra of Er2O3 coating specimens baked at different temperatures showed microstructural evolution during sintering process.

(5) Trace tritium handling technology

Supporting DD experiment of LHD and application to helical reactors



2. R&D Study on the Fusion Technology Basis

工学基盤構築に向けた研究

(1) Whether or not the FERP has served as a COE dedicated for fusion technology development

核融合工学分野における基盤技術開発のCOEとしての役割を果たしているか

(2) Whether or not the FERP is enhancing interdisciplinary researches to strengthen the basis of the fusion engineering study (from the 2nd mid-term plan)

工学研究の基礎となる学際領域の研究拡充を図っているか（第二期中期計画より）

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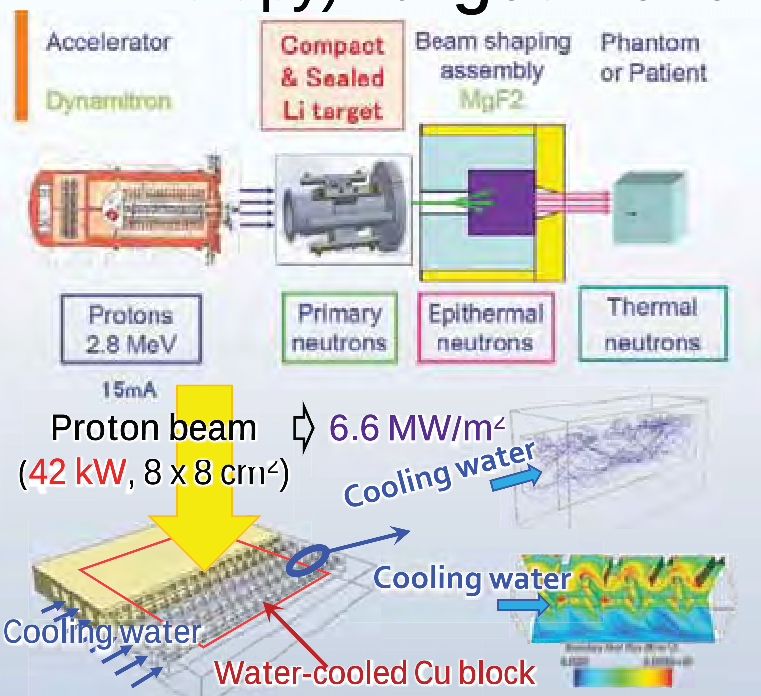
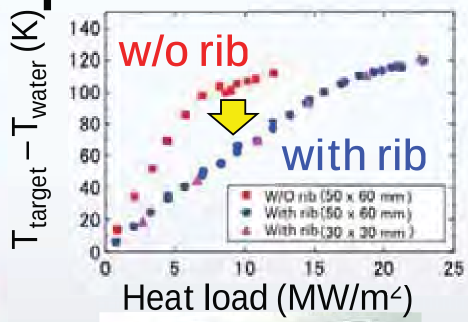
Examples of collaboration with non-fusion area (Joint research titles)

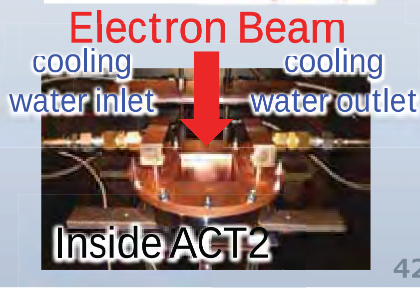
- Proton-conductor for H monitoring (metal casting)
- Micro-arcing (automobile transmission)
- Microwave heating (chemical processes)
- High heat loading (BNCT target)

ACT2 for BNCT (Boron Neutron Capture Therapy) Target Development



Heat transfer and turbulence in the V-type rib structure (flow velocity = 2 m/s, simulation by the Tsuji Lab. in Nagoya Univ.)





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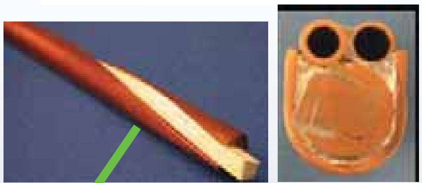
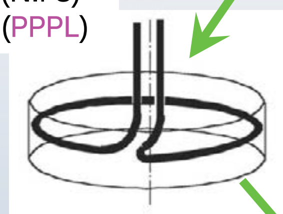
Superconducting Magnet Facility for International Collaborations

JT-60SA Central Solenoid (one module) was tested at NIFS SCM Lab.

HTS STARS Conductor (NIFS) FEM Model (PPPL)

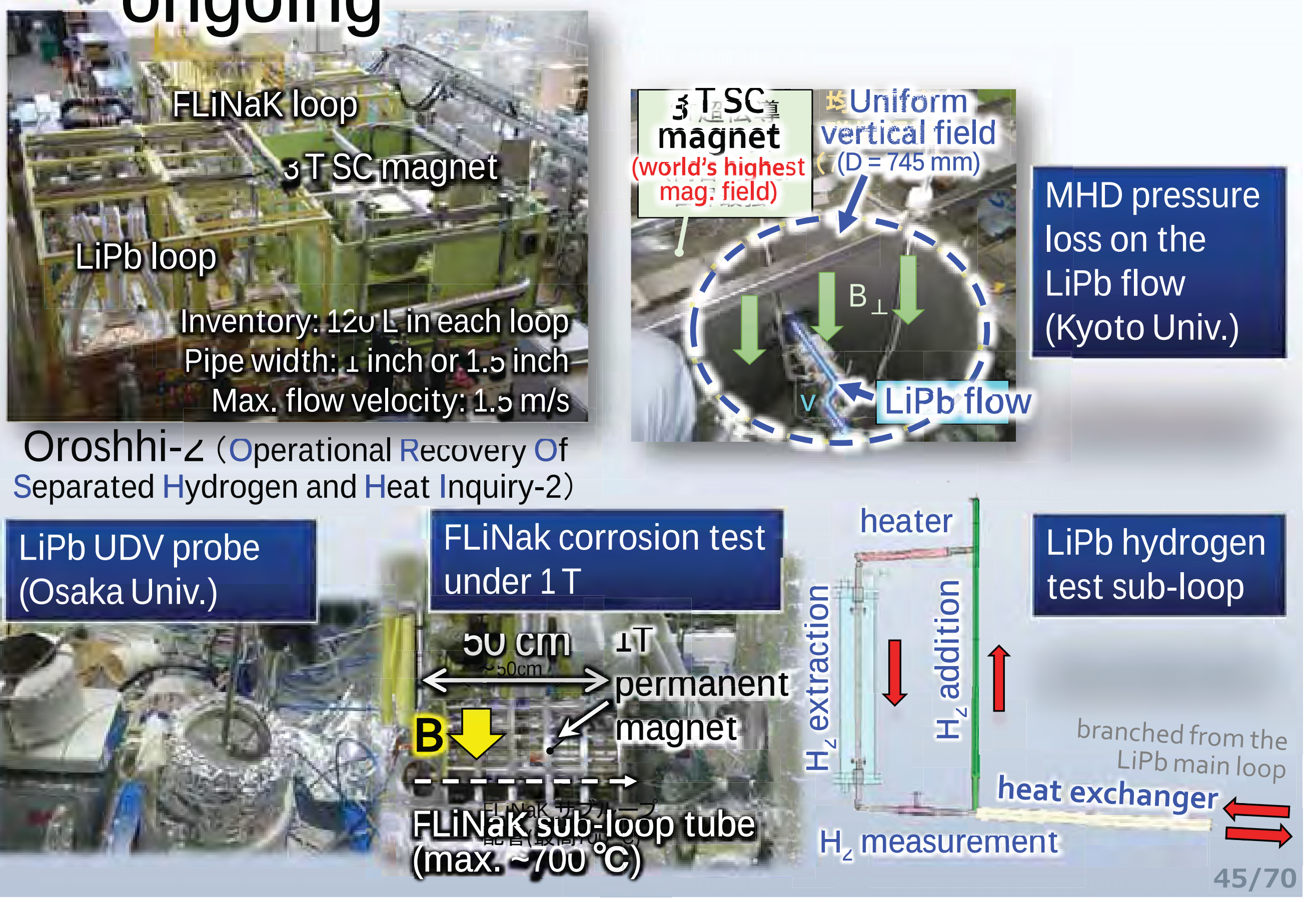
HTS TSTC Conductor Sample (MIT)





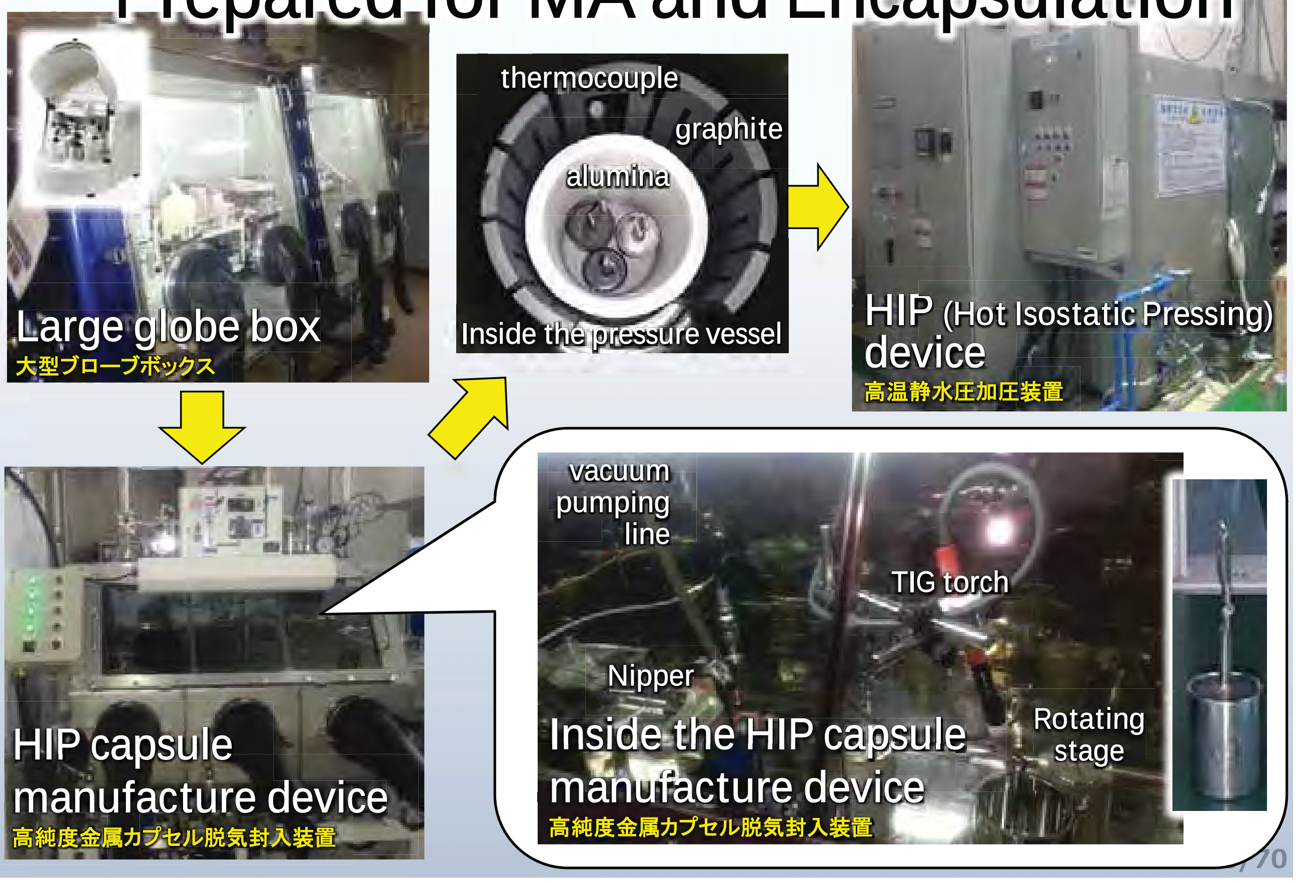
- “Large-Bore High-Field Magnet Test Facility” (13 T , ϕ700 mm) is ready to operate
- MIT’s TSTC HTS conductor sample will be tested in Feb., 2018
- Temp. variable refrigerator will supply 4-50 K liquid & gas helium

Oroshhi-2: various experiments are ongoing



Oroshhi-2 (Operational Recovery Of Separated Hydrogen and Heat Inquiry-2)

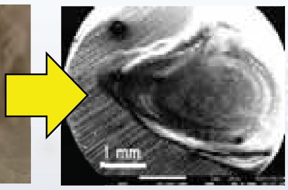
HIP: A Super-Clean Environment is Prepared for MA and Encapsulation



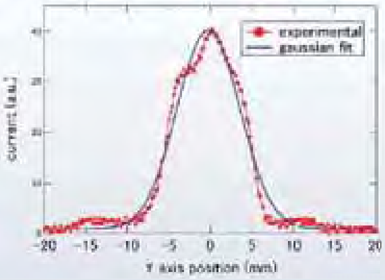
ACT2: EB Control System and Cooling System have been Improved

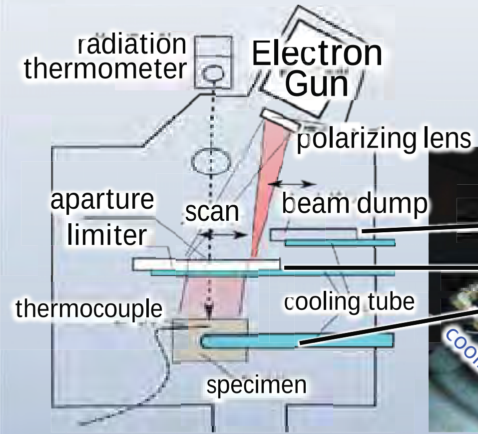
Tungsten target before irradiation

Tungsten target after irradiation

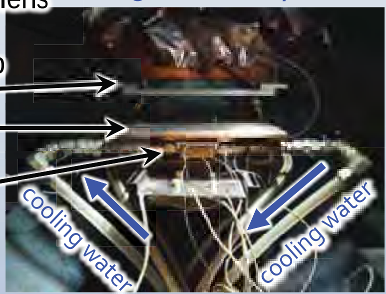


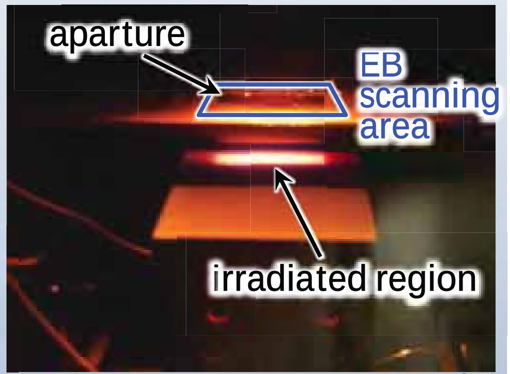
Electron beam profile is Gaussian with the FWHM ~ 10 mm





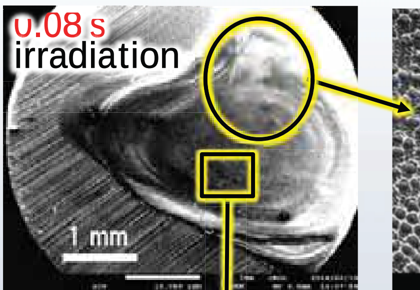
W-Cu alloy divertor target mockup test

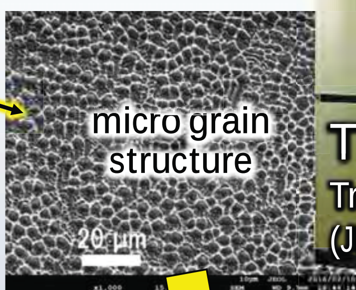


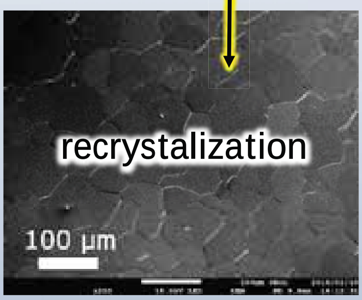


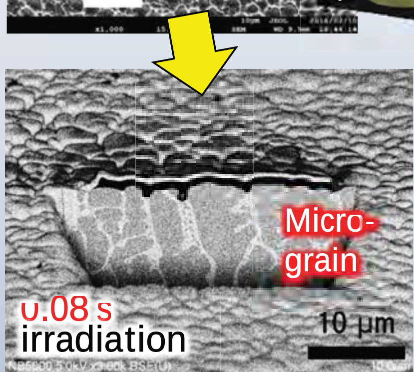
TEM and FIB: Powerful tool by the combination

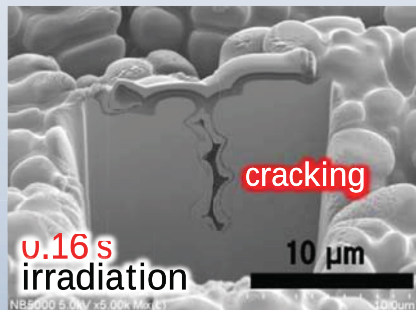
Tungsten alloy after 0.08 – 0.16 s irradiation at 230 MW/m^2 in ACT2









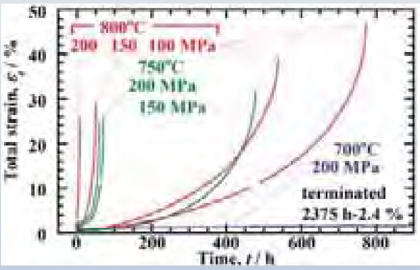


Thermal Creep Test Facilities

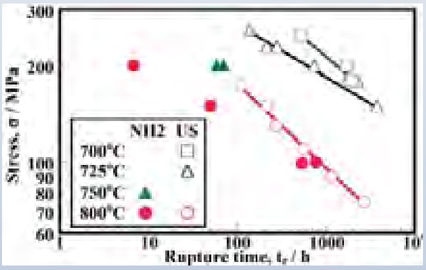
Eight thermal creep test facilities were installed

- High temperature (~1173K)
- High vacuum ($1x10^{-7}$Pa)
- Small specimens
  - (5mm gauge length)
- (for testing advanced materials)

Precise temperature and stress control is necessary



Creep Strain for V-4Cr-4Ti



Rupture Time vs Stress for V-4Cr-4Ti

2. R&D Study on the Fusion Technology Basis

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"Bilateral Collaboration Research" and "LHD Project Collaboration Research

Examples of bilateral collaboration research

- Divertor simulation in GAMMA-10 (Tsukuba U.)
- Edge plasma study in Heliotron-J (Kyoto U.)
- Co-deposition layer research in QUEST (Kyushu U.)
- Thermo-fluid study of liquid metal in the first wall in the Institute of Laser Engineering (Osaka Univ.)
- Tritium behavior in plasma facing materials (U. of Toyama)
- PWI for neutron irradiated materials (Tohoku U.)

"Bilateral Collaboration Research" and "LHD Project Collaboration Research

Examples of LHD project collaboration

Plasma-wall Interactions
- In-situ diagnostics with LIBS (UCSD and Kanazawa U.)
- PWI with gas impurities (Hokkaido U.)
- TDS technology in (Shizuoka U.)
- Irradiation effects on hydrogen retention (Osaka U.)
- Linear plasma device in hot laboratory (Nagoya U. and Tohoku U.)
- Tungsten coated graphite (U. of Toyama)

Plasma facing components/ materials
- Advancement of tungsten alloys (Tohoku U.)
- Advanced copper alloys (Kyoto U./Tohoku U.)
- Heat conversion in divertor system (Kyoto U.)

Blanket technology
- Liquid lithium technology from IFMIF/EVEDA project (Kyoto U.)
- Oxide film coating for blanket application (Tokai U. and TIT)

Magnet technology
- Advanced helical winding for HTS (Meiji U.)
- Advanced helical winding for Nb-Sn (Sophia U.)

A&M
- Cross-section for charge exchange reaction of tungsten (Niigata U.)
- Molecular detrapping (Toho U.)

Tritium science and technology
- Isotope effect of dynamics of tritium transport (Shizuoka U.)
- Isotope separation of hydrogen (Nagoya U.)
- Biological effects of low-level tritium (Hiroshima U.)
- Environmental tritium transport (Kyushu U.)
- Tritium removal from LHD (U. of Toyama)

2. R&D Study on the Fusion Technology Basis (contd.)

工学基盤構築に向けた研究

(5) Whether or not the FERP has served as a COE to contribute to the international activities including ITER and BA, jointly with universities (from the 2nd mid-term plan)

国際熱核融合実験炉及び「幅広いアプローチ」等の国際事業に対して、卓越した研究拠点として大学とともに連携協力を図っているか（第二期中期計画より）

(6) Whether or not the FERP is providing distinctive education in the field of fusion engineering research, taking advantage of the function as an Inter-University Research Institute (from the 2nd mid-term plan)

大学共同利用機関としての機能を生かして、核融合工学分野での特色ある教育を実施しているか（第二期中期計画より）

(7) Whether or not the FERP has been closely working with foreign institutions by enhancing researcher exchange and collaboration, based on the international agreements (from the 2nd mid-term plan)

国際交流協定などに基づき、海外の研究拠点との研究者交流、共同研究により連携を進めているか（第二期中期計画より）

(8) Whether or not the FERP has contributed to creating the research results from universities (from the 3rd mid-term plan)

大学からの研究成果創出に資しているか（第三期中期計画より）

Collaboration with ITER

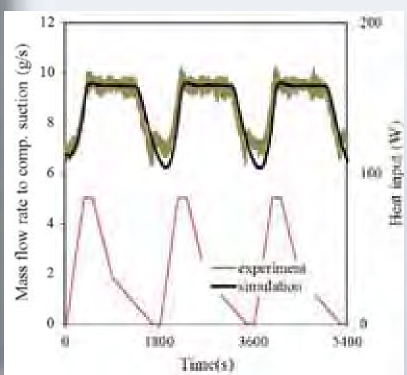
✓SC magnet and cryo system

- ITER-TF conductor joint samples (final specification) tested and confirmed low-resistance requirement
- Cryo-system simulation code C-PREST

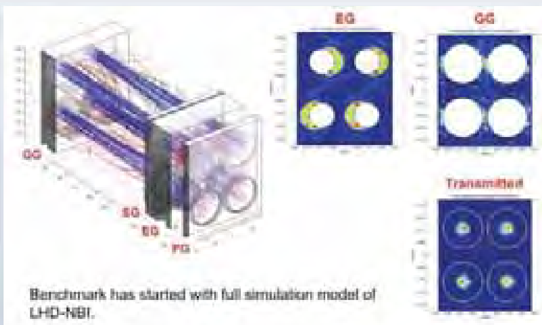
✓Neutral Beam Injection (NBI)

- Beam simulation and experiments in NIFS test stand

Performance test of a ITER-TF joint sample at NIFS



Simulation results of the Mass flow rate from LHe reservoir to the compressor suction, by C-PREST at NIFS



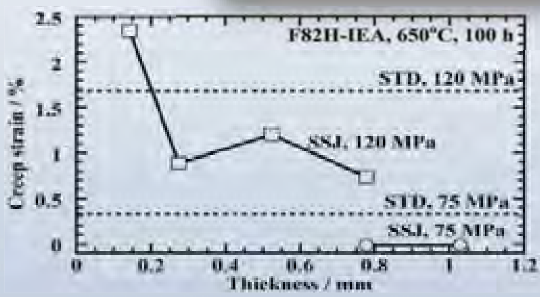
3D-beamlet simulation including secondary charged particles

Collaboration with BA

Performance tests of the JT-60SA CS model and module coils

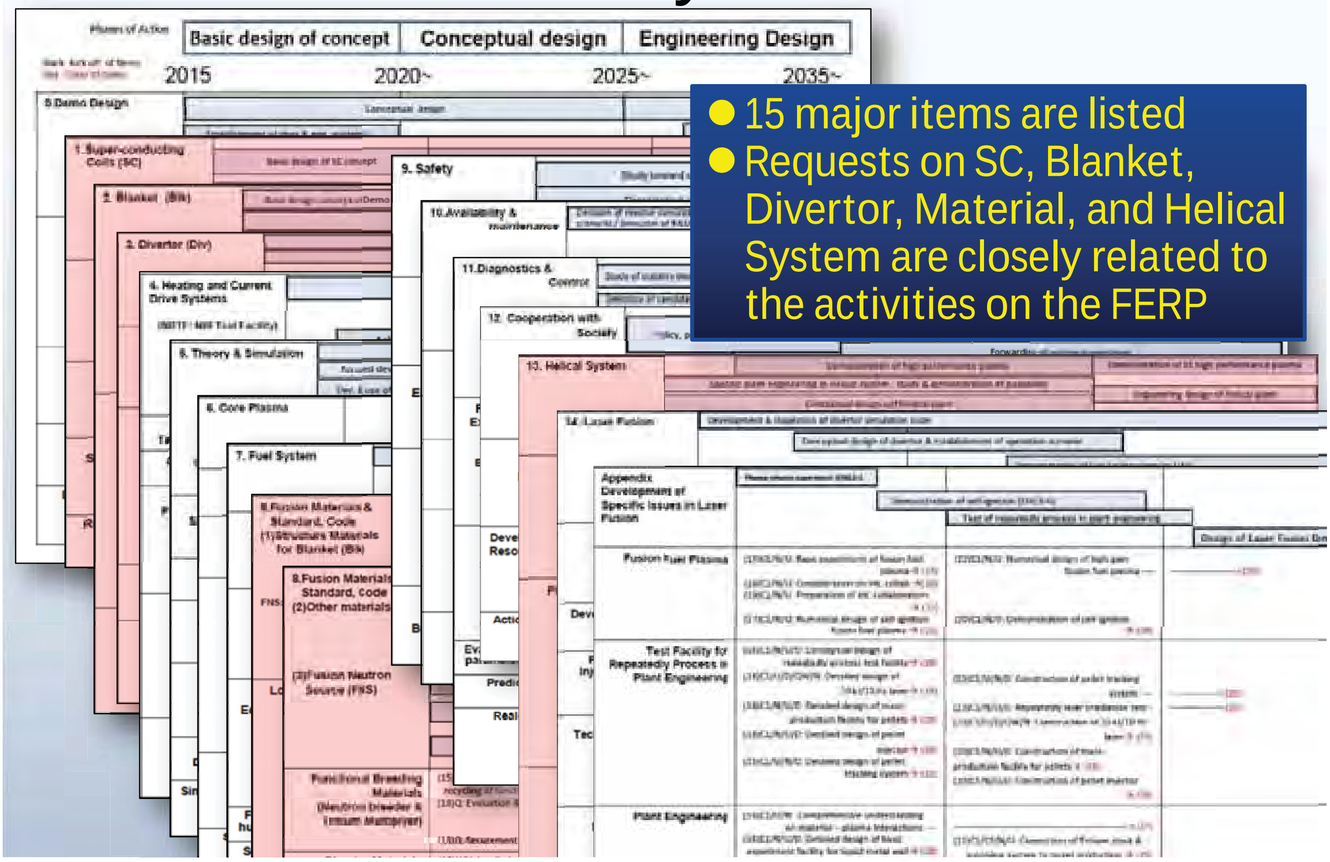
- ✓JT-60SA
  - SC magnet testing ➔ One of the actual CS coils tested
- ✓IFERC (DEMO-R&D)
  - Specimen size effects on thermal creep tests
  - Tritium control in DEMO
  - System code
  - PWI experiment in JET
- ✓IFMIF-EVEDA
  - Hydrogen monitoring in Liquid Li

Hydrogen monitoring and trapping with Y-Nb for flowing Li



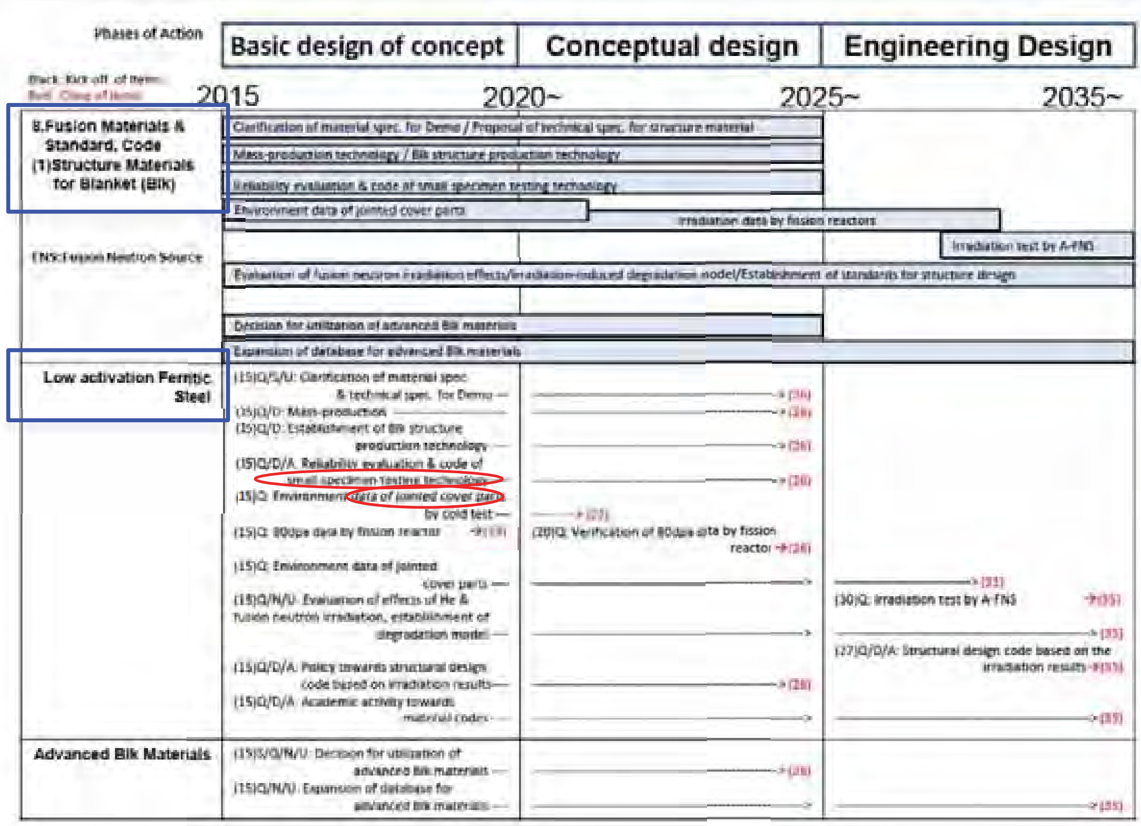
Specimen thickness effects on creep rupture for RAFM (Reduced Activation Ferrite Materials)

The Action Plan for Tokamak DEMO has been Issued by the Joint Core Team



- 15 major items are listed
- Requests on SC, Blanket, Divertor, Material, and Helical System are closely related to the activities on the FERP

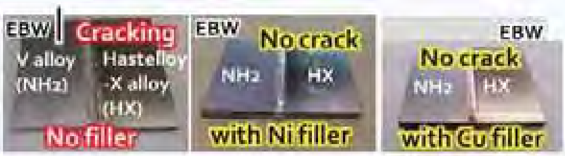
An Example of Possible NIFS Contribution to the Action Plan



Progress in Joining Technology

EBW: Electron-beam welding, HIP: Hot-isostatic pressing

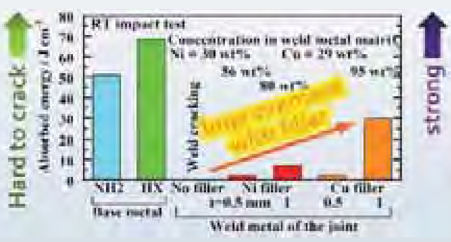
25L x 50w x 2.86t mm



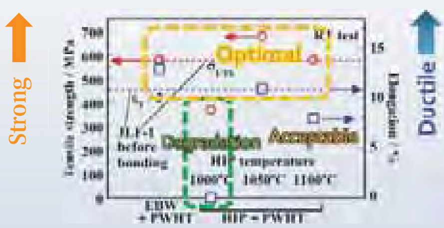
EBW of V alloy and hastelloy with or w/o Ni or Cu filler

25L x 50w x 5t mm f24 x 20t mm f24 x 5t mm

Reinforcement of the ferritic steel material by joining with ODS



Absorbed energy at a RT



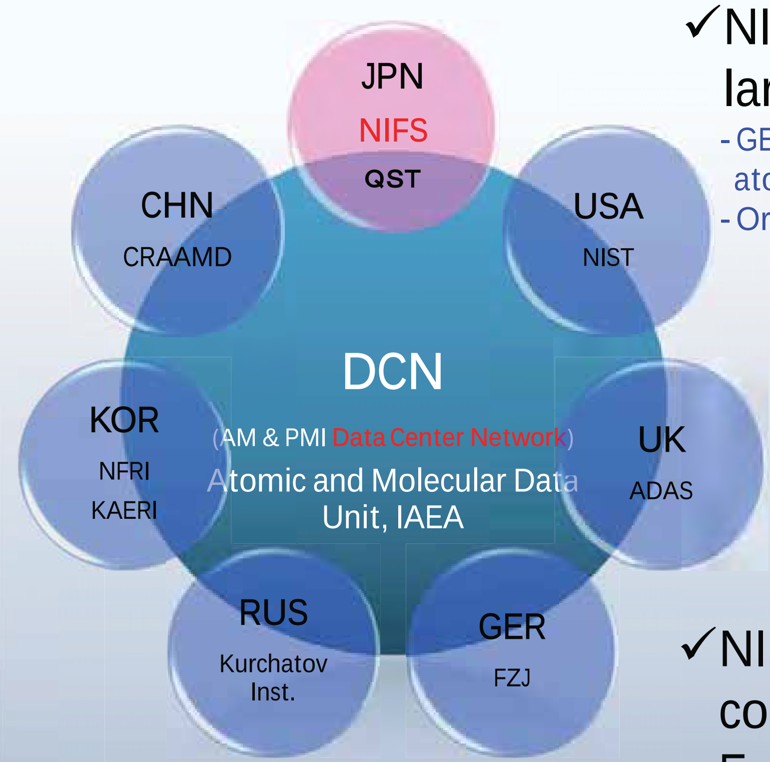
Tensile strength and elongation

- The ductility of V-alloy/Hastelloy joint drastically improves with Cu filler
- The strength of RAFM/ODS/RAFM recovers after PWHT (Post-Weld-Heat-Treatment)

Application to advanced blankets

Application to enhancing DEMO blanket performance

Collaboration on Atomic and Molecular Database



✓NIFS is providing the largest database to GENIE
- GENIE is the worldwide search engine of atomic and molecular database
- Organized by DCN (IAEA)

http://www-amdis.iaea.org/GENIE/

✓NIFS as a DCN member contributes to Data Evaluation activities.

2. R&D Study on the Fusion Technology Basis (contd.)

工学基盤構築に向けた研究

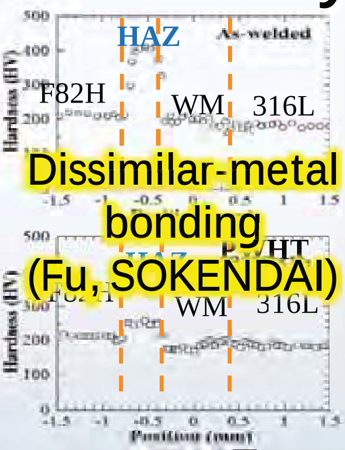
(5) Whether or not the FERP has served as a COE to contribute to the international activities including ITER and BA, jointly with universities (from the 2nd mid-term plan)
国際熱核融合実験炉及び「幅広いアプローチ」等の国際事業に対して、卓越した研究拠点として大学とともに連携協力を図っているか（第二期中期計画より）

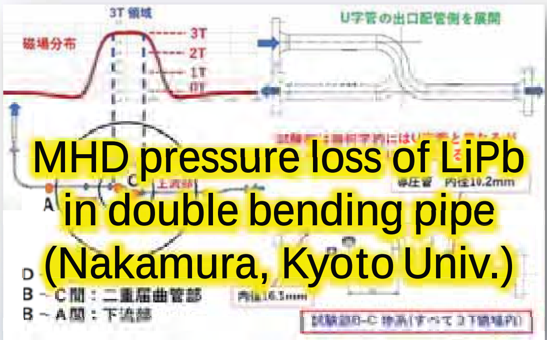
(6) Whether or not the FERP is providing distinctive education in the field of fusion engineering research, taking advantage of the function as an Inter-University Research Institute (from the 2nd mid-term plan)
大学共同利用機関としての機能を生かして、核融合工学分野での特色ある教育を実施しているか（第二期中期計画より）

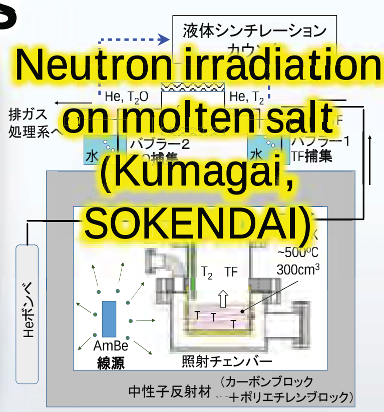
(7) Whether or not the FERP has been closely working with foreign institutions by enhancing researcher exchange and collaboration, based on the international agreements (from the 2nd mid-term plan)
国際交流協定などに基づき、海外の研究拠点との研究者交流、共同研究により連携を進めているか（第二期中期計画より）

(8) Whether or not the FERP has contributed to creating the research results from universities (from the 3rd mid-term plan)
大学からの研究成果創出に資しているか（第三期中期計画より）

Variety of Studies are being Carried Out by Doctoral Students







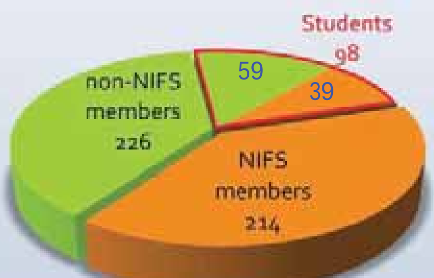
- Dissimilar-metal bonding (Fu, SOKENDAI (2017))
- High-temperature superconductor (Terazaki, SOKENDAI (2017))
- MHD pressure drop in the double bending pipe (Nakamura, Kyoto Univ.)
- Neutron irradiation on molten salt (Kumagai, SOKENDAI)
- MHD effect on the liquid metal jet (Ohgo, SOKENDAI)
- …

Human Resource Development

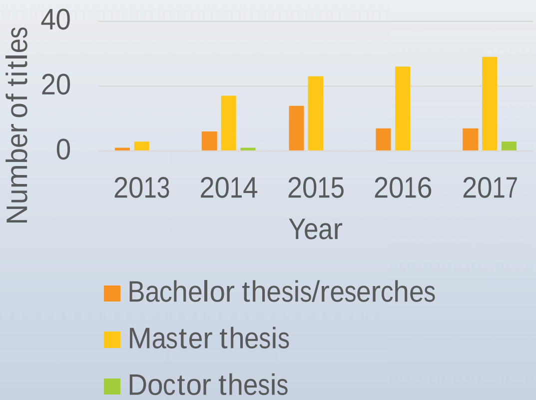
~Whether or not FERP is bringing up young researchers who can support long-range growth of international fusion study

人材育成 ～核融合研究の長期的な発展を支える国際的に活躍できる人材の育成に貢献しているか

✓ 98 papers (39 by NIFS students, and 59 by University students) have been published by the students through the collaboration with FERP from FY2013.



Breakdown of published papers



Academic degrees including NIFS collaboration results

2. R&D Study on the Fusion Technology Basis (contd.)

工学基盤構築に向けた研究

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Collaboration based on international agreements etc.

US–Japan Collaboration

- Joint project of TITAN and PHENIX
- Workshops (Reactor design and PWI/HHF and others)
- Personal exchanges

China –Japan, Korea-Japan Collaborations

- JWG (J-C)
- JCM (J-K)
- A3 foresight program (J-C-K) (JSPS)
- Post-CUP (J-C) (NIFS internal budget)

IEA Stellarator/Heliotron

IEA PWI

IAEA Coordinated Research Project and Workshops

Others

Collaboration in US-J Joint Projects

Technological interaction between US-Japan Joint Project and NIFS collaboration

TITAN : Tritium, Irradiation and Thermofluid (FY2007-2012)

PHENIX : PFC evaluation by tritium plasma, heat, neutron irradiation (FY2013-2018)

TPE in INL (TITAN/PHENIX)

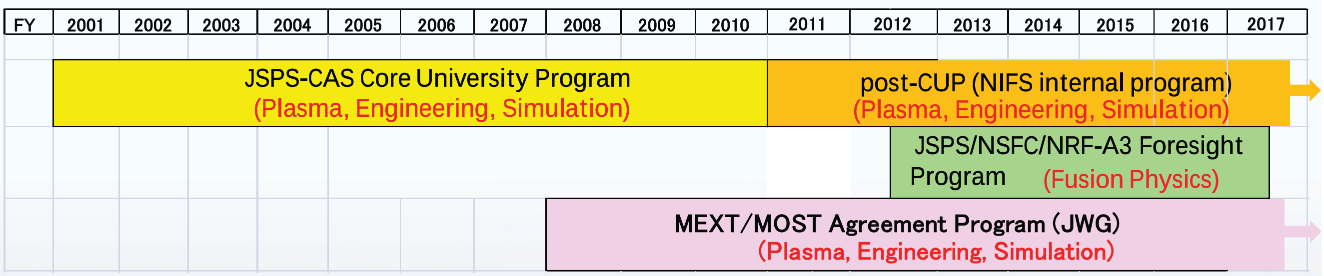
Plasma device in Oarai Center, Tohoku University (NIFS collaboration with Nagoya U.)

MTOR in UCLA (TITAN) Orishhi-2 in NIFS

Thermofluid of liquid breeders in magnetic fields

Plasma exposure to neutron-irradiated materials

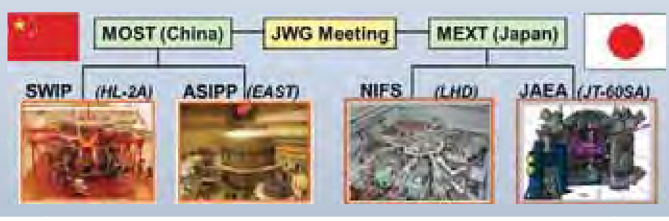
Framework of Collaboration with China



"Post-CUP" continued based on NIFS internal budget with smaller size than CUP
Major platform for fusion engineering collaboration between Japanese and Chinese Institutes and Universities (material, blanket, tritium)

J/C/K/ A3-Foresight Program started in 2012 for 5 years
Mostly physics but includes plasma-wall interactions and A&M

MEXT/MOST agreement program (JWG) started in 2008 including fusion engineering
NIFS&JAEA - ASIPP&SWIP program
(LHD/JT-60SA/EAST/HL2A, reactor design, magnet etc)



2. R&D Study on the Fusion Technology Basis (contd.)

工学基盤構築に向けた研究

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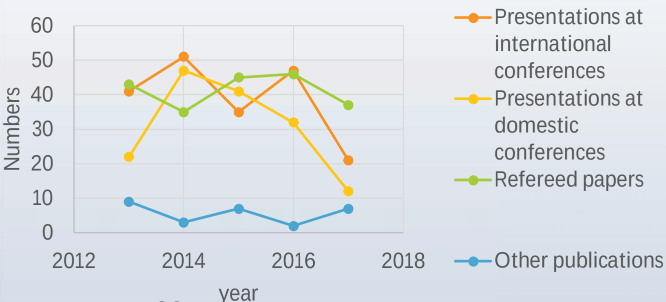
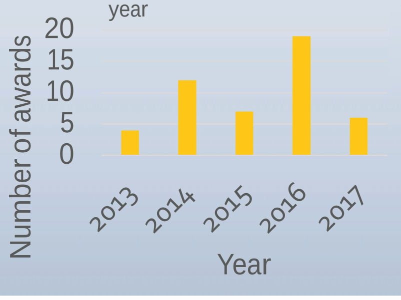
(8) Whether or not the FERP has contributed to creating the research results from universities (from the 3rd mid-term plan)

大学からの研究成果創出に資しているか（第三期中期計画より）

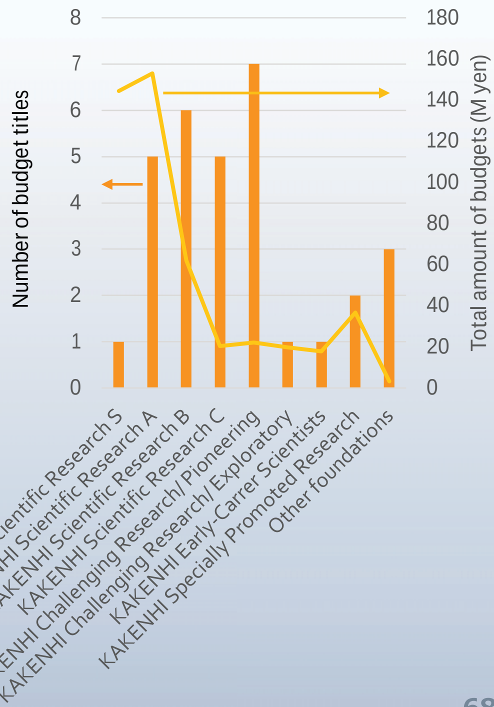
Creating research results from universities

- University researchers obtain research budgets from JSPS and other foundations as a result of their collaboration researches with FERP
- University researchers are given awards from the related society or conferences for their researches on FERP





Total number of budget titles (bars) and amounts (lines) during FY2013-FY2017 for non-NIFS researchers.



Publications

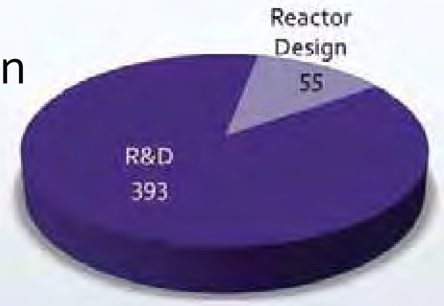
Publications in 2013-2017: 440 in total

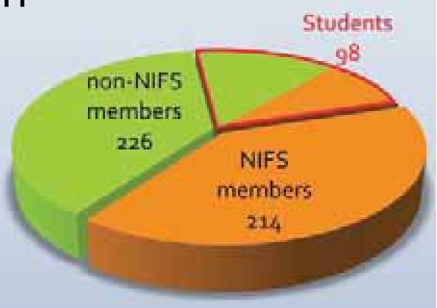
✓393 on R&D
(67 on SC magnet & Cryogenics, 57 on Low activation materials,
81 on Blanket & First wall, 158 on Divertor, 41 on Tritium & Safety)

✓55 on Reactor Design
(21 on Concept & System design, 13 on Core plasma control,
23 on Plant equipment & related technology)

✓226 written by non-NIFS staffs

✓98 written by students





Future Plan

✓1. Execution and completion of the 3rd Midterm Plan by FY2021
- Engineering design for prototype magnet and blanket systems for helical reactors
- Establishing research roadmap toward helical reactors
- Establishing NIFS as a COE for fusion engineering by collaboration using the facilities installed
- Contribution to creation of research outcomes by Universities

✓2. Application of research results to DEMO Action Plan and C&R

✓3. Further enhancement of the research
- Pursuing more attractive helical reactor concepts
  Passive safety
  Load following
  Social receptivity
- R&D contributing to formulating post-LHD concepts

References

Table of Evaluation Results for the 2017 External Peer Review

“Fusion Engineering Research Project”

Table of Evaluation Results for the 2017 External Peer Review "Fusion Engineering Research Project"

Ⅰ. Points for Evaluation

1. Design Study on the Helical Fusion Reactor

(1)Whether or not the FERP has shown continued progress on upgrading and refinement of the helical reactor design study

(2)Whether or not the FERP has summarized the conceptual design study of the helical fusion reactor and embodied the numerical targets for each development issue

(3)Whether or not the design study of the helical fusion reactor and the R&D activities of the major components are closely related with each other

2.R&D Study on the Fusion Technology Basis

(1) Whether or not the FERP has served as a COE dedicated for the fusion technology development.

(2) Whether or not the FERP is enhancing the interdisciplinary researches to strengthen the basis of the fusion engineering study

(3) Whether or not the FERP is improving the facilities for the fusion engineering study and enhancing the joint-use and collaboration

(4)Whether or not the FERP is enhancing the collaboration research by utilizing the frameworks of “Bilateral Collaboration Research” and “LHD Project Collaboration Research”

(5)Whether or not the FERP has served as a COE to contribute to the international activities including ITER and BA, jointly with

(6)Whether or not the FERP is providing distinctive education in the field of fusion engineering research, taking advantage of the function as an inter-university research institute

(7)Whether or not the FERP has been closely cooperating with foreign institutions by enhancing researcher exchange and collaboration, based on the international agreements

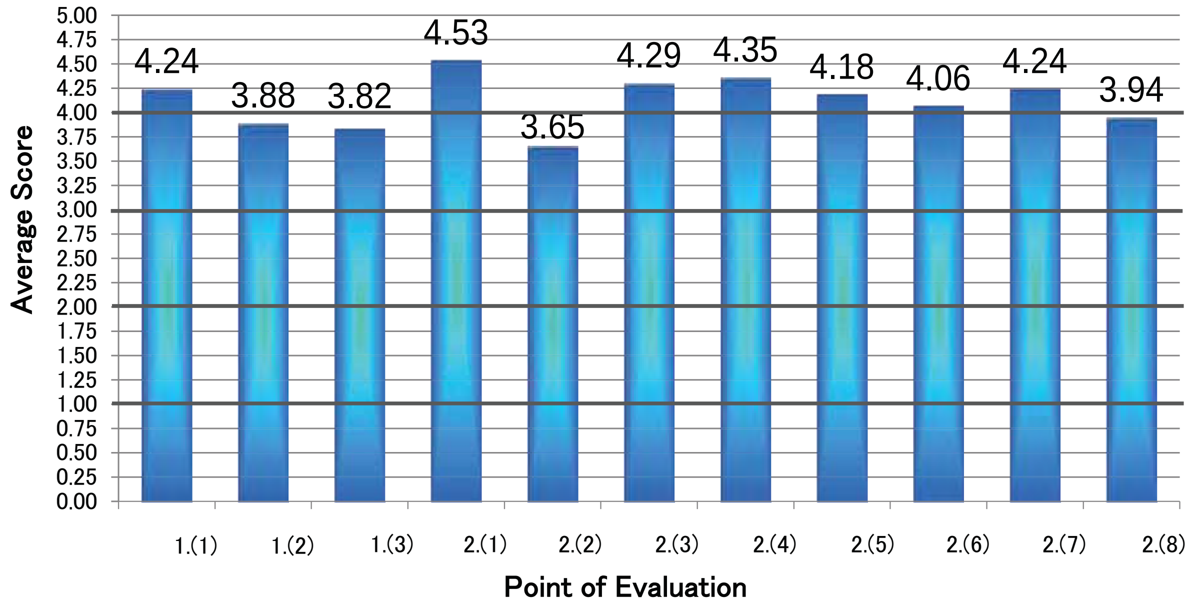
(8)Whether or not the FERP has contributed to creating the research results from universities

Ⅱ. Tabele of Evaluation

Number of persons

Point of Evaluation / Score	1. Design Study on the Helical Fusion Reactor			2. R&D Study on the Fusion Technology Basis							
	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
5 (Extremely highly commmendable)	6	2	4	10	2	7	6	5	3	6	4
4 (Highly commendable)	9	11	7	6	7	8	11	10	12	9	9
3 (Commendable)	2	4	5	1	8	2	0	2	2	2	3
2 (Adequate)	0	0	1	0	0	0	0	0	0	0	1
1 (Inadequate)	0	0	0	0	0	0	0	0	0	0	0
Average Score	**4.24**	**3.88**	**3.82**	**4.53**	**3.65**	**4.29**	**4.35**	**4.18**	**4.06**	**4.24**	**3.94**

※The evaluation result is a combination of the results of domestic committee members (13 persons) and foreign committee members (4 persons).



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