National Institute of Natural Sciences

National Institute for Fusion Science

# NIFS Peer Review Reports in FY2018

March, 2019

National Institute for Fusion Science

Advisory Committee External Peer Review Committee

# Contents


Chapter 1 Background …… 1

Chapter 2 Summary of the Evaluation, and Recommendation …… 5

[1] Summary of Evaluation …… 5

[2] Recommendations …… 10

Chapter 3 In Closing …… 12

Documents

1. 2018 External Peer Review Presentation Materials

References

1. Table of Evaluation Results for the 2018 External Peer Review

# 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 toroidal 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 and fusion research we have organized three research projects, these being LHD, theory and simulation, and reactor engineering. Looking forward toward achieving the fusion reactor, initiated research programs 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) for enhancing further the domestic research collaboration. Upon becoming an inter-university research 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 2015 the Numerical Simulation Reactor Research Project, in 2016 Collaborative Research, and in 2017 the Reactor Engineering Research Project were topics evaluated by external reviewers. This year, 2018, the “Large Helical Device 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, there were two 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 September 18, 2018. 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 1, 2018, the second meeting of the External Peer Review Committee and 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 session also was held. Subsequently, the third meeting of the External Peer Review Committee and the Experts’ Committee was held on January 25, 2109. 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 discussions 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, in the external evaluation regarding “LHD Project” which was implemented this fiscal year, the perspectives for the evaluation were determined as follows. The perspectives for the evaluation are considered indispensable in the evaluation of the “LHD 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, we have consulted the following points in the evaluation which are based upon the recommendations implemented in the External Peer Review Report of the “LHD Project” in 2011 and the “Deuterium Experiment Implementation Planning” in 2014.

**Recommendations in the External Evaluation Review in Fiscal Year Heisei 23:**

(1) It is desired that the LHD as the leading device of inter-university research activities continues to serve as a large scale experimental platform for fusion research in the world.

(2) It is hoped that the installation of closed divertor will be completed and the deuterium experiment will start as soon as possible in order to push the maximization of the LHD capability forward.

(3) It is desired that the LHD activity continuously encompass the work for the ITER project and the BA activities.

(4) It is hoped the LHD project will guide the world's fusion research and produce internationally competitive human resources.

(5) It is desired that a discussion start regarding a plan that looks to the future after the deuterium campaign is completed.

**Recommendations in the External Evaluation Review in Fiscal Year Heisei 26:**

(1) Referencing improvement of confinement and the preparation of both heating devices and diagnostic equipment, which are accompanied by the deuterium experiment, we anticipate that the contribution to a comprehensive understanding of toroidal plasma will be undertaken through deepening further discussion of concrete experiment planning formulation together with enhancing modeling. We anticipate further continuation and support of research networks throughout Japan that focus on neutron diagnostics, tritium recovery, and plasma-wall interaction constructed through joint research aimed at the deuterium experiment.

(2) To begin the deuterium experiment on schedule, we anticipate completion without delay of the formulation of the planning for implementation of preparation, the preparation of equipment, the improvement of facilities, and the establishment of the safety management system, all of which are aimed at the deuterium experiment, under the Division of Deuterium Experiments Management.

(3) Since NIFS has the standing as an inter-university research institute that summarizes research in fusion studies at universities, succeeding safely in completing the deuterium experiment is extremely important. In particular, while respecting laws and regulations, respecting the opinions of local residents, and maintaining an awareness of a good balance of academic development, it is important to respond flexibly. Further, the actual safety management is expected to proceed politely and steadily in such a way that the appointment period for supervisors will overlap and that new supervisors will be appointed appropriately.

(4) We can highly evaluate NIFS' explanations for local residents and cooperation activities with local governing bodies over these many years. From now, through achieving safety management and constant effort, it is hoped that this endeavor will gain understanding and

support for fusion.

**The perspectives for the evaluation**

**[Implementation system and the state of implementation]**

(1) Is the implementation system built to achieve deuterium experiments with coordinating domestic and international researchers? (From the third mid-term plan)

(2) Are preparations of safety management equipment and of facilities and their countermeasures performed appropriately for starting the deuterium experiments? Was the safety management system built as planned? (From the third mid-term plan)

**[Results of initial experiments and future research development]**

(3) Does the LHD project obtain high-performance plasma by the deuterium experiments and produce excellent research achievements with high academic value? (From the third mid-term plan)

(4) Does the LHD project obtain prospects for development of academic research toward a comprehensive understanding of toroidal plasmas? (From the third mid-term plan)

(5) Is preparation of necessary devices and facilities for the main device, heating systems, diagnostics, and others advanced appropriately according to the research plan of the deuterium experiments?

(6) Will the LHD project consider further research development towards the realization of a fusion reactor based on the achievements of the LHD project?

**[Promotion of collaboration]**

(7) Does the LHD project play the role of a global COE in the research with helical devices by constructing and using the research network among domestic and international universities and research institutes?

(8) Does the LHD project promote cooperation with and contribute to ITER/BA? Further, does the LHD project contribute to the research and development of the DEMO reactor? (From the third mid-term plan)

**[Human Resource Development and Efforts toward Understanding by Society]**

(9) Does the LHD project contribute to the human resource development of researchers who are active internationally and lead the domestic and international fusion research?

(10) Does the LHD project cooperate with local governments and engage in deepening the understanding of the deuterium experiments by local residents? Does the project also contribute to achieving a broad social understanding of fusion research?

# Chapter 2 Summary of the Evaluation, and Recommendation

We summarize the key points of the evaluation, and report in writing the recommendation regarding promotion of the LHD Project.

### [ 1 ] Summary of the Evaluation

#### [Implementation system and the state of implementation]

**(1) Is the implementation system built to achieve deuterium experiments with coordinating domestic and international researchers? (From the third mid-term plan)**

Four topical groups centering on the LHD experimental meeting were established, and they operate the systems which have researchers at universities in Japan as chairpersons. A new LHD International Program Committee is established as well as the operating system based on the existing achievement, and the implementation system with an eye to promotion of international collaborative research with foreign institutes is established as well. These systems are highly evaluated. Especially, increasing the number of researchers from abroad since the LHD International Program Committee was established and the improvement of the presence of LHD research are highly evaluated. Open research system is established with transmitting machine time, daily research report, and other communications which are written in English through the Internet. This is also evaluated.

On the other hand, establishing a place to discuss consistency between a domestic collaborative research submission and an experimental submission of LHD International Program Committee, and a place to gather collaborative research results are believed to be necessary.

**(2) Are preparations for safety management equipment and of facilities and their countermeasures done appropriately for starting the deuterium experiments? Was the safety management system built as planned? (From the third mid-term plan)**

Systems to complement the experimental research safely such as establishing the deuterium experiment promotion task force, systematically developing or modifying equipment, and of radiation control and monitoring system were developed. And the deuterium experiment was started and implemented according to the plan. They are highly evaluated. Also, in the radiation safety management system, neutron flux monitors, neutron activation foil, and vertical neutron camera were adopted for neutron yield control, and these measurement instruments are operated appropriately. Tritium yield is controlled tightly. These preparations are also highly evaluated.

Especially, removal rate in tritium removal system exceeded the initial design value of 95% and achieved 99.8%, which is worthy of note. Furthermore, NIFS Safety Monitoring Committee was established based on the agreement and the memorandum with local government bodies, and operated appropriately. This is highly evaluated.

It is necessary to endeavor to secure workers' safety with paying attention to tritium remaining in the vacuum vessel or exhaust system, and appropriate management of radiation protection for workers in vacuum vessel.

On the other hand, there is concern for excessive burden on the NIFS staff regarding safety measures. In order to implement the continuing safety management, it is necessary to conduct a review of necessary matters on a constant basis and devise rational management systems with progress in technology and sophistication of knowledge.

**[Results of initial experiments and future research development]**

**(3) Does the LHD project obtain high-performance plasma by the deuterium experiments and produce excellent research achievements with high academic value? (From the third mid-term plan)**

Early in the deuterium experiments, the initial goal to reach the ion temperature of 10keV was achieved, and the electron temperature of 10keV was obtained with low electron cyclotron heating power. And they are highly evaluated. Knowledge regarding academic understanding of isotope effect is absolutely gained, and the understanding is advanced by applying computational science and theory. Reduction of turbulent transport in the deuterium plasma had been predicted by theoretical research with gyro-kinetic simulation before the deuterium experiment started, which is exceeding high results academically, and is also highly evaluated internationally. Furthermore, the confinement of high-energy particles in the LHD in the Triton burnup experiment is evaluated, and exhibits the confinement property equivalent to equally sized Tokamak devices. And they are evaluated.

On the other hand, many unsolved points and points to be conducted including isotope effect still remain. Thus it is expected to pursue researches continuously and achieve great results. Also, in order to promote research which requires a large budget, it is vitally necessary to be recognized by researchers from other research fields, and it is also necessary to publish the research results in highly evaluated academic journals beyond research fields, and confirm the value.

**(4) Does the LHD project obtain prospects for development of academic research toward a comprehensive understanding of toroidal plasmas? (From the third mid-term plan)**

The direction of research to clarify the differences of characteristics between Deuterium plasma and Hydrogen plasma through sophisticated experimental researches such as advancement of measurement system including D/H ratio measurement method, and behavior of high-energy ions generated by deuterium fusion reaction, is appropriate and highly evaluated. Regarding isotope effect on confinement characteristics, interaction between energetic particles and MHD modes, and others, it is expected that there will be prospects for academic development of comprehensive understanding of toroidal plasma in complementary studies with LHD experiment and theory/simulation. Regarding tritium inventory, it is highly evaluated to make it possible to acquire and verify data.

Regarding isotope effect, we cannot say that there are enough experiment results to confirm the effect, and it is desirable to clarify the complete picture of the isotope effect. We will expect further progress in academic understanding of isotope effect by devising experiment plans with the knowledge gained from computer simulation. However, there would be some limitation to flexibility of experiment because it is necessity to cope with neutron production and tritium production. Further, it would be necessity to discuss the possible range of effectively deepening and extending the research under the limitation of neutron yield. It is required to clarify overall prospects such as engineering tasks and comparisons with theory/simulation further.

**(5) Is preparation of necessary devices and facilities for the main device, heating systems, diagnostics, and others advanced appropriately according to the research plan of the deuterium experiments?**

It is highly evaluated that equipment in the vacuum vessel, gas puffing and solid hydrogen pellet injector, closed divertor pumping, cooling water supply system, plasma heating device, diagnostics device, and relevant analysis code are appropriately prepared for the preparation of devices and facilities for the deuterium experiments. Also, enhancement of detailed measurement of H/D ratio and measurement of edge/divertor region will significantly support clarifying the isotope effect in the future. Thus, we expect the future progress of data-analysis. The monitoring system for tritium concentration in gas from all pumping systems are meaningful to evaluate tritium balance in addition to safety warranty. Further research progress will be expected.

There are possibilities that various control parts malfunction under the neutron production environment, and it is preferable to continue conducting the operation with fail-safe. The negative ion NBI which was optimized for hydrogen is applied to the operation of deuterium, and it caused the operation with performance degradation. Therefore, enhancement and adjustment of the system are required. Since some tritium produced remains in the vacuum vessel, it is necessary to consolidate the systems to measure tritium distribution on protection plate or carbon tiles, and to examine a mechanism of tritium capture.

**(6) Will the LHD project consider further research development towards the realization of a fusion reactor based on the achievements of the LHD project?**

It is evaluated to promote academic research regarding plasma confinement characteristics, plasma instabilities, and behavior of energetic particles with utilizing high-performance plasma which were produced in the deuterium experiments, and develop the physical database required for design and fabrication for the future helical fusion reactor. It is also evaluated to focus on plasma facing material research such as divertor under high heat load environment and the research about behavior of hydrogen isotope in plasma facing material, to accelerate understanding of hydrogen isotope balance in future fusion reactor and to accumulate necessary engineering database for realization of fusion reactor.

For the next step, it is desirable to aim for steady-state sustainment of high performance discharge for the realization of helical type fusion reactor with incorporating future deuterium experiment results. Also, under the high results in LHD, FFHR-d1 and others are examined as demo reactor. It is preferable to be committed to the promotion of more concrete reactor design and research promotion of relevant development matters, including future expected deuterium experiment results. It is desirable to define the academic and the engineering role the LHD experiment will play for the realization of fusion reactor regardless of reactor type, and pursue research with taking a large view of the whole fusion research.

**[Promotion of collaboration]**

**(7) Does the LHD project play the role of a global COE in the research with helical devices by constructing and using the research networks among domestic and international universities and research institutes?**

Domestic network of collaboration researches is built throughout the general collaboration research, the LHD project collaboration research, and the bilateral collaboration research, and the LHD project is highly evaluated to play the role as domestic COE. Japan-United States, Japan-Korea, Japan-China bilateral collaboration researches are advanced actively, and international collaboration researches are advancing under the IEA Stellarator Agreement. Therefore, the LHD project is evaluated to play the role as a international COE. It is necessary to further develop international collaboration research strategically, to develop researches in various field by NIFS researchers as leaders of helical fusion research, and to increase the number of international joint papers.

On the other hand, it is indispensable to visualize research networks among domestic and international universities and institutes and research achievements which are created by the network, and to transmit the research achievement of universities from NIFS, as COE, for the purpose of revitalizing fusion research in universities.

**(8) Does the LHD project promote cooperation with and contribute to ITER/BA? Further, does the LHD project contribute to the research and development of DEMO? (From the third mid-term plan)**

It is evaluated that the LHD project makes large contributions to many research fields such as neutron measurement, ion cyclotron emission measurement, dispersion interferometer, ICRF oscillator, NBI, low temperature equipment, superconducting magnet of JT-60SA, inter connection resistance conductor measurement of ITER conductor sample, and planning of JT-60SA research. Also, three researchers from NIFS joined ITER/BA as members of QST DEMO design joint special team, and they are making large contributions.

However, it is necessity to make more effort to summarize these achievements and contributions statistically, and to transmit the information. Furthermore, it is also necessary to have strategic and active approaches to ITER Project and BA activities. Further contribution to researches in accordance with the MEXT DEMO Action Plan is expected considering the commonality of DEMO development for magnetic confinement fusion systems.

**[Human Resource Development and Efforts toward Understanding by Society]**

**(9) Does the LHD project contribute to the human resource development of researchers who are active internationally and lead the domestic and international fusion research?**

It is highly evaluated that researchers who are active internationally and domestically are fostered through LHD project research. The education of students is conducted at the Graduate University for Advanced Studies, Department of Fusion Science, and each collaborative graduate school. It is also highly evaluated that NIFS accepts students from various universities as special collaborative researchers. Furthermore, NIFS accepts internship students, and the number of the internship students is increasing yearly. They are also highly evaluated.

On the other hand, it is necessity to evaluate how much the LHD project contributes to “the human resource development of researchers who are active internationally and lead the domestic and international fusion research” based on the quantitative results. It is also necessary to give proper roles and numerical goals to human resource development through contributions from universities and collaboration research, and to lead the effort to make the necessary effort for realization.

**(10) Does the LHD project cooperate with local governments and engage in deepening the understanding of the deuterium experiments by local residents? Does the project also contribute to achieving a broad social understanding of fusion research?**

The cooperation through the periodic explanation meetings with three local cities and Gifu Prefecture, NIFS Safety Inspection Committee which is jointly established by local governments, and NIFS Deuterium Experiment Safety Evaluation Committee which are organized by outside leaders including local governments as observers, collaboration research with Toki City Plasma Research Committee, development of satellite-telephone system with local governments, and establishment of Local Community Cooperation Office, are highly evaluated. Additionally, the cooperation with local governments and efforts to gain understanding of the local residents¥ for implementing the deuterium experiment¥ such as acceptance of NIFS facility tour, contribution to science education, and open meetings for local residents, are highly evaluated. “Public Relations Committee” is established, and conducts public relations activities cooperating with Public Relations Enhancement Task Group of the Research Enhancement Strategy Office. This is also highly evaluated.

On the other hand, because the outreach activities are slightly biased toward local areas, it is necessity to conduct public relations activities about the significance and perspective of fusion research by widely extending the target area. It is desirable to establish an outreach headquarters cooperating with QST and universities based on the public relation activities NIFS has conducted, and to take leadership in such activities.

**[ 2 ] Recommendations**

In the present evaluation, we discussed the LHD project in NIFS. Based upon the contents of the discussion, we describe the recommendations regarding the future plan of the LHD project below.

(1) Systematic research regarding isotope effect in torus plasma including helical system is dramatically enhanced by the LHD deuterium experiments. It is desirable to accumulate data and gain academic understanding continuously, and to build up the fusion science research field which can present a quantitative prospect of the research progress.

(2) LHD project should undertake the new development of the LHD project strenuously based on results of the deuterium plasma experiment. In particular, it is necessity to accelerate the development of the steady-state research plan that encompasses the physical and engineering

perspective taking advantage of the steady-state sustainment of high temperature plasma which is the most important features of the LHD.

(3) It is expected to examine the development scenarios for the Helical type fusion reactor which is attractive as a steady-state system. In addition to extracting research topics related to fusion reactors, it is desirable to promote comprehensive research including previous reactor engineering research results.

(4) Regarding the safety measures, it is required to maintain the current safe experimental environment with due consideration to tritium remaining in the LHD and especially the appropriate management of radiation protection for workers in the vacuum vessel. As such, it is desirable to conduct reviews of necessary matters on a constant basis and devise rational and sustainable safety management systems with progress in technology and the sophistication of knowledge.

(5) It is necessary to have a strategic approach to ITER Project and BA activities, and to set sight on the commonality of the DEMO development and make contributions to research and development in accordance with MEXT Action Plan for the DEMO development, as well. Also, it is necessary to make more effort to summarize the achievements and contributions regarding the ITER Project and BA activities statistically, and to transmit information.

(6) It is desirable to lead outreach activities strategically with cooperating with QST and universities in order to develop the public relations activities which NIFS has conducted, and to conduct public relations activities focusing on the significance of fusion research and future perspective nationwide.

# Chapter 3 In Closing

Since 2010, in order to further strengthen the centripetal power of NIFS as a COE in the field of plasma and fusion research we have organized three research projects, these being LHD, theory and simulation, and reactor engineering. Looking forward toward achieving the fusion reactor, NIFS has initiated research programs that will integrate these research 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 their choice. 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 2015 the Numerical Simulation Reactor Research Project, in 2016 the Collaborative Research, and in 2017 the Reactor Engineering Research Project were evaluated. Thus, in this current year of 2018 the Advisory Committee undertook an external evaluation that focused on "The LHD Project." The External Peer Review Committee was composed of the members of the Advisory Committee outside of NIFS and three members from abroad, and, as the experts, two members outside of NIFS and one member from abroad.

**[Evaluation points in External Peer Review in Fiscal Year 2018]**

**[Implementation system and the state of implementation]**

(1) Is the implementation system designed to achieve deuterium experiments coordinating domestic and international researchers? (From the third mid-term plan)

(2) Are the preparations of safety management equipment and of facilities and their countermeasures done appropriately for starting the deuterium experiments? Was the safety management system built as planned? (From the third mid-term plan)

**[Results of initial experiments and future research development]**

(3) Does the LHD project obtain high-performance plasma by the deuterium experiments and produce excellent research achievements with high academic value? (From the third mid-term plan)

(4) Does the LHD project obtain prospects for development of academic research toward a comprehensive understanding of toroidal plasmas? (From the third mid-term plan)

(5) Is preparation of necessary devices and facilities for the main device, heating systems, diagnostics, and others advanced appropriately according to the research plan of the deuterium experiments?

(6) Will the LHD project consider further research development towards the realization of a fusion reactor based on the achievements of the LHD project?

**[Promotion of collaboration]**

(7) Does the LHD project play the role of a global COE in the research with helical devices by constructing and using the research network among domesticuniversities, international universities, and research institutes?

(8) Does the LHD project promote cooperation with and contribute to ITER/BA? Further, does the LHD project contribute to the research and development of DEMO? (From the third mid-term plan)

**[Human Resource Development and Efforts toward Understanding by Society]**

(9) Does the LHD project contribute to the human resource development of researchers who are active internationally and lead the domestic and international fusion research?

(10) Does the LHD project cooperate with local governments and engage in deepening the understanding of the deuterium experiments by local residents? Does the project also contribute to achieving a broad social understanding of fusion research?

The External Peer Review Committee was convened four times from September 2018 through February 2019 including the e-mail discussion committee. Detailed explanations of the evaluation topics were provided from NIFS and active discussions were held. The External Peer Review Committee members summarize evaluation results based on discussion at the committee and submit this report.

As the result of the external evaluation of the “LHD Project,” in general, a recommendation of an exceedingly high evaluation and a high evaluation are received for all of the above evaluation points. Especially building of implementation system with coordinating domestic and international researchers, preparation of safety management equipment and facilities, and building of safety management system, and furthermore, the effort to engage in deepening the understanding of the deuterium experiments by local residents, in particular for starting the deuterium experiments, are highly evaluated. Therefore, we pay respect to NIFS for their sincere effort for the deuterium experiment. The LHD project obtains high-performance plasma by the deuterium experiments steadily. Contribution to comprehensive understanding of toroidal plasmas including the helical type are made. They are also highly evaluated. On the other hand, it is difficult to say that further research development towards the realization of a fusion reactor is highly evaluated at this moment. As mentioned in the recommendation, in addition to undertaking the new development of the LHD project strenuously taking advantage of the steady-state sustainment of high temperature plasma which is the most important feature of the helical type, it is expected to extract research topics toward the steady-state helical fusion reactor, and to construct the development scenarios.

In conclusion, we suggest the following recommendations regarding the future plan of the LHD project.

(1) Systematic research regarding isotope effect in torus plasma including helical system is dramatically progressed by the LHD deuterium experiments. It is desirable to accumulate data and gain academic understanding continuously, and to build up the fusion science research field which can present a quantitative prospect.

(2) LHD project should undertake the new development of the LHD project strenuously based on results of the deuterium plasma experiment. In particular, it is necessary to accelerate the development of the steady-state research plan that encompasses the physical and engineering perspective taking advantage of the steady-state sustainment of high temperature plasma which are the most important feature of the LHD.

(3) It is expected to examine the development scenarios for the Helical type fusion reactor which is attractive as a steady-state system. In addition to extracting research topics related to fusion reactors, it is desirable to promote comprehensive research including previous reactor engineering research results.

(4) Regarding the safety measures, it is required to maintain the current safe experimental environment with due consideration on tritium remaining in the LHD and especially the appropriate management of radiation protection for workers in the vacuum vessel. As such, it is desirable to conduct reviews of necessary matters on a constant basis and devise rational and sustainable safety management system with progress in technology and sophistication of knowledge.

(5) It is necessary to have a strategic approach to the ITER Project and the BA activities, and to set sights on the commonality in the DEMO development and make contributions to research and development in accordance with MEXT Action Plan for DEMO development as well. Also, it is necessary to make more effort to summarize the achievements and the contributions about the ITER Project and BA activities statistically, and to transmit the information.

(6) It is desirable to lead outreach activities strategically with cooperating with QST and universities in order to develop the public relations activities which NIFS has conducted, and to conduct public relations activities regarding the significance of fusion research and future perspective nationwide.

# Documents

1. 2018 External Peer Review Presentation Materials

# LHD Project

**2018 NIFS External Review (Nagoya, Dec. 1, 2018)**



# Objectives of LHD project

LHD started its operation in 1998 to realize high performance reactor relevant plasma in heliotron configuration, clarifying the underlying physics and engineering issues

In the "orange book" published in 1989, main objectives of LHD is shown, as follow,

(1) Realize plasma with a high fusion triple product and conduct extensive confinement study, which can be extrapolated to a fusion reactor

(2) Realize beta exceeding 5 % and explore related physics.

(3) Employ divertor, conduct long pulse experiment and accumulate basic data for steady state operation.

(4) Investigate high energy particles in helical fields and conduct simulation experiment of alpha particles in a reactor plasma.

(5) Conduct complementary study to tokamak and deepen comprehensive understanding of toroidal plasmas.

target:

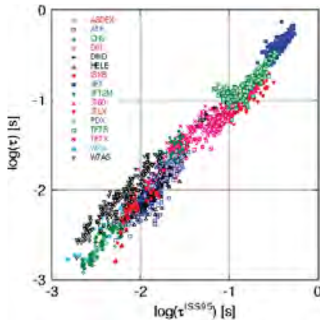
$n\tau T$: $\langle T\rangle$ = 3-4 keV, $\langle n\rangle = 1\times10^{20}$ m$^{-3}$, $\tau_E$ = 0.1-0.3s

$T_i(0)$ = 10 keV with $\langle n\rangle = 2\times10^{19}$ m$^{-3}$

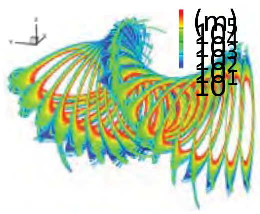
$\langle\beta\rangle \geqq 5\%$, B = 1-2 T

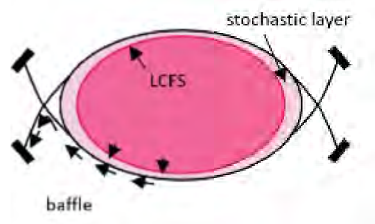
# Physics, progressed

*LHD has demonstrated potential of heliotron*




- thermal transport in LHD presents gyro-Bohm nature
- observation of non-local transport
- operational regime and path to achieve high beta plasma
- 3-d effect on
  - transport (viscosity) => neoclassical, turbulent (zonal flow)
  - MHD stability (magnetic topology) => island
  - edge (stochastic region) => detachment, ELM control






- edge heat and particle control with divertor
  - etc.



# What is expected in deuterium experiment

| Device | country | improvement factor |
| --- | --- | --- |
| JFT-2M | Japan | 1.1 – 1.4 |
| JT-60U | Japan | 1.2 – 2 |
| Alcator-C | USA | 1.5 |
| DIII-D | USA | 1.4 – 2 |
| ISX-B | USA | 1.4 |
| TFTR | USA | 1.2 |
| ASDEX | Germany | 1.3 – 2 |
| ASDEX-U | Germany | 1.5 |
| TEXTOR | Germany | 1.4 |
| JET | EU | 1.2 – 1.4 |
| FTU | Italy | 1.4 |

Confinement improvement by a factor of ~ 1.4 was observed in deuterium experiment in many tokamaks.

However, little improvement has been seen in small/medium helical devices.

Obvious improvement is expected in LHD with divertor

# Objectives of the LHD deuterium experiment

*LHD should demonstrate potential of the helical reactor*

1. Achievement of high-performance plasmas through confinement improvement
   - ✓ Scientific research in more reactor-relevant conditions
2. Clarification of isotope effect on confinement
   - ✓ Long-standing mystery in world fusion research
   - ✓ Needs to be understood towards burning plasma
3. Demonstration of confinement capability of energetic ions in helical systems
   - ✓ Perspectives towards helical reactor
4. Enhanced PWI studies using hydrogen isotopes
   - ✓ Global particle balance



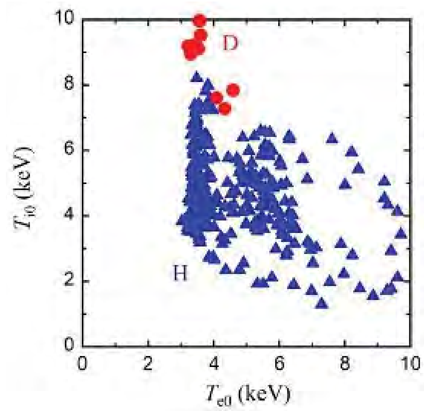
# Annual Plan for LHD Deuterium Experiment

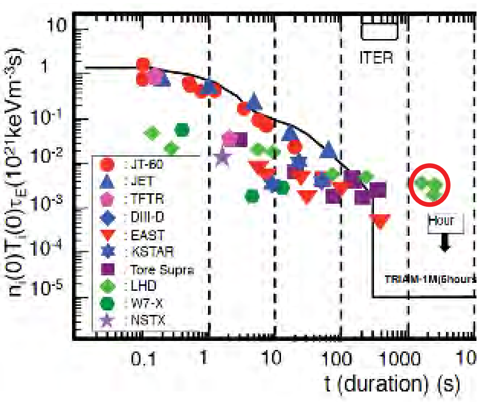
| | First 6 years | | Second 3 years | |
|---|---|---|---|---|
| FY | 1st year | 2nd – 6th year | 7th – 9th year | After 10th year |
| Experiments | Preliminary Exp. (Commissioning) | Plasma Exp. For Target Parameters | Integrated High-Performance Exp. | Post-LHD Project |
| Maximum Annual Yield of Tritium | $3.7x10^{10}$ Bq (1 Ci) (Integrated yield) | | $5.55x10^{10}$ Bq (1.5 Ci) (Integrated yield) | --- |
| Maximum Annual Discharge of Tritium | $3.7x10^{9}$ Bq (0.1 Ci) (Integrated yield) | | | --- |
| Maximum Annual Yield of Neutron | $2.1x10^{19}$ (Integrated yield) | | $3.2x10^{19}$ (Integrated yield) | --- |

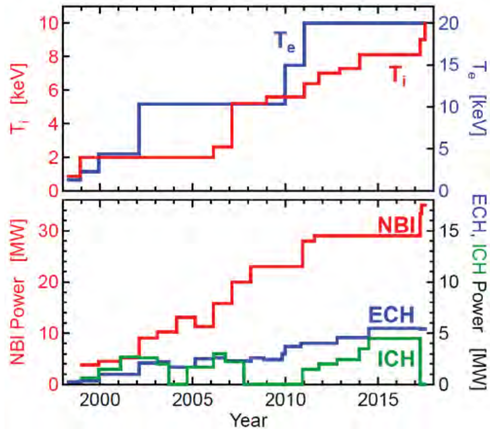
# Parameters, achieved

*LHD extended its operational regime with D plasma*

| | |
|---|---|
| $T_i$ | 10 keV ($n_e$ = 1.3 ×$10^{19}$ $m^{-3}$) |
| $T_e$ | 20 keV (2.0 ×$10^{18}$ $m^{-3}$)<br>10 keV (1.6 ×$10^{19}$ $m^{-3}$) |
| $n_e$ | 1.2×$10^{21}$$m^{-3}$ ($T_e$ = 0.25 keV) |
| $\beta$ | 5.1 % ($B_T$ = 0.425 T)<br>4.1 % (1.000 T) |
| *Δt* duration | 54min. 28sec (0.5MW, 1keV, 4.0×$10^{18}$$m^{-3}$)<br>47min. 39sec. 3.36GJ (1.2MW, 2keV, 1.2×$10^{19}$$m^{-3}$) |






# Recommendations in the External Evaluation Review 2014

(1) Referencing improvement of confinement that is accompanied by the deuterium experiment and the preparation of both heating devices and diagnostic equipment, through deepening further discussion of concrete experiment planning formulation together with enhancing modeling we anticipate that this will contribute to a comprehensive understanding of toroidal plasma. We anticipate further continuation and support of research networks throughout Japan that focus on neutron diagnostics, tritium recovery, and plasma-wall interaction constructed through joint research aimed at the deuterium experiment.

重水素実験に伴う閉じ込め改善及び加熱機器や計測機器の整備を踏まえ、具体的な実験計画策定に向けた議論を更に深めるとともにモデリングを充実させることにより、トロイダルプラズマの包括的理解に貢献することを期待する。重水素実験に向けた共同研究により形成された中性子計測、トリチウム回収、プラズマ壁相互作用等の全国的な研究ネットワークを今後も継続・維持することを期待する。

(2) To begin the deuterium experiment on schedule, and under the Division of Deuterium Experiments Management, we anticipate completion without delay of the formulation of preparation implementation planning, the preparation of equipment, the improvement of facilities, and the establishment of the safety management system, all of which are aimed at the deuterium experiment.

重水素実験を当初の予定通りに開始すべく、新たに設置された重水素実験推進本部の下で、重水素実験に向けた整備実施計画の策定並びに設備の整備、施設の改修、安全管理体制の確立等を遅延なく完了させることを期待する。



Recommendations in the External Evaluation Review 2014

(3) NIFS has the standing as an inter-university research institute that summarizes research in fusion studies at universities, and succeeding safely in completing the deuterium experiment is extremely important. In particular, while respecting laws and regulations, respecting the opinions of local residents, and maintaining an awareness of a good balance of academic development, it is important to respond flexibly. Further, regarding the actual safety management, it is expected that the appointment period for supervisors will be overlapped and that new supervisors will be appointed appropriately, and that this will proceed politely and steadily.

核融合科学研究所は大学における核融合科学の研究を取りまとめる立場であり、重水素実験を安全に成功裏に完結することはきわめて大切である。特に、法令の遵守、地元の意見の尊重、学術の発展のバランス良い感覚を維持しながら、柔軟に対応していくべきと思われる。また実際の安全管理に関しては、主任者の選任期間を重複させ適切に交代するなど、丁寧かつ堅実に進めることが望まれる。

# Recommendations in the External Evaluation Review 2014

(4) We can highly evaluate NIFS' explanations for local residents and cooperation activities with local governing bodies over these many years. From now, through achieving safety management and constant effort, it is hoped that this endeavor will gain understanding and support for fusion.

核融合科学研究所が長年にわたって行ってきた地元市民への説明、自治体との連携活動への努力は高く評価でき、今後も安全管理に対する実績と不断の実践を通じて、核融合に対する理解と支援を得るべく務めることが望まれる。



# Issues for Evaluation (1)

**(Implementation system and the state of implementation)**
（実施体制・実施状況）

1. Is the implementation system built to achieve deuterium experiments with coordinating domestic and international researchers? (From the third mid-term plan)
   国内外の研究者を取りまとめて重水素実験を実施する体制が構築されているか。
   （第三期中期計画より）

2. Is preparations of safety management equipment and of facilities and their countermeasures done appropriately for starting the deuterium experiments? Was the safety management system built as planned? (From the third mid-term plan)
   重水素実験の開始にあたり、安全管理機器・設備等の整備や対応策が適切になされるとともに、安全管理体制が計画通り確立されているか。
   （第三期中期計画より）

# Issues for Evaluation (2)

**(Results of initial experiments and future research development)**
初期実験の成果と今後の研究展開

3. Does the LHD project obtain high-performance plasma by the deuterium experiments and produce excellent research achievements with high academic value? (From the third mid-term plan)
重水素実験でプラズマの高性能化が図られ、学術的価値の高い成果が得られているか。

4. Does the LHD project obtain prospects for development of academic research toward a comprehensive understanding of toroidal plasmas? (From the third mid-term plan)
環状プラズマの総合的な理解に向けた学術研究の展開の見通しが得られているか。

5. Is preparation of necessary devices and facilities for the main device, heating systems, diagnostics, and others advanced appropriately according to the research plan of the deuterium experiments?
研究計画に従って、装置本体、加熱、計測、周辺機器などの整備等が進められているか。

6. Will the LHD project consider further research development towards the realization of a fusion reactor based on the achievements of the LHD project?
プロジェクトの成果を踏まえて、核融合炉実現に向けた今後の研究展開を検討しているか。



# Issues for Evaluation (3)

**(Promotion of collaboration)**

7. Does the LHD project play the role of a global COE in the research with helical devices by constructing and using the research network among domestic and international universities and research institutes?
国内外の大学や研究機関との研究ネットワークが構築・活用され、ヘリカル型装置研究における国内外のCOEとしての役割を果たしているか。

8 Does the LHD project promote cooperation with and contribute to ITER/BA? Further, does the LHD project contribute to the research and development of a reactor? (From the third mid-term plan)
ITER計画・BA活動との連携、貢献が行われているか。また、原型炉研究開発に寄与しているか。

# Issues for Evaluation (4)

**(Human Resource Development and Efforts toward Understanding by Society)**
人材育成、社会の理解へ向けた取り組み

9. Does the LHD project contribute to the human resource development of researchers who are active internationally and lead the domestic and international fusion research?
国内外の核融合研究を牽引し、国際的にも活躍する人材の育成に貢献しているか。

10. Does the LHD project cooperate with local governments and engage in deepening the understanding of the deuterium experiments by local residents?
自治体との連携を図るとともに、重水素実験に対する地域住民の理解を深める取組みを行っているか。



# IMPLEMENTATION SYSTEM AND THE STATE OF IMPLEMENTATION

# Issues for Evaluation (1)

➢ **Implementation system and the state of implementation**
（実施体制･実施状況）

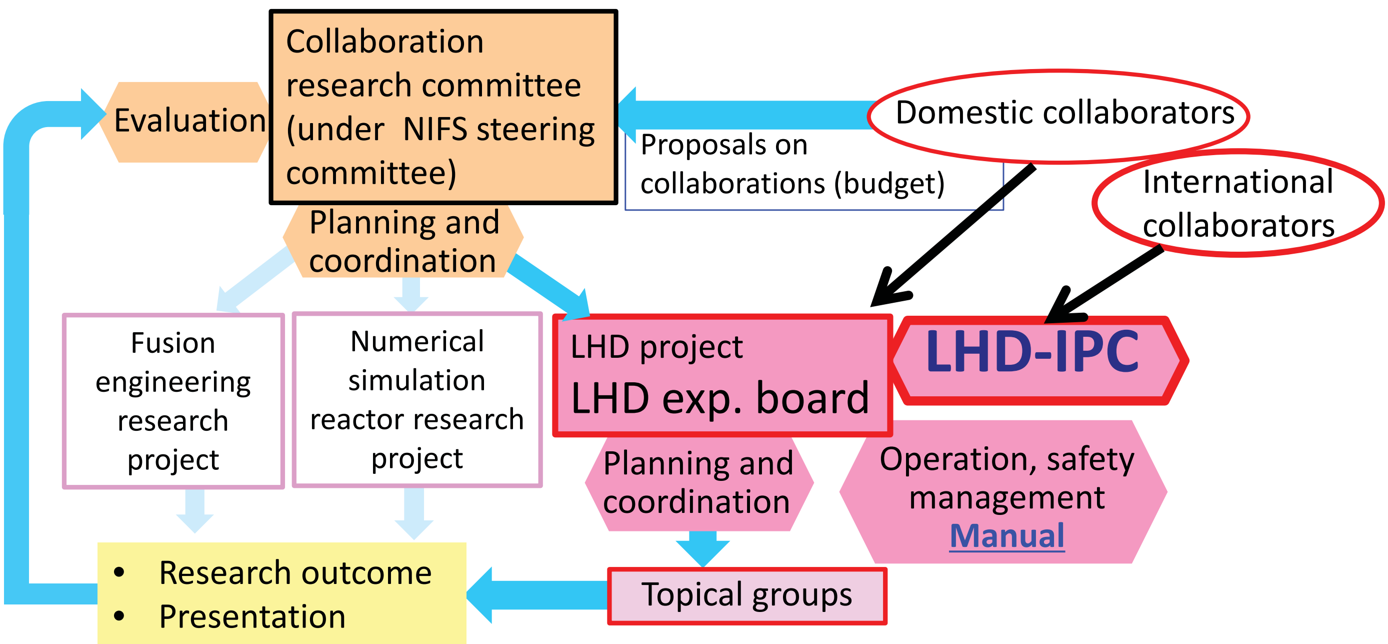
1. Is the implementation system built to achieve deuterium experiments with coordinating domestic and international researchers? (From the third mid-term plan)
国内外の研究者を取りまとめて重水素実験を実施する体制が構築されているか。（第三期中期計画より）

2 Is preparations of safety management equipment and of facilities and their countermeasures done appropriately for starting the deuterium experiments? Was the safety management system built as planned? (From the third mid-term plan)



# LHD project collaboration system

LHD experiment is governed by **LHD experiment board** which consists of division directors, topical group leaders, directors of engineering divisions.



# Topical groups and leaders

May 23, 2018

| Topical Group | NIFS | Universities |
| --- | --- | --- |
| High performance plasma | ***Hiromi TAKAHASHI**<br>Kiyofumi MUKAI,<br>*Collaborating with*<br>*Tatsuya KOBAYASHI, Kenji TANAKA, Suguru MASUZAKI, Yasuhiro SUZUKI* | ***Sadayoshi MURAKAMI** (Kyoto University)<br>Akira EJIRI (University of Tokyo) |
| Transport and confinement | ***Kenji TANAKA**<br>Mikiro YOSHINUMA<br>Tohru TSUJIMURA | ***Shigeru INAGAKI** (Kyushu University)<br>Shinsuke OHSHIMA (Kyoto University) |
| Edge, divertor, atomic and molecular processes | ***Suguru MASUZAKI**<br>Chihiro SUZUKI<br>Tetsutaro OISHI | ***Mizuki SAKAMOTO** (University of Tsukuba)<br>Hirohiko TANAKA (Nagoya University) |
| High beta, MHD, energetic particles | ***Yasuhiro SUZUKI**<br>Kunihiro OGAWA<br>Yoshiro NARUSHIMA | ***Kazunobu NAGASAKI** (Kyoto University)<br>Takumi ONCHI (Kyushu University) |

***Principal**



# LHD International Program Committee (LHD-IPC)

To enhance the international collaboration on LHD, **LHD-IPC** was established, and first meeting was held in Kyoto in Oct. 2016

June 6, 2018

*Overseas*
X. Duan (SWIP)
P. Gohil (GA)
C. Hidalgo (CIEMAT)
W. Heidbrink (UC Irvine)
L. Hu (ASIPP)
H.K. Park (NFRI)
B. Pégourié (CEA/IRFM)
Maria-Ester Puiatti (RFX)
U. Stroth (IPP-Garching)
R. Wolf (IPP-Greifswald)
M. Zarnstorff (PPPL)

*LHD board members*
T. Morisaki
M. Osakabe
S. Kubo
S. Sakakibara

*Topical Group Leaders (2018-2019 campaign)*
H. Takahashi (NIFS)
S. Murakami (Kyoto U.)
K. Tanaka (NIFS)
S. Inagaki (Kyushu U.)
S. Masuzaki (NIFS)
M. Sakamoto (U. Tsukuba)
Y. Suzuki (NIFS)
K. Nagasaki (Kyoto U.)

1st: Kyoto (Oct. 21, 2016) 21
2nd: Kyoto (Oct. 4, 2017) 16+4
3rd: NIFS (Sep. 19, 2018) 15+8

# International Workshop on LHD Deuterium Experiment

**International Workshop on LHD Deuterium Experiment (LHD D-WS)**
**9-10, February 2016**
**NIFS (Administration Building 4th floor, Meeting Room #1)**

**9 February (Tue)**

| | | |
|---|---|---|
| **Chair: T.Morisaki (NIFS)** | | |
| 10:05-10:10 | Y. Takeiri (NIFS) | Welcome Address |
| 10:10-10:40 | M. Osakabe (NIFS) | Plans of LHD deuterium experment |
| 10:40-11:10 | S. Sakakibara (NIFS) | Diagnostics capabilities on LHD deuterium experiment |
| 11:10-11:40 | U. Stroth (IPP Garching) | 25 years of research on the isotope effect |
| 11:40-12:10 | P. Gohil (GA) | H-mode studies in hydrogen, helium and deuterium plasmas in DIII-D |
| | Lunch | |
| **Chair: B.Pégourié (CEA/IRFM)** | | |
| 13:00-13:30 | K. Tanaka (NIFS) | H/D comparison experiments in CHS and H/He comparison experiments in LHD |
| 13:30-14:00 | S. Murakami (Kyoto Univ.) | Integrated simulation of deuterium experiment plasma of LHD |
| 14:00-14:30 | M. Zarnstorff (PPPL) | Species scaling in TFTR and Ideas for LHD |
| 14:30-15:00 | F. Auriemma (Consorzio RFX) | The RFX-mod experience on the isotope effect |
| | Coffee Break | |
| **Chair: Y.Xu (SWIP)** | | |
| 15:20-15:50 | S. Ohshima (Kyoto Univ.) | Isotope effects on long range correlation and turbulence in Heliotron J |
| 15:50-16:20 | C. Hidalgo (CIEMAT) | Influence of the isotope mass on fluctuations and transport in tokamaks and stellarators (particularly TJ-II, ISTTOK and JET) |
| 16:20-16:50 | M. Yagi (JAEA) | Isotope Effect on MHD/Transport and Related Issue |
| 16:50-17:30 | M. Nakata (NIFS) | Gyrokinetic turbulence simulation researches for heliotron and stellarator plasmas with hydrogen isotope |
| 17:30-17:50 | M. Nunami (NIFS) | Anomalous and neoclassical transport of impurity ions in LHD plasmas |
| 18:10 | Bus departs for workshop dinner | |

**10 February (Wed)**

| | | |
|---|---|---|
| **Chair: C.Hidalgo (CIEMAT)** | | |
| 9:10-9:40 | K. Ogawa (NIFS) | Study on Energetic Ion Confinement in LHD Deuterium Experiment |
| 9:40-10:10 | Y. Xu (SWIP) | Edge turbulence and isotopic dependence - a comparative study between tokamaks and stellarators |
| | Coffee Break | |
| **Chair: U.Stroth (IPP Garching)** | | |
| 10:30-11:20 | K. Itoh (NIFS) | Detection of Isotope Effect via Hysteresis in Transport Relation |
| 11:20-11:50 | S. Yoon (NFRI) | Recent Progress of KSTAR Research: including Issues with Deuterium Operation and Potential Collaboration Topics |
| | Lunch | |
| **Chair: M.Zarnstorff (PPPL)** | | |
| 13:00-13:40 | B. Lyu (ASIPP) | Curent status of EAST and future plan |
| 13:40-14:10 | H. Kasahara (NIFS) | Developments of steady-state plasma duration in the LHD and significances of international collaborations in long-pulse plasma devices |
| 14:10-14:55 | B. Pégourié (CEA/IRFM) | Particle balance and fuel retention in a carbon-dominated device: the example of Tore Supra |
| | Coffee Break | |
| 15:10-16:10 | | Summary and Discussion on international collaborations |

**The 2nd International Workshop on LHD Deuterium Experiment (LHD D-WS)**
**7-8, February 2018**
**NIFS (Administration Building 4th floor, Meeting Room #1)**

**7 February (Wed.)**

| | | |
|---|---|---|
| **Chair: M. Osakabe (NIFS)** | | |
| 10:00-10:10 | Y. Takeiri (NIFS) | Welcome Address |
| 10:10-10:40 | K. Ogawa (NIFS) | Enhancement of energetic-ion confinement studies by using comprehensive neutron diagnostics in the Large Helical Device |
| 10:40-11:10 | S. Murakami (Kyoto U.) | Simulation study of fusion reaction rate and comparisons with experimental results in LHD |
| 11:10-11:40 | H. Matsuura (Kyushu U.) | Observation of a knock-on tail in LHD deuterium plasmas |
| 11:40-12:10 | Makoto Kobayashi (NIFS) | First measurements of neutron flux distribution in LHD torus hall generated by deuterium plasma experiment |
| | *Lunch* | |
| **Chair: B. Pégourié (CEA/IRFM)** | | |
| 13:30-14:00 | K. Nagaoka (NIFS) | Transport characteristics of ion internal transport barrier plasma in LHD |
| 14:00-14:30 | K. Mukai (NIFS) | Carbon impurities behavior in high-ion-temperature deuterium discharges on LHD |
| 14:30-15:00 | T. Oishi (NIFS) | Effect of deuterium plasmas on carbon impurity transport in the edge ergodic layer of Large Helical Device |
| 15:00-15:30 | P. A. Schneider (IPP-Garching) | Challenging the isotope effect myth |
| | *Coffee Break* | |
| **Chair: H-S. Bosch (IPP-Greifswald)** | | |
| 16:00-16:30 | H. Yamada (NIFS) | Isotope effect on energy confinement and thermal transport of dimensionally similar NBI heated plasmas in LHD |
| 16:30-17:00 | K. Tanaka (NIFS) | Isotope effects on transport and turbulence in ECRH plasma of LHD |
| 17:00-17:30 | F. Warmer (IPP-Greifswald) | Energy confinement of hydrogen and deuterium electron-root plasmas in the Large Helical Device |
| 17:30-18:00 | M. Nakata (NIFS) | Gyrokinetic simulation studies of isotope effects on turbulent transport in LHD |
| 18:10-19:15 | *Banquet (NIFS cafeteria)* | |

**8 February (Thur.)**

| | | |
|---|---|---|
| **Chair: Y. Todo (NIFS)** | | |
| 10:00-10:30 | K. Watatabe (NIFS) | Dependence of RMP penetration threshold on plasma parameters and ion species in helical plasmas |
| 10:30-11:00 | S. Ohdachi (NIFS) | Helically-trapped energetic particle driven resistive interchange mode in the deuterium experimental campaign |
| 11:00-11:30 | H. Nuga (NIFS) | Fokker-Planck analysis of beam slowing down process in LHD |
| 11:30-12:00 | H. Sugama (NIFS) | Theory and simulation researches in neoclassical and turbulent transport |
| | *Lunch* | |
| **Chair: S. Kubo (NIFS)** | | |
| 13:30-14:00 | H-S. Bosch (IPP-Greifswald) | Progress in W7-X experiments, and outlook for OP1.2b and beyond |
| 14:00-14:30 | K. Ikeda (NIFS) | Exploring deuterium beam operation and behavior of Co-extracted electron in negative ion based neutral beam injector |
| 14:30-15:00 | M. Tanaka (NIFS) | Behavior and mass balance of hydrogen isotope in exhaust gas from LHD |
| 15:00-15:40 | B. Pégourié (CEA/IRFM) | From Carbon to Tungsten walls, plasma wall interaction research in Tore Supra and WEST |
| | *Coffee Break* | |
| **Chair: S. Sakakibara (NIFS)** | | |
| 16:00-16:30 | S. Masuzaki (NIFS) | Study of the divertor plasma in H, D and He discharges in LHD |
| 16:30-17:00 | G. Motojima (NIFS) | Edge neutral particle control with a closed helical divertor pumping in LHD |
| 17:00-17:30 | K. Ida (NIFS) | Isotope effect on impurity and bulk ion particle transport in Large Helical Device |
| 17:30-18:00 | T. Morisaki (NIFS) | Summary, outlook, and discussion on international collaborations |



# Information transmission for LHD experiment

English portal site for LHD experiment is open for collaborators, by which one can get, e.g., machine time allocation table, daily/weekly schedule, daily report, specifications of diagnostics, heating devices, etc.

# Issues for Evaluation (1)

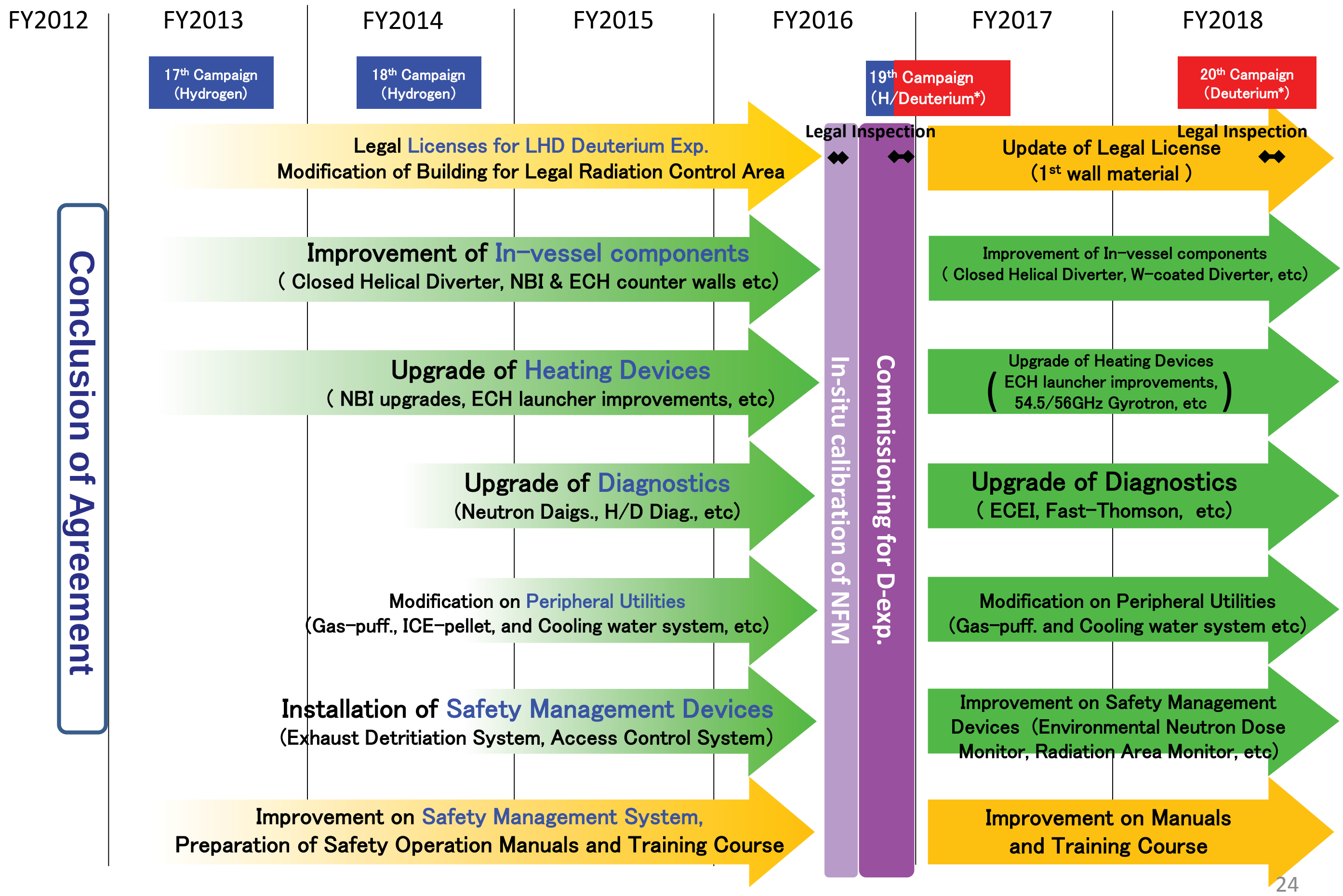
➢ **Implementation system and the state of implementation**

(1) Is the implementation system built to achieve deuterium experiments with coordinating domestic and international researchers? (From the third mid-term plan)

(2) Is preparations of safety management equipment and of facilities and their countermeasures done appropriately for starting the deuterium experiments? Was the safety management system built as planned? (From the third mid-term plan)
重水素実験の開始にあたり、安全管理機器・設備等の整備や対応策が適切になされるとともに、安全管理体制が計画通り確立されているか。
（第三期中期計画より）

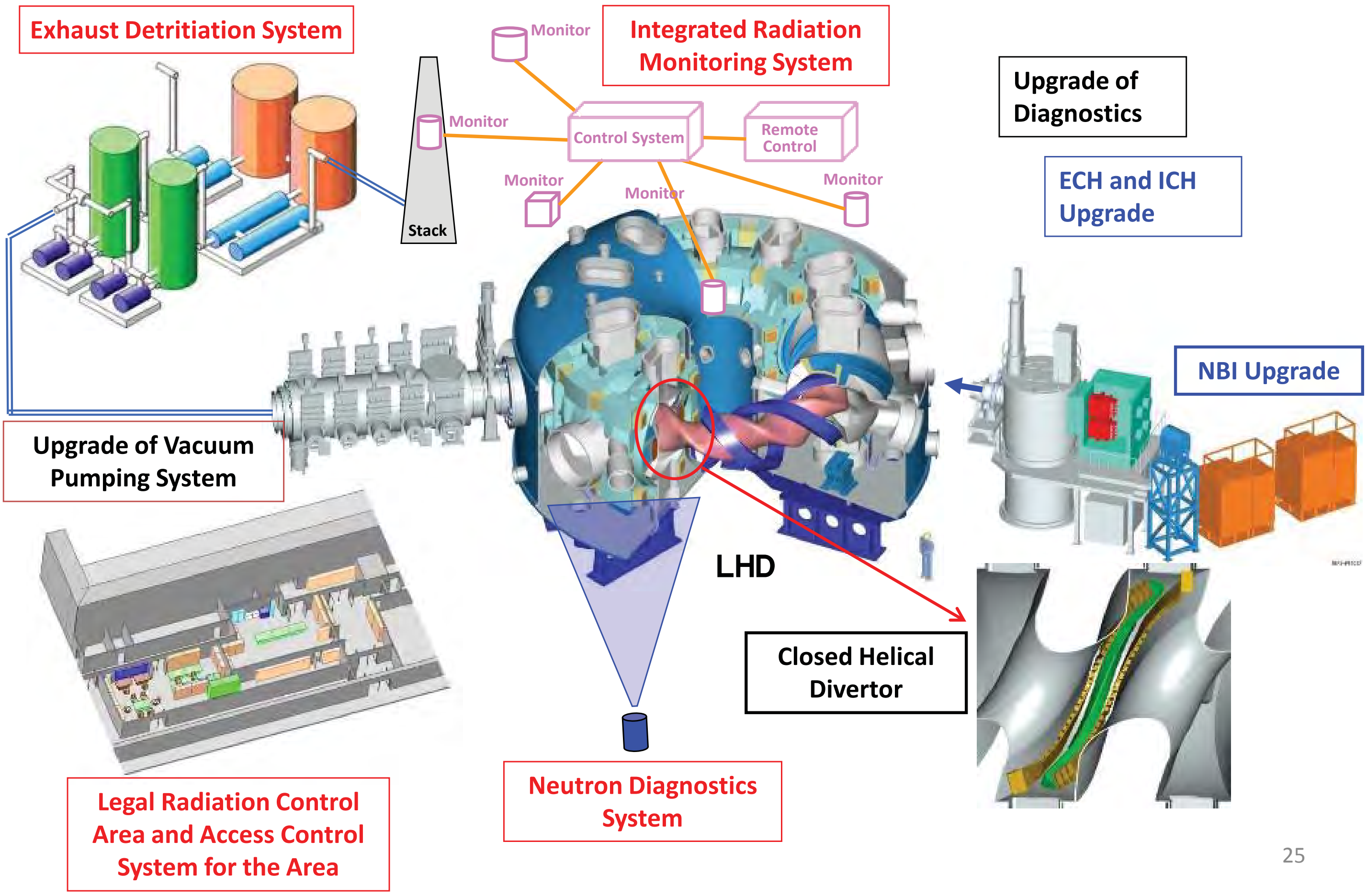


# Schedules of device upgrades, modification and installation for Deuterium Experiment




*Hydrogen operation is performed during the last one month of D-exp.

# Upgraded and newly installed devices for the LHD Deuterium Experiment






# Preparation for the initiation of deuterium experiment

- Deuterium experiment management division is responsible for the preparation and implementation of the LHD deuterium experiment.
- D-exp management division mainly consists of division directors of NIFS, including safety-related divisions, which enables fast decision and top-down implementation.
- Under the D-exp management division, Deuterium Experiment Preparation Task Force (DEPTF)*, carries out the design and construction for individual items including the safety management, according to the planned preparation schedule for the initiation of the deuterium experiment.

Member list of ATFDE, which is a successor to DEPTF

重水素実験推進支援グループ名簿

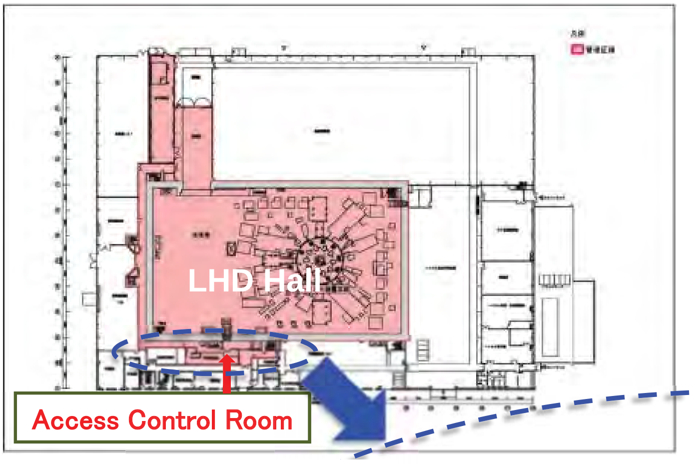
平成３０年１０月１５日現在

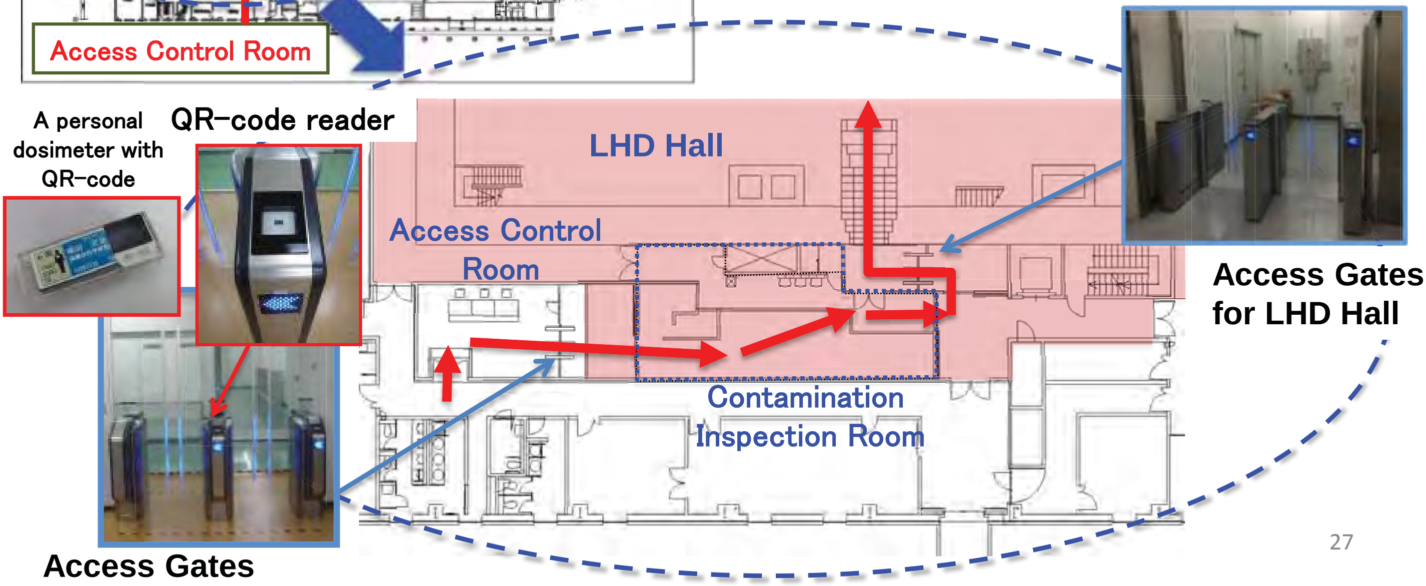
| | | |
|---|---|---|
| 磯部光孝 | 高温プラズマ物理研究系 | 教授 |
| 長壁正樹 | 大型ヘリカル装置計画実験統括主幹・重水素実験推進本部長・教授 | |
| 西村清彦 | 安全衛生推進部長・重水素実験推進本部副本部長・教授 | |
| 森崎友宏 | 大型ヘリカル装置計画研究総主幹・高密度プラズマ物理研究系主幹・教授 | |
| 坂本隆一 | 高密度プラズマ物理研究系 | 教授 |
| 庄司　主 | 高密度プラズマ物理研究系 | 准教授 |
| 本島　厳 | 高密度プラズマ物理研究系 | 准教授 |
| 成嶋吉朗 | 高密度プラズマ物理研究系 | 助教 |
| 中西秀哉 | 高温プラズマ物理研究系 | 准教授 |
| 向井清史 | 高温プラズマ物理研究系 | 助教 |
| 小川国大 | 高温プラズマ物理研究系 | 助教 |
| 西谷健夫 | 高温プラズマ物理研究系 | 特任教授 |
| 関　哲夫 | プラズマ加熱物理研究系 | 准教授 |
| 吉村泰夫 | プラズマ加熱物理研究系 | 准教授 |
| 木崎雅志 | プラズマ加熱物理研究系 | 助教 |
| 今川信作 | 装置工学・応用物理研究系 | 教授 |
| 田中照也 | 装置工学・応用物理研究系 | 准教授 |
| 赤田尚史 | 装置工学・応用物理研究系 | 准教授 |
| 佐瀬卓也 | 装置工学・応用物理研究系 | 准教授・放射線取扱主任者 |
| 濱口真司 | 装置工学・応用物理研究系 | 准教授 |
| 小林　真 | 装置工学・応用物理研究系 | 助教 |
| 増崎　貴 | 核融合システム研究系 | 教授 |
| 時谷政行 | 核融合システム研究系 | 助教 |
| 矢嶋美幸 | 核融合システム研究系 | 助教 |
| 林　浩 | 計測技術課 | 課長 |
| 横田光弘 | 計測技術課 | 課長代理 |
| 小渕　隆 | 計測技術課 | 係長 |
| 大砂真樹 | 計測技術課 | 係長 |
| 林　浩己 | 装置技術課 | 課長 |
| 安井孝治 | 装置技術課 | 課長代理 |
| 上伏順之 | 装置技術課 | 係長 |
| 鈴木直之 | 装置技術課 | 係長 |
| 野村吾郎 | 加熱技術課 | 課長代理 |
| 伊藤　哲 | 加熱技術課 | 係長 |
| 渋谷真之 | 加熱技術課 | 係長 |
| 駒田誠司 | 加熱技術課 | 技術職員 |
| 施設・安全管理課 | | |
| 三宅　均 | 核融合科学研究所 | シニア・アドバイザー・放射線取扱主任者 |

***The DEPTF is renamed to Assistance Task Force for Deuterium Experiment implementation (ATFDE) after the start of LHD D-exp.**

# Establishment of the Legal Radiation Controlled Area (LRCA)

- **Personnel access to the LRCA must pass through the access control room.**
- **The access is also controlled by the personnel authentication with QR-code at access gates placed at the entrance room of LRCA.**





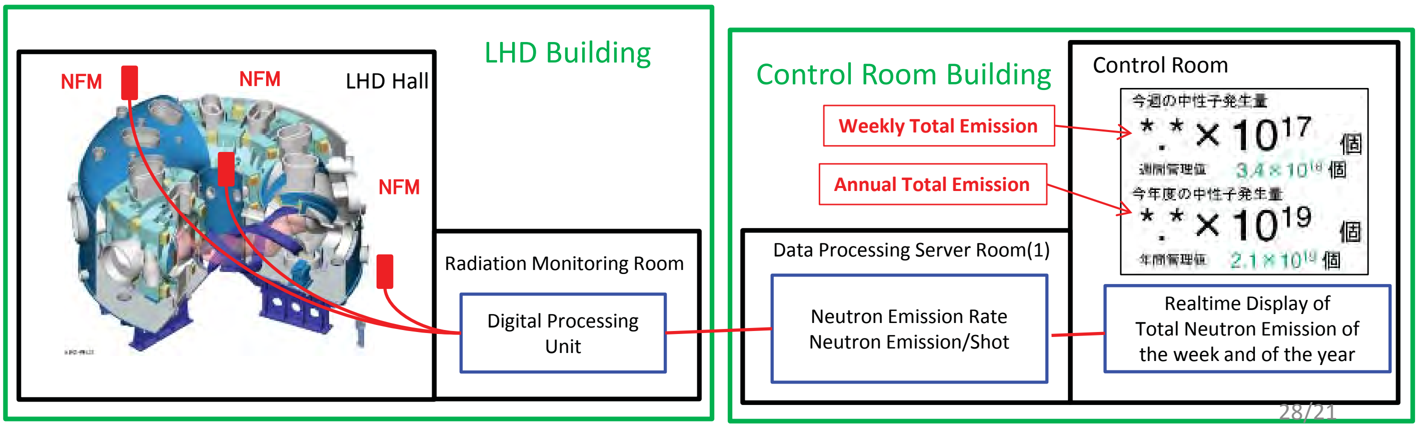

# Neutron and tritium measurements and control

Amount of neutron and tritium production must be grasped for the safety control of deuterium experiment.

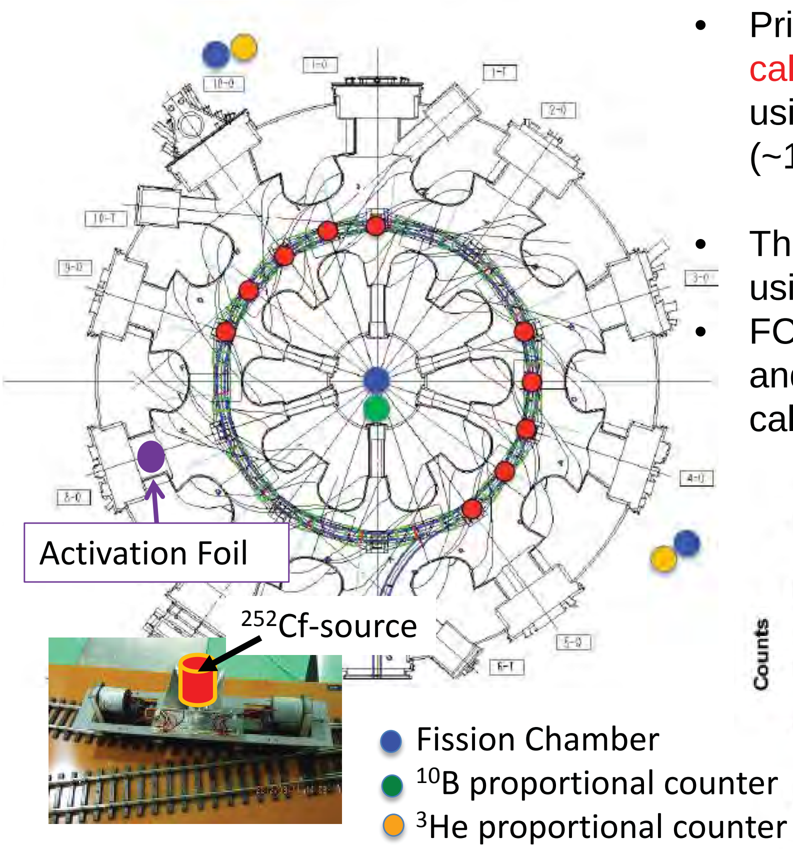
D + D → (50%) T + p
D + D → (50%) $^3$He + n

**Number of Tritium = Number of Neutron** ➡ Tritium production rate can be evaluated from neutron emission rate.

Annual total neutron (tritium) yield must be smaller than $2.1\times10^{19}$[n] (37[GBq])for the first 6 years, while the amount must be smaller than $3.2\times10^{19}$[n] (55.5[GBq])for the last 3 years

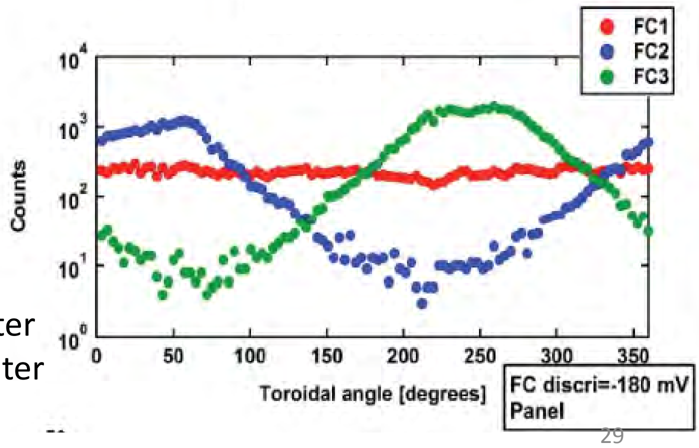


# Calibration of Neutron Diag.




- Prior to D-exp. an in situ neutron calibration experiment was carried out by using a $^{252}$Cf neutron source of 800 MBq (~1x10$^{8}$[n/s]) in November 2016.

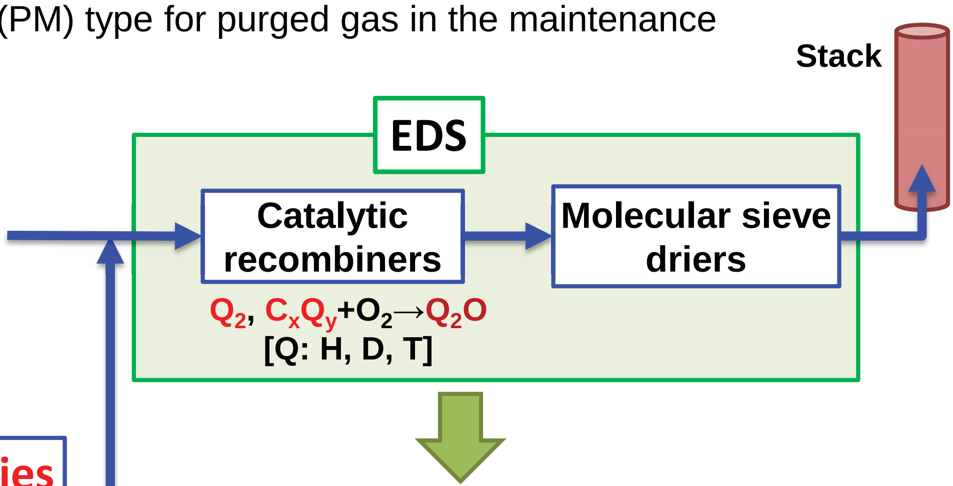
- The source was circulated in the tours using a toy train.
- FC, $^{3}$He-, and $^{10}$B -proportional counter and activation foil system (8-o) were calibrated






# Exhaust Detritation System (EDS)

Two types of exhaust detritiation system were installed.
- Molecular sieve (MS) type for exhausted gas in the vacuum pumping during plasma experiments
- Polyimide membrane (PM) type for purged gas in the maintenance




**All Peripheral Facilities Using Vacuum Pumps**

**NBIs, Gas puff,**
**Ice pellet injector, and**
**Plasma diagnostics, etc**

**<u>Initial operation results</u>:**
**(Mar. 6 – May 22, 2017)**
**Tritium recovery rate > 99.8 %**
**Cf. > 95% (Designed)**

- All of the tritium exhausted from the vacuum vessel of the peripheral facilities as well as LHD are monitored at the entrance of the EDS.

## Legal License as a Radiation Generator and Radio Isotope Facility and the 1st Legal Inspection

- **Application of Legal License and the approval**
  - Application of Legal License as a radiation generator ( Jan. 7th, 2015)
    - ✓ Since the accelerator of the Heavy Ion Beam Probe (HIBP) is classified as a Legal Radiation Generator, the application was done by adding the LHD to the License of HIBP accelerator.
  - Approval of the application (Sept. 4th ,2015)
- **Establishment of Legal Radiation Controlled Area (LRCA) Since Nov. 7, 2016 ~**
  - The LRCA for the use of $^{252}$Cf neutron source and FC (Nov. 7th, 2016 – Mar. 5th ,2017)
    - ✓ Implementation of the Absolute Calibration of Neutron Flux Monitor (NFM) using a $^{252}$Cf neutron source.
  - The LRCA for the use of Radiation Generator (Mar. 6th ,2017 – Now)
    - ✓ Implementation of the LHD Deuterium experiment
- **1st Legal Inspection**
  - A preliminary inspection to check the interlock system and radiation shielding ability of the LRCA.
    - ✓ Performed during the period of the Absolute Calibration of NFM (Nov. 14th –15th ,2016).
  - The definitive inspection to examine the radiation shielding ability of the LRCA using the neutron produced from LHD plasmas.
    - ✓ Performed during the commissioning phase of Deuterium experiment (Mar. 7th –17th , 2017)
    - ✓ No radiation from the LHD D–plasmas was detected by the dosimeters placed just outside the radiation shielding wall of the LHD hall and by the RMSAFE.
    - ⇒ This proves sufficient radiation shielding performance of the 2m–thick concrete wall.

**Certification for the Legal Inspection was issued for LHD on Mar. 29th, 2017.**



## Status of safety management facilities and system

**Integrated Radiation Monitoring System (IRMS)**

- IRMS unify the information from the access control system, radiation monitoring system (RMSAFE), and centrally controls the interlock system related to radiation safety.
  - ⇒ It is confirmed system works properly as designed.
  - ⇒ Live data from IRMS are displayed on the web.-page of.
- Function of the IRMS and its proper operation were checked at the 1st legal inspection.

**Training exercise**

- ✓ Fire-fighting and/or evacuation drills during experiment with Toki fire-fighting team are performed annually.
- ✓ New training course for tritium handling in NIFS started for operators of LHD.

**Constant vigil**

- ✓ IRMS and other important facilities are kept vigil by NIFS staff (researchers and engineers), preparing for the initial troubles and accident.

Simulator in NIFS for training on safety handling of tritium.

Fire-fighting drill

# Table of manuals for deuterium experiment

重水素実験における基準及び各種マニュアル

| 章 | 節 | マニュアル名 |
|---|---|---|
| 基準 | | 0 1 1 1 放射線管理基準 |
| | | 0 1 1 2 空調メンテナンス時の対応について |
| | | 0 1 2 1 プラズマ実験開始時のRMSAFE運転基準 |
| | | 0 1 2 2 インターロック管理値 |
| | | 0 1 3 呼気検査の管理基準 |
| | | 0 1 4 1 放射線障害のおそれに係る基準 |
| | | 0 1 4 2 業務従事者被ばく線量の管理目標値 |
| | | 0 1 4 3 真空容器内作業における被ばく線量の管理目標値 |
| | | 0 1 5 教育訓練実施基準 |
| | | 0 2 1 研究所における放射線を用いた非破壊検査の実施について(お願い) |
| | | 0 2 2 大型ヘリカル実験棟本体室北側遮蔽扉(1A)の開閉制限について |
| | | 0 3 対処フロー図 |
| 1_放射線管理マニュアル | 1_1_LHD運転監視マニュアル | 1 1 1 LHD運転監視マニュアル |
| | 1_2_入退管理マニュアル | 1 2 1 入退管理マニュアル |
| | 1_3_真空容器管理出入り口使用マニュアル | 1 3 1 真空容器管理出入り口使用マニュアル |
| | 1_4_真空容器内作業マニュアル | 1 4 1 真空容器内作業マニュアル |
| | 1_5_ポート作業マニュアル | 1 5 1 ポート作業マニュアル |
| | 1_6_真空系取扱マニュアル | 1 6 1 真空系取扱マニュアル |
| | 1_7_本体室作業マニュアル | 1 7 1 本体室作業マニュアル |
| | | 1 7 2 ガス供給システム保守点検作業マニュアル |
| | | 1 7 3 グロー放電洗浄装置保守点検作業マニュアル |
| | | 1 7 4 ゲートバルブ制御装置保守点検作業マニュアル |
| | | 1 7 5 圧空システム・GN2供給装置点検作業マニュアル |
| | | 1 7 6 真空排気装置保守点検作業安全マニュアル |
| | | 1 7 7 真空容器・ダイバータ加熱冷却装置保守点検作業マニュアル |
| | | 1 7 8 閉構造ダイバータ排気装置保守点検作業マニュアル |
| | | 1 7 9 補助排気装置保守点検作業マニュアル |
| | | 1 7 10 本体冷却水システム保守点検作業マニュアル |
| | 1_8_トリチウム含有水回収マニュアル | 1 8 1 トリチウム含有水回収マニュアル |
| | 1_9_252−Cf取扱マニュアル | 1 9 1 252−Cf取扱マニュアル |
| | 1_10_フィッションチェンバー取扱マニュアル | 1 10 1 フィッションチェンバー取扱マニュアル |
| | 1_11_NBI取扱マニュアル | 1 11 1 NBI安全管理マニュアル |
| | | 1 11 2 NBI真空容器内作業マニュアル |
| | 1_12_物品搬出入マニュアル | 1 12 1 物品搬出入マニュアル |
| | 1_13_試料取扱マニュアル | 1 13 1 試料取扱マニュアル |
| | | 1 13 2 試料駆動装置試料交換手順マニュアル |
| | | 1 13 3 LHD照射後試料の取扱マニュアル |
| | 1_14_保守作業室・試料加工室作業マニュアル | 1 14 1 保守作業室作業マニュアル |
| | | 1 14 2 試料加工室作業マニュアル |
| | 1_15_分析エリア作業マニュアル | 1 15 1 分析エリア作業マニュアル |
| | | 1 15 2 測定室(1)使用マニュアル |
| | | 1 15 3 測定室(2)使用マニュアル |
| | | 1 15 4 測定室(3)使用マニュアル |
| | | 1 15 5 貯蔵室(1)使用マニュアル |
| | | 1 15 6 微細構造解析室使用マニュアル |
| | | 1 15 7 分析室作業マニュアル |
| | | 1 15 8 保管廃棄室使用マニュアル |
| | 1_16_管理区域設備点検マニュアル | 1 16 1 管理区域設備点検マニュアル |
| | 1_17_室外排気配管からの水抜き作業マニュアル | 1 17 1 室外排気配管からの水抜き作業マニュアル |
| | 1_18_本体室及び本体室地下において採取した水の分析方法 | 1 18 1 本体室及び本体室地下において採取した水の分析方法 |
| 2_LHD運転マニュアル | 2_1_本体運転マニュアル | 2 1 1 本体ユーティリティー(本体系冷却水システム)運転マニュアル |
| | | 2 1 2 真空容器・ダイバータ加熱冷却装置運転マニュアル |
| | | 2 1 3 本体ユーティリティー(圧空システム・GN2供給装置)運転マニュアル |
| | | 2 1 4 真空排気装置運転マニュアル |
| | | 2 1 5 補助排気装置運転マニュアル |
| | | 2 1 6 ガス供給システム運転マニュアル |
| | | 2 1 7 コイル電源運転マニュアル |
| | | 2 1 8 LIDコイル用電源運転マニュアル |
| | | 2 1 9 グロー放電洗浄装置運転マニュアル |
| | | 2 1 10 ゲートバルブ制御装置運転マニュアル |
| | | 2 1 11 閉ダイバータ排気装置運転マニュアル |
| | | 2 1 12 ボロニゼイション運転マニュアル |
| | | 2 1 13 真空容器換気システム運転マニュアル |
| | 2_2_本体冷却マニュアル | 2 2 1 本体冷却運転マニュアル |
| | 2_3_NBI運転マニュアル | 2 3 1 NBI運転マニュアル |
| | 2_4_ECH運転マニュアル | 2 4 1 ECH運転マニュアル |
| | 2_5_ICH運転マニュアル | 2 5 1 ICH運転マニュアル |
| | 2_6_計測器運転マニュアル | 2 6 1 ダイバータ分光計測運転マニュアル |
| | | 2 6 2 高速イオンゲージ運転マニュアル |
| | | 2 6 3 本体ペレット入射装置運転マニュアル |
| | | 2 6 4 電子銃・試料駆動装置運転マニュアル |
| | | 2 6 5 ダイバータ静電プローブ運転マニュアル |
| | | 2 6 6 高速掃引静電プローブ運転マニュアル |
| | | 2 6 7 マイクロ波反射計運転マニュアル |
| | | 2 6 8 ミリ波干渉計運転マニュアル |
| | | 2 6 9 磁束ループ運転マニュアル |
| | | 2 6 10 ダイバータ熱電対運転マニュアル |
| | | 2 6 11 ヘリウムビームプローブ運転マニュアル |
| | | 2 6 12 3m直入斜分光器運転マニュアル |
| | | 2 6 13 イメージング結晶分光器運転マニュアル |
| | | 2 6 14 不純物ペレット入射装置運転マニュアル |
| | | 2 6 15 不純物モニター運転マニュアル |
| | | 2 6 16 トロイダル結晶分光器運転マニュアル |
| | | 2 6 17 ディスパーション干渉計運転マニュアル |
| | | 2 6 18 FIRレーザー干渉計運転マニュアル |
| | | 2 6 19 RFスペクトロメータ運転マニュアル |
| | | 2 6 20 ダイバータ干渉計運転マニュアル |
| | | 2 6 21 重イオンビームプローブ装置運転マニュアル |
| | | 2 6 22 高速度HAアレイ装置 運転マニュアル |
| | | 2 6 23 損失高速イオンプローブ運転マニュアル |
| | | 2 6 24 CNPA運転マニュアル |
| | | 2 6 25 可視分光計測装置運転マニュアル |
| | | 2 6 26 磁気計測運転マニュアル |
| | | 2 6 27 VUV分光器運転マニュアル |
| | | 2 6 28 SOXMOS装置運転マニュアル |
| | | 2 6 29 CO2レーザー計測運転マニュアル |
| | | 2 6 30 AXUVD運転マニュアル |
| | | 2 6 31 TESPEL・TECPEL入射装置運転マニュアル |
| | | 2 6 32 LHD計測データ集録システム運転マニュアル |
| | | 2 6 33 本体真空計運転マニュアル |
| | | 2 6 34 ペニング真空計分光運転マニュアル |
| | | 2 6 35 SOI検出器運転マニュアル |
| | | 2 6 36 トムソン散乱計測装置運転マニュアル |
| | | 2 6 37 ビーム強度分布計測運転マニュアル |
| | | 2 6 38 E／／B−NPA運転マニュアル |
| | | 2 6 39 磁気プローブ運転マニュアル |
| | | 2 6 40 複合型方向性プローブ運転マニュアル |
| | | 2 6 41 ダスト検出器運転マニュアル |
| | | 2 6 42 6O真空計運転マニュアル |
| | | 2 6 43 SXシンチレータアレイ運転マニュアル |
| | | 2 6 44 第一壁プローブ運転マニュアル |
| | | 2 6 45 プラズマ監視カメラ・高速カメラ運転マニュアル |
| | | 2 6 46 中性子フラックスモニタシステム運転マニュアル |
| | | 2 6 47 放射化箔装置運転マニュアル |
| | | 2 6 48 中性子プロファイルモニタ運転マニュアル |
| | | 2 6 49 IRボロメータ運転マニュアル |
| | | 2 6 50 荷電交換分光計測、ビーム発光分光計測、モーショナルシュタルク効果分光計測運転マニュアル |
| | | 2 6 51 協同トムソン散乱装置運転マニュアル |
| | | 2 6 52 マイクロ波吸収体型漏洩波モニタ運転マニュアル |
| | | 2 6 53 14MeV中性子検出器運転マニュアル |
| | | 2 6 54 中性子揺動検出器運転マニュアル |
| | | 2 6 55 赤外線カメラ運転マニュアル |
| | | 2 6 56 ミリ波散乱計測器運転マニュアル |
| | | 2 6 57 真空容器内長期設置試料運転マニュアル |
| | | 2 6 58 DNPA運転マニュアル |
| | | 2 6 59 CVDダイヤモンド検出器運転マニュアル |
| | | 2 6 60 中性子スペクトロメータ運転マニュアル |
| | | 2 6 61 キャピラリープレート中性子検出器運転マニュアル |
| | 2_7_入退管理装置運転マニュアル | 2 7 1 入退管理装置運転マニュアル |
| | 2_8_放射線総合監視システム運転マニュアル | 2 8 1 放射線総合監視システム運転マニュアル |
| | | 2 8 2 RMSAFE運転マニュアル |
| | | 2 8 3 排気塔トリチウム捕集装置運転マニュアル |
| | | 2 8 4 本体室ガスモニタ運転マニュアル |
| | | 2 8 5 排気塔ガスモニタ運転マニュアル |
| | | 2 8 6 排水・ドレン水取扱いマニュアル |
| | 2_9_トリチウム除去装置運転マニュアル | 2 9 1 トリチウム除去装置運転マニュアル |
| | 2_10_分析機器運転マニュアル | 2 10 1 分析機器運転マニュアル |
| 3_管理区域関連マニュアル | 3_1_イオンビーム解析装置運転マニュアル | 3 1 1 イオンビーム解析装置運転マニュアル |
| | | 3 1 2 イオンビーム解析装置放射線管理マニュアル |
| | 3_2_ECH運転マニュアル | 3 2 1 ECH運転マニュアル |
| | 3_3_NBI運転マニュアル | 3 3 1 NBI運転マニュアル |
| | 3_4_校正用X線源マニュアル | 3 4 1 校正用X線源運転マニュアル |
| | 3_5_ESCA・XRD運転マニュアル | 3 5 1 X線光電子分光分析装置(ESCA)運転マニュアル |
| | | 3 5 2 X線回折装置(XRD)運転マニュアル |
| | | 3 5 3 X線光電子分光分析装置(ESCA)放射線管理マニュアル |
| | | 3 5 4 X線回折装置(XRD)放射線管理マニュアル |
| | 3_6_微量密封線源取扱マニュアル | 3 6 1 微量密封線源取扱マニュアル |
| 4_災害及び異常時対応マニュアル | 4_1_通報・連絡マニュアル | 4 1 1 通報・連絡マニュアル |
| | 4_2_衛星電話が不通の場合の職員の派遣マニュアル | 4 2 1 衛星電話が不通の場合の職員の派遣マニュアル |
| | 4_3_宿日直マニュアル | 4 3 1 宿日直マニュアル |
| | 4_4_防災マニュアル | 4 4 1 防災マニュアル |
| | 4_5_盗難・不法侵入等対応マニュアル | 4 5 1 盗難・不法侵入等対応マニュアル |
| | 4_6_放射線関係対応マニュアル | 4 6 1 放射線関係対応マニュアル |
| | 4_7_漏水対応マニュアル | 4 7 1 漏水対応マニュアル |
| | 4_8_NBI異常時対応マニュアル | 4 8 1 NBI異常時対応マニュアル |
| | 4_9_LHD真空異常時対応マニュアル | 4 9 1 LHD真空異常時対応マニュアル |
| | 4_10_トリチウム除去装置異常時対応マニュアル | 4 10 1 トリチウム除去装置異常時対応マニュアル |

These manuals are available on the web site of Division of Health and Safety Promotion



# RESULTS OF INITIAL EXPERIMENTS AND FUTURE RESEARCH DEVELOPMENT

# Issues of Evaluation (2)

➢ **Results of initial experiments and future research development**

(3) Does the LHD project obtain high-performance plasma by the deuterium experiments and produce excellent research achievements with high academic value? (From the third mid-term plan)
重水素実験でプラズマの高性能化が図られ、学術的価値の高い成果が得られているか。（第三期中期計画より）

(4) Does the LHD project obtain prospects for development of academic research toward a comprehensive understanding of toroidal plasmas? (From the third mid-term plan)
環状プラズマの総合的な理解に向けた学術研究の展開の見通しが得られているか。（第三期中期計画より）

(3) Is preparation of necessary devices and facilities for the main device, heating systems, diagnostics, and others advanced appropriately according to the research plan of the deuterium experiments?

(4) Will the LHD project consider further research development towards the realization of a fusion reactor based on the achievements of the LHD project?



# Issues of Evaluation (2)

➢ **Results of initial experiments and future research development**

(3) Does the LHD project obtain high-performance plasma by the deuterium experiments and produce excellent research achievements with high academic value? (From the third mid-term plan)
重水素実験でプラズマの高性能化が図られ、学術的価値の高い成果が得られているか。（第三期中期計画より）

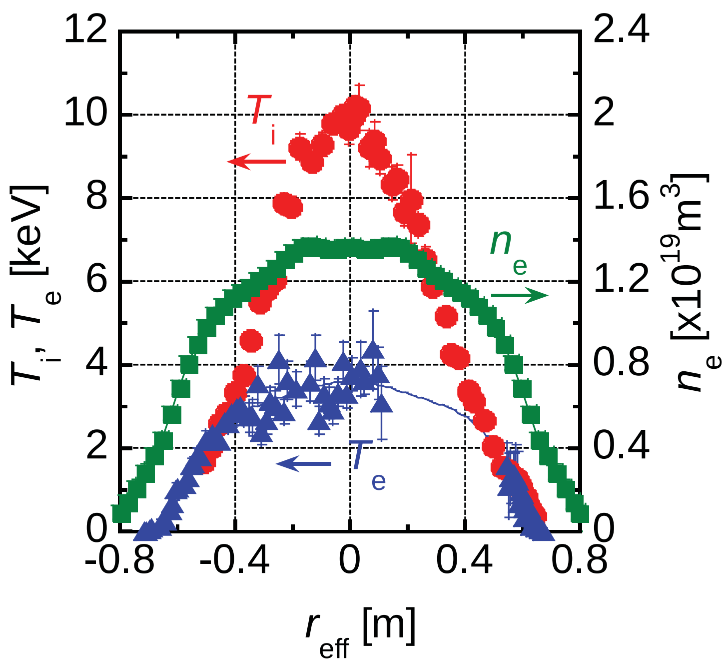
(4) Does the LHD project obtain prospects for development of academic research toward a comprehensive understanding of toroidal plasmas? (From the third mid-term plan)
環状プラズマの総合的な理解に向けた学術研究の展開の見通しが得られているか。（第三期中期計画より）

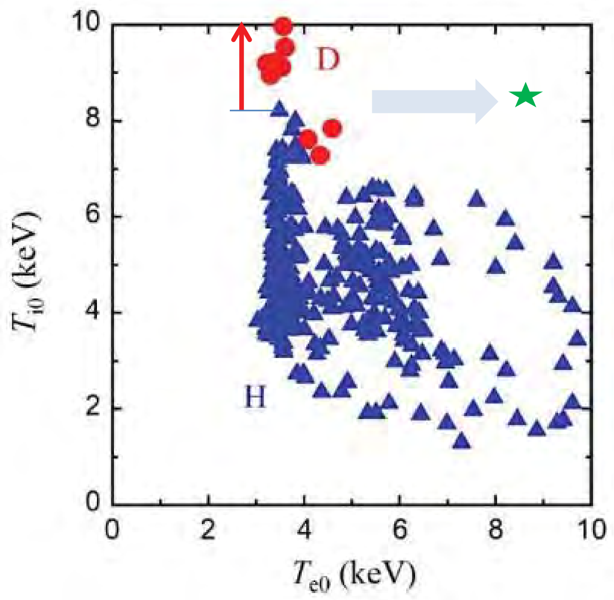
These two issues (item(3) and (4)) can be satisfied by realizing the objectives of D-exp.

- Achievement of high-performance plasmas through confinement improvement
- Clarification of isotope effect on confinement
- Demonstration of confinement capability of energetic ions in helical systems
- Enhanced PWI studies using hydrogen isotopes

(4) Will the LHD project consider further research development towards the realization of a fusion reactor based on the achievements of the LHD project?

# Ion temperature range is extended by the D- exp.




$T_i$ = 10 keV was achieved in helical devices for the first time. The LHD succeeded to realize higher performance plasma in Deuterium experiment than in Hydrogen experiments. Now, we are trying to expand temperature region to $T_e$=$T_i$=8.6keV to explore the physics close to reactor plasma parameter.



# By starting D-exp., the LHD can explore the physics on Isotope effect, which is known to be a long-standing mystery

**Isotope effect on the confinement is widely observed in Tokamak plasmas, but its physical mechanism is not clear.**

- Empirical Scaling of isotope by $\tau_E \sim A^{\alpha}$ is often mentioned.
  - The α is different in the discharge scinarios and machine.
    - ITER89-P: α=0.5[1], ITERH93-P:α=0.4,
    - DD/DT: TFTR(supershot): α=0.85[3],
      JET(H-mode): α=0.03(total) (α=-0.17(core), α=0.5(pedestal))[4]
- Gyro-bohm scaling indicates:
  α=-0.2[4](in Engineering scaling).
  (in Physics Scaling: α=-0.5 as $\tau_E{}^{GB} \sim \frac{a^2}{\chi^{GB}}$ and $\chi^{GB} \sim \frac{\rho^2 V_{\mathrm{th}}}{R} \sim \frac{m^{0.5} T^{1.5}}{R q^2 B^2}$)

**There are several mechanisms which might influence the plasma confinement property by changing the ion species from H to D.**

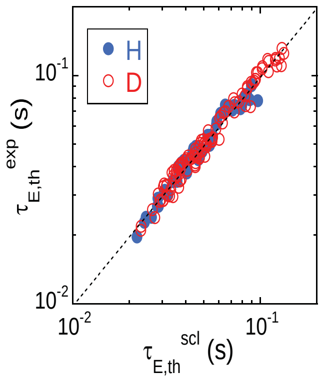
- Bulk ion species, itself <= direct effect
- Neutral penetration <= Neutral recycling is widely known as a key control knob for achieving high performance plasmas [5]
- Impurity influx <= The $Z_{eff}$ at the edge influences the H-mode pedestal performance[6].

**In order to understand the mechanisms of isotope effect, the following items must be studied in addition to the evaluation on isotope dependence of confinement time:**

✓ Influences of ion-species, including impurity ions, on confinement property.
✓ The comparison of experimental results to theoretical investigation, i.e., turbulence simulation.

[1] P.N.Yushmanov, et.al., NF **30**(1990)1999 , [2] M. Bessenrodt-weberpals, et.al., NF**22**(1993)1205, [3] S.D.Scott, et.al., POP **2**(1995)2299 , [4] J.Jacquinot, et.al., PPCF **41**(1999)A13 , [5] C.F.Magi, et.al., IAEA-FEC 2014 EX3-3 , [6] G.P. Maddison, et.al., NF**54**(2014)073016

# Global energy confinement is clearly improved in D from H in gyro-Bohm nature

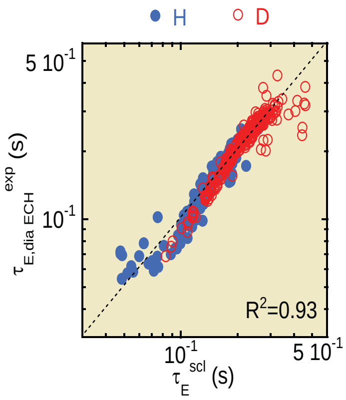



Energy confinement time in **NBI** plasma

$$\tau_{E,th,NBI}^{scl} \propto A^{-0.01\pm0.02} B^{0.85\pm0.02} \bar{n}_e^{0.78\pm0.01} P_{abs}^{-0.87\pm0.01}$$

$(A_D/A_H)^{-0.01} = 2^{-0.01} = 0.99$

- No significant mass dependence, which indicates clear **discrepancy from gyro-Bohm model (isotope effect)**
- Comparison between dimensionally similar plasmas also indicates clear isotope effect




Energy confinement time in **ECH** plasma

$$\tau_{E,th,ECH} \propto A^{0.24\pm0.01} \bar{n}_e^{0.58\pm0.01} P_{abs}^{-0.52\pm0.01}$$

$(A_D/A_H)^{0.24} = 2^{0.24} = 1.18$

- **Obvious mass dependence** (**isotope effect**) identified

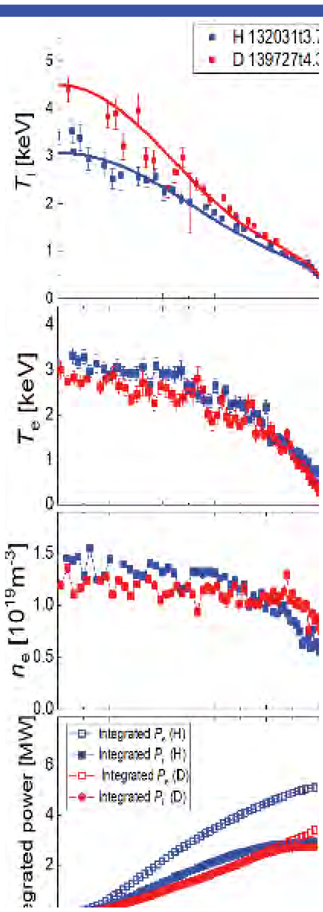
✓ Each experiment was performed with purity of H and D > 80%

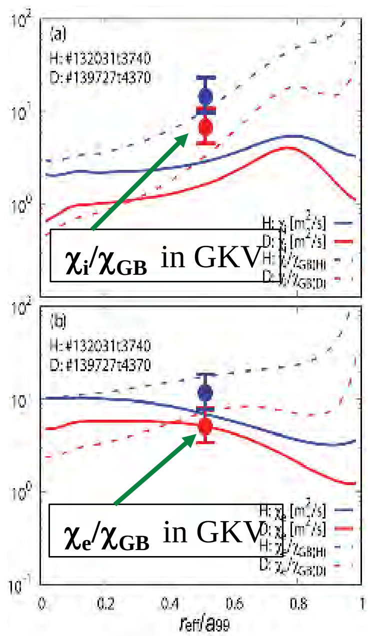
**Isotope effect was recognized for both NBI and ECH plasmas on the LHD**

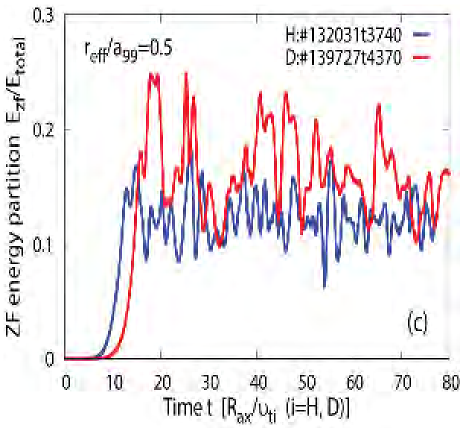


# Isotope effect is also observed for ITB plasmas

*Significant isotope effect was observed both in ion and electron heat transports*



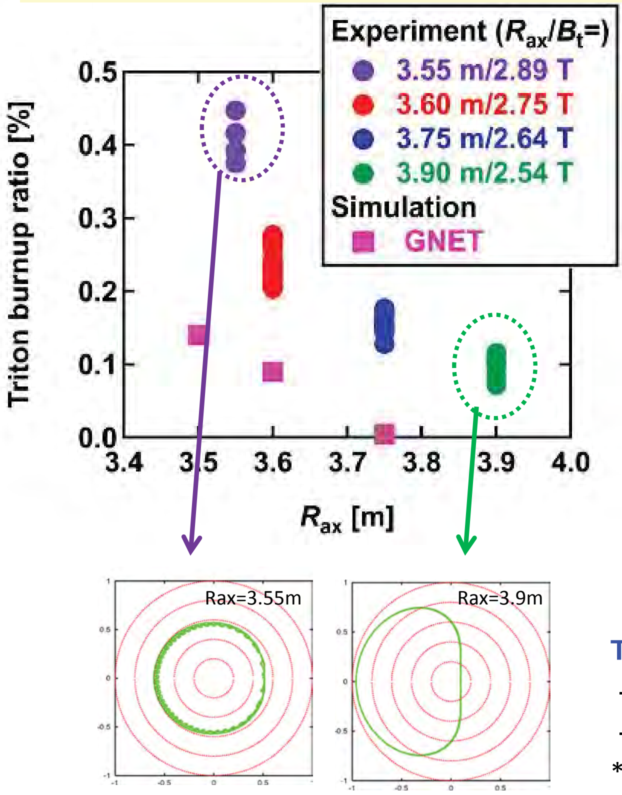

Zonal flow enhancement was also confirmed in GKV simulation

Reduction of $\chi_i/\chi_{GB}$ and $\chi_e/\chi_{GB}$ in D plasma were reproduced with the nonlinear GKV simulations

Comparison of turbulence levels between measurement and simulation is ongoing

# EP confinement comparable to similar size tokamaks are demonstrated by Triton burn-up experiment

***Triton burnup experiment can examine behavior of alpha-particle confinement in the machine. ($\because \rho_{T(1MeV)} \approx \rho_{\alpha(3.5MeV)}$)***




Typical trapped particle orbits

D + D => $^3$He + **n**(2.5MeV)
D + D => p + **T**(1 MeV)

**T** + D => **n**(14MeV) + $^4$He (3.5 MeV)
Max. @ 40keV(COM)

$$(\text{T burn-up ratio}) \equiv \frac{S_n^{14MeV}}{S_n^{2.5MeV}}$$

- Inward-shifted configuration provides “better” EP confinement although worse MHD stability
- The tendency of Triton burn-up ratios well explained by theoretical predictions

**T burn-up ratio in similar size tokamaks :**

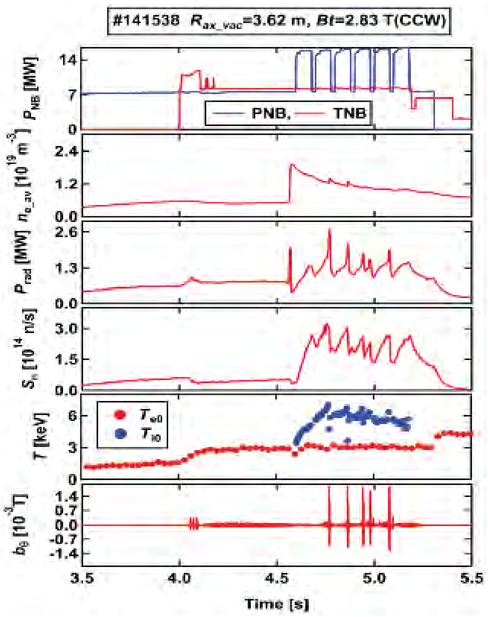
- TFTR~0.7%*
- KSTAR~0.45%**

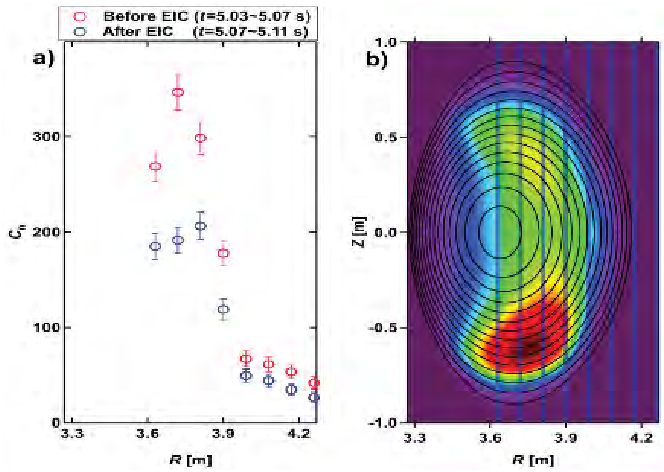
*C.Barnes, *et al.*, NF**38**(1998)597, ** J. Jo, *et al.* RSI**87**(2016)11D828



# Interactions between EPs and MHD modes

Interaction between low-frequency MHD (interchange) mode and ripple trapped Energetic Particle, which is called as Energetic particle driven InterChange mode (EIC), was observed.
⇒ Analogous to the FishBone mode(FB) and/or Energetic particle driven resistive Wall mode (EWM) in tokamaks.
⇒ Comprehensive understanding on the interaction between EPs and MHD modes in toroidal devices will be provided.



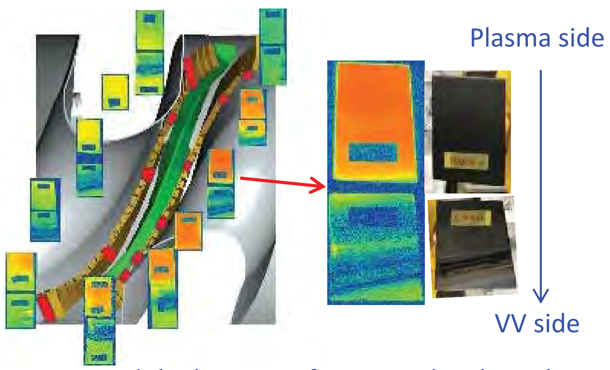




(a)Change of line integrated neutron emission profile before and after EIC measured by VNC,
(b)Calculated 2D Neutron emission profile along the sight line of Vertical Neutron Camera (VNC)

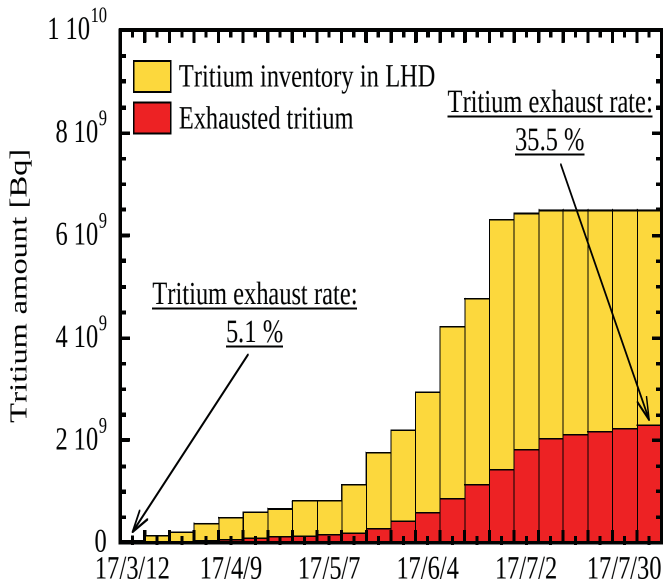
# Exhaust Behavior and Mass Balance of Tritium

*Exhaust detritiation system with precise detector revealed tritium behavior in LHD*

- 35.5 % of produced tritium was exhausted until the end of the first D-campaign, and 64 % was still retained in vacuum vessel or evacuation system
- By the tritium measurement using imaging plates at one helical section, 15.6-31.2% of produced tritium was evaluated to be implanted into the carbon divertor tiles.



IP images and the location of measured carbon plates



Mass balance of tritium during the first deuterium experimental campaign from March 6 to August 7



# Issues of Evaluation (2)

➤ **Results of initial experiments and future research development**

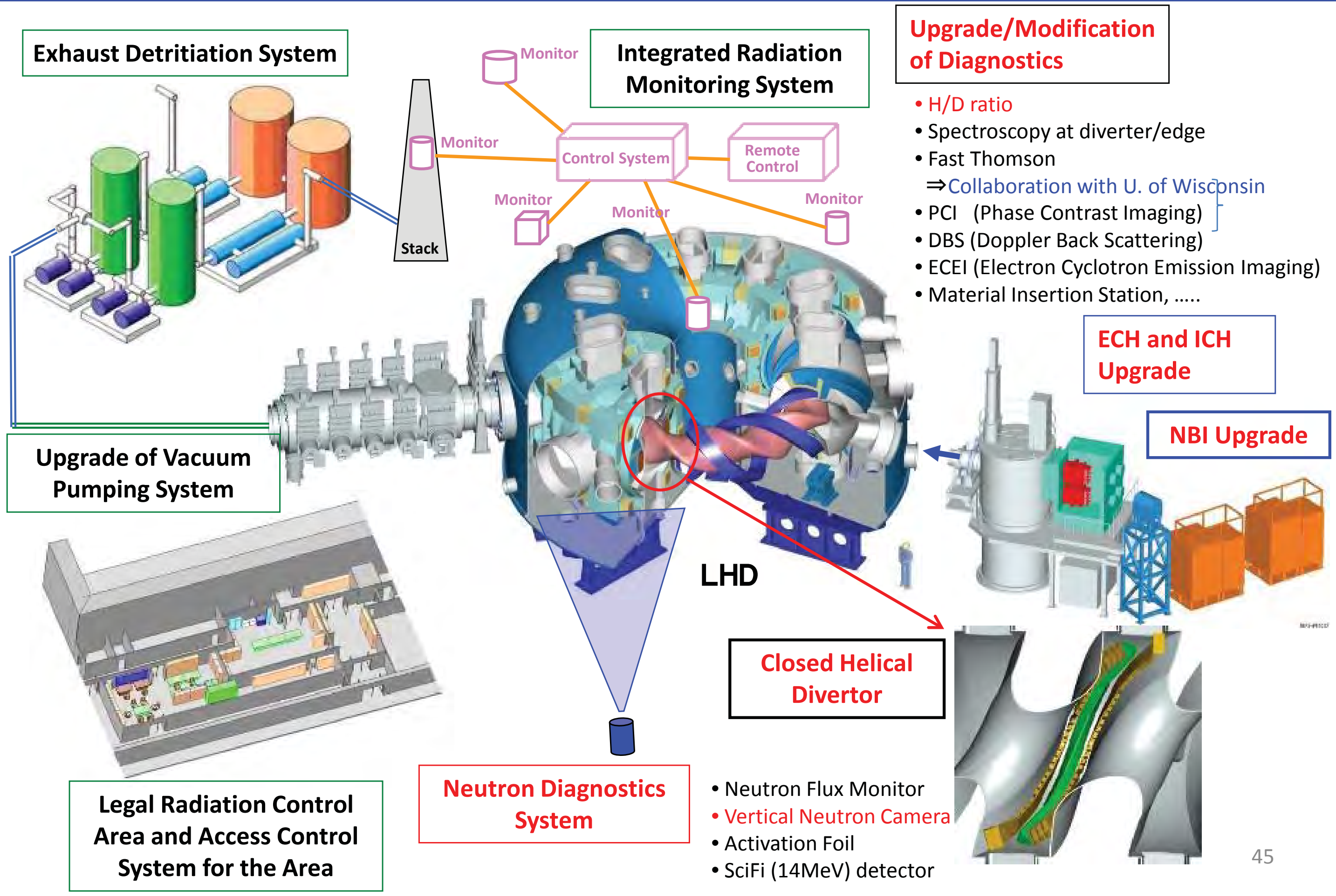
(3) Does the LHD project obtain high-performance plasma by the deuterium experiments and produce excellent research achievements with high academic value? (From the third mid-term plan)

(4) Does the LHD project obtain prospects for development of academic research toward a comprehensive understanding of toroidal plasmas? (From the third mid-term plan)

(5) Is preparation of necessary devices and facilities for the main device, heating systems, diagnostics, and others advanced appropriately according to the research plan of the deuterium experiments?
重水素実験の研究計画に従って、装置本体、加熱、計測、周辺機器など必要な機器の整備等が進められているか。

(6) Will the LHD project consider further research development towards the realization of a fusion reactor based on the achievements of the LHD project?

# Upgraded and newly installed devices for the LHD Deuterium Experiment

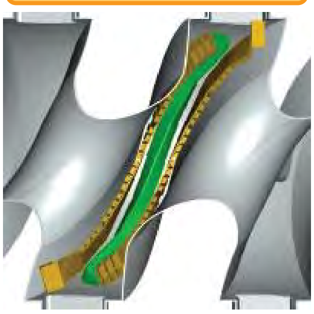


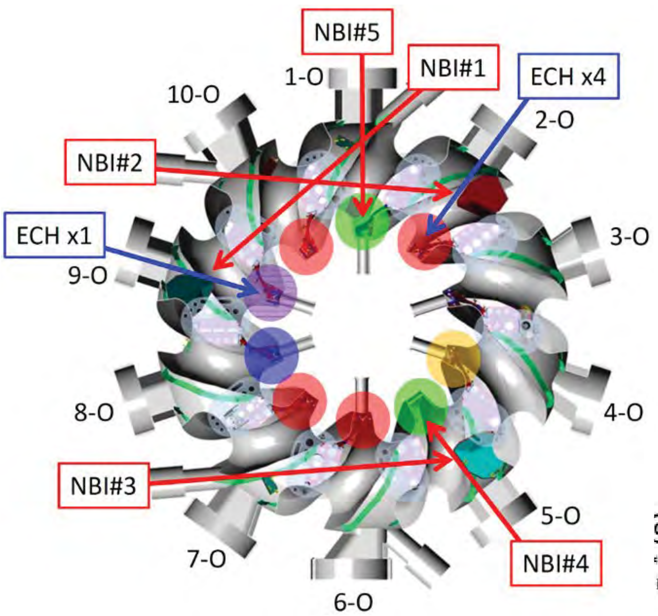



# To suppress the particle and impurity influx to LHD plasmas, closed helical diverters were installed

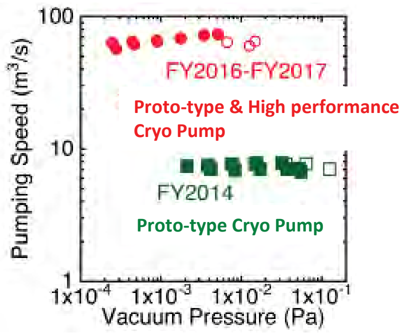
Open Divertor

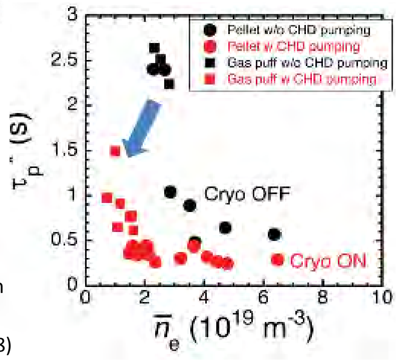
Closed Divertor



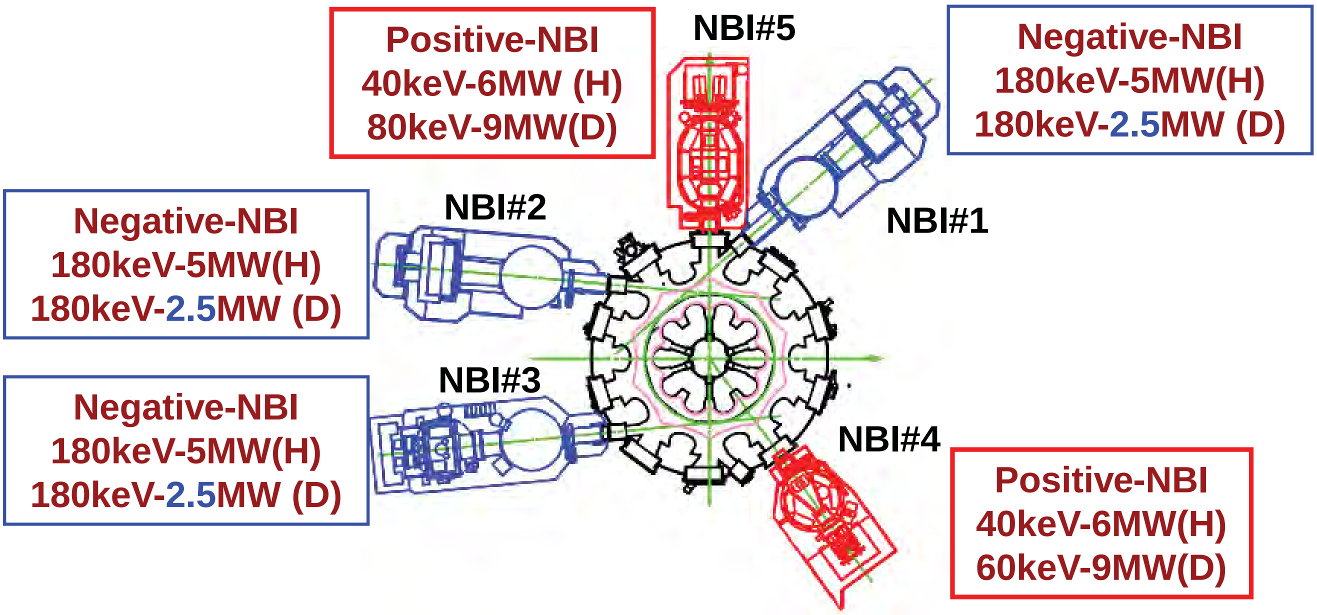



- Closed Diverter with Proto-type Cryo Pump
- Closed Diverter with High-performance Cryo Pump
- Closed Diverter without Pump + NB counter wall protection
- Closed Diverter without Pump
- Closed Diverter with non-evaporating Getter Pump (FY2018)



# Operation of NBI with Deuterium




- **Positive-NBI:** Injection energies can be increased from 40 to 60/80keV without the deterioration of neutralization efficiency changing the beam ion species from H to D.
- **Negative-NBI:** Injection energy remains same at 180keV. No significant optimization for D-operation is done for N-NBI. Their injection power is expected to be degraded according to the Child-Langmuir law, i.e., $I_{beam} \propto m^{-1/2} \Rightarrow I_{D^-}/I_{H^-}$~0.7. It is necessary to reduce the beam current further ($I_{D^-}/I_{H^-}$~0.5) due to the isotope effect on negative-ion production.

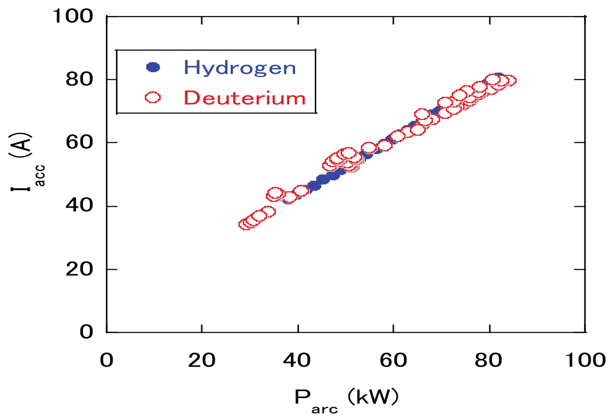


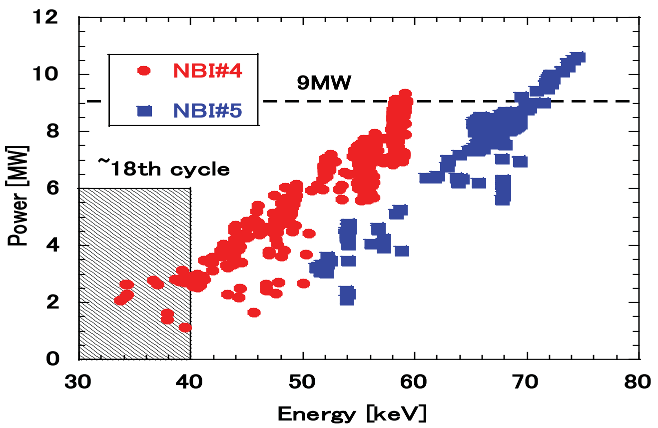
# Upgrade of positive-ion NBI

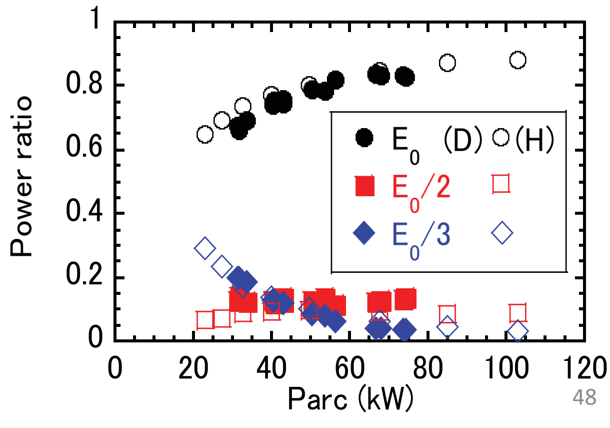
With the change of beam ion species from H to D.,

1. the arc efficiency of the ion source remains same, and
2. The proton ratio of beam also remains same.

The injection power of P-NBI is successfully increased from 6 to 9MW.

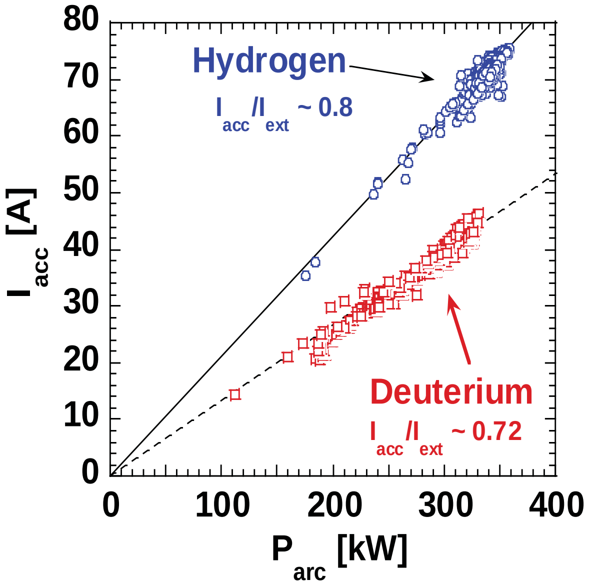


# The Deuterium operation of N-NBI

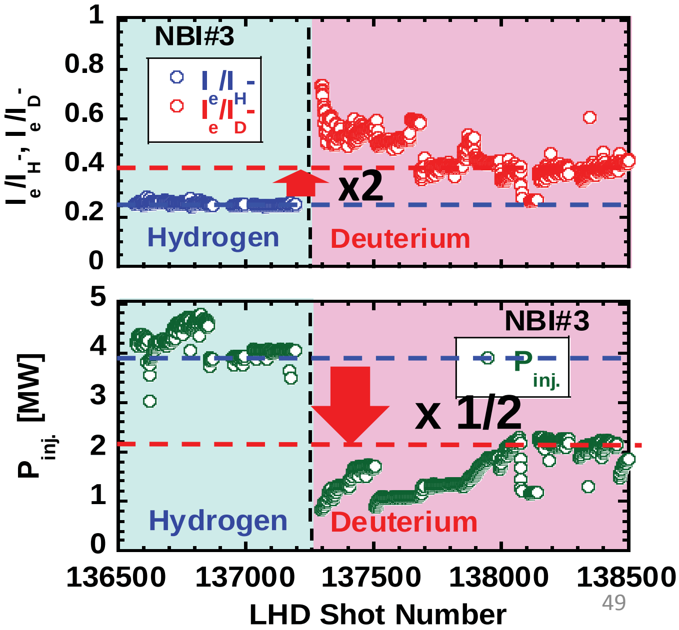
The arc-efficiency was reduced by a factor of 0.7 which is consistent to the prediction.




The degradation of injection power and the beam velocity reduction in D-operation disables the plasma initiation by N-NB.

The fraction of co-extracted electron increases with a factor of 2. (isotope effect)

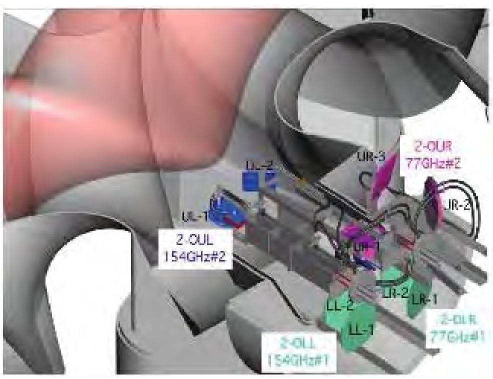
⇒This increases the heat load onto the grids of the ion-source and limits the power of the source about the half.

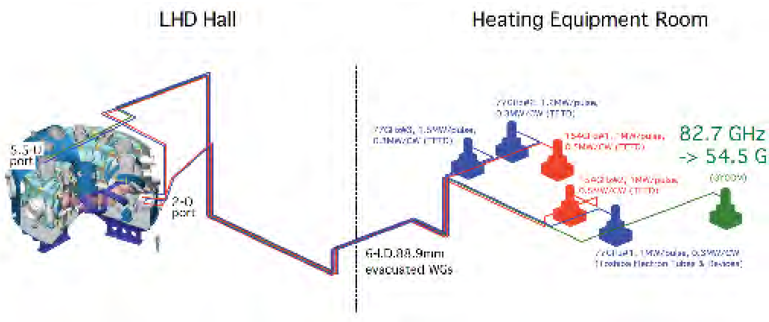





# Upgraded ECH system for deuterium experiment

- Three 77GHz- and two 154GHz-ECH systems, each of which injects >1MW for a short pulse and >300kW for CW, have been installed.
  - The launchers of two 77GHz- and two 154GHz-ECH systems are replaced to 2-O port, where the better ECH absorption is expected, to maximize the heating efficiency.
  - Another ECH launcher locates at 5.5-U port.
  - Additional ECH launcher is in preparation at 9-O port.
- Instead of an 82.7GHz-ECH(5.5-U) system which was used up to the 19th cycle, 54.5/56GHz-ECH system is newly installed to enable the LHD operation at 1T with Deuterium N-NB operation.



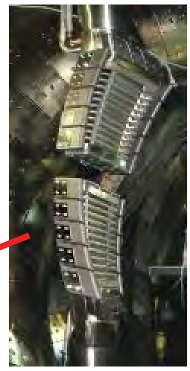
# ICH antennae are tentatively removed, but will be reinstalled for 21st campaign (FY2019).

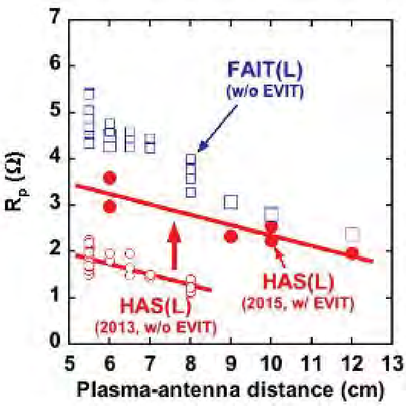
- Each antenna injects >1MW for pulse and >0.5MW for CW.

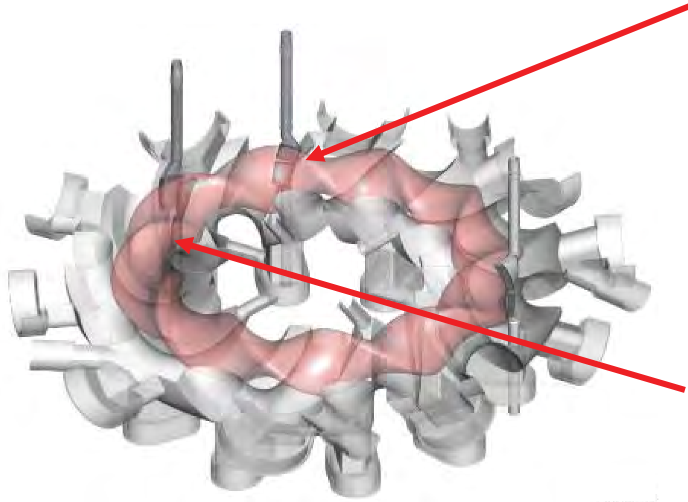
- 2 straps of FAIT (Field-Aligned Impedance-Transforming) antenna
- 2 straps of HAS (HAsu-Seigyo) antenna with Ex-Vessel Impedance Transformers (EVIT)

- With the benefit from Impedance Transformers, the effective impedance of antenna are increased although it requires to operate at the fixed frequency of 38.5 MHz.

4.5U/L FAIT antenna





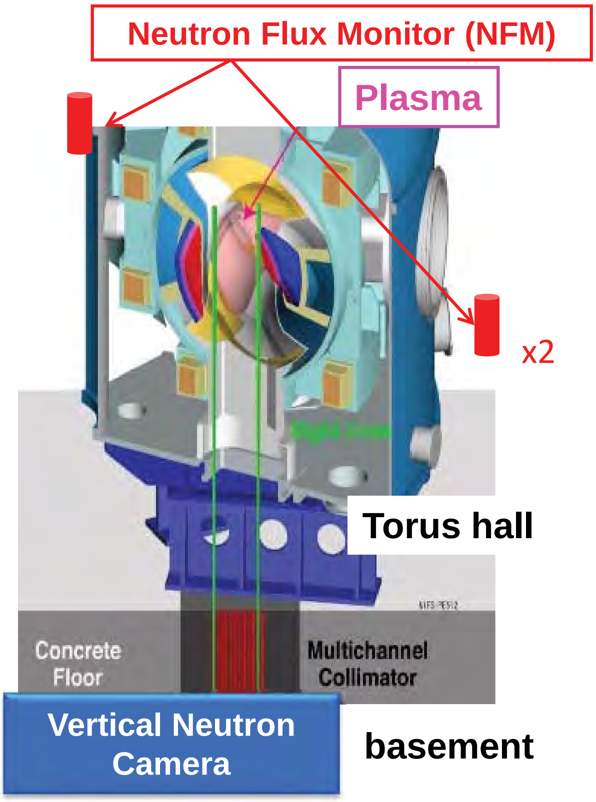



3.5U/L HAS antenna

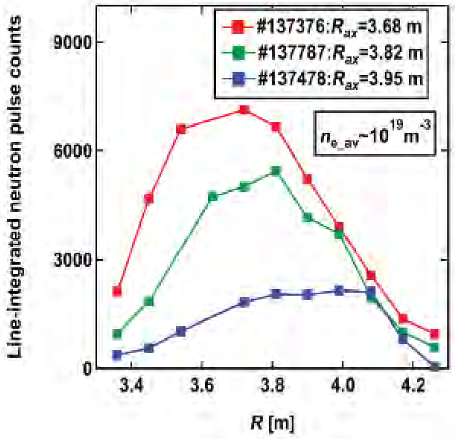


# Neutron Diagnostic

**Neutron diagnostic is newly installed for the LHD deuterium experiment. Because DD-reaction rate is larger for lager relative velocity, this will accelerates the EP confinement studies on Helical Devices**



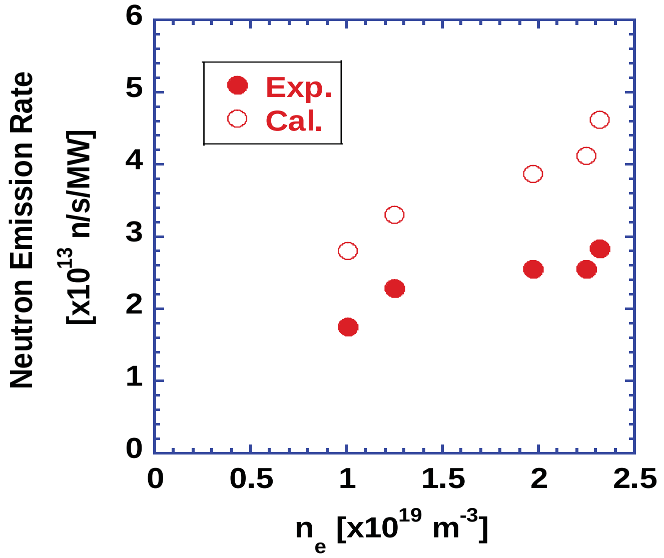

- Neutron Flux Monitor x3
- Vertical Neutron Camera
- Activation Foil System
- SciFi (14MeV) detector




Change of line integrated neutron emission profile with the magnetic axis location

# Neutron Emission evaluation codes are also prepared.

- Neutron budget is another constraints in proceeding the D.-exp. in addition to the total machine time.
- The fit3d-dd code, which is based on Fokker-Plank model, was prepared so that every collaborator can quickly evaluate neutron emission rate for his/her proposed machine time.

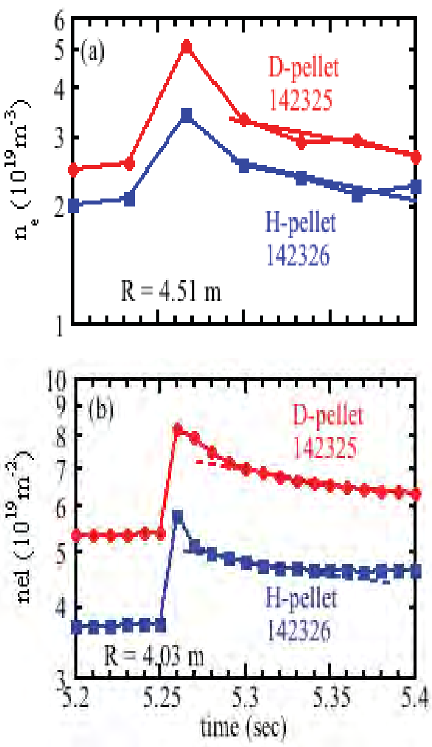


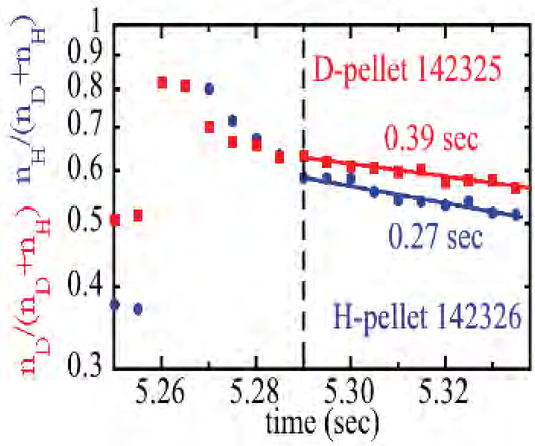

The fit3d-dd code overestimates the neutron emission rate by a factor of 2. This comes from the model which does not account the effect of orbit loss during the slowing down process of energetic particles.



# H/D ratio profile measurement based on an active Charge Exchange diagnostic revealed different particle confinement property of Deuterium ions from Hydrogen ions in the Hydrogen isotope mixture plasma although electron density behave same

Transient behavior after Hydrogen/Deuterium ice pellet injection are examined.
Decay time of electron density is similar in both cases.



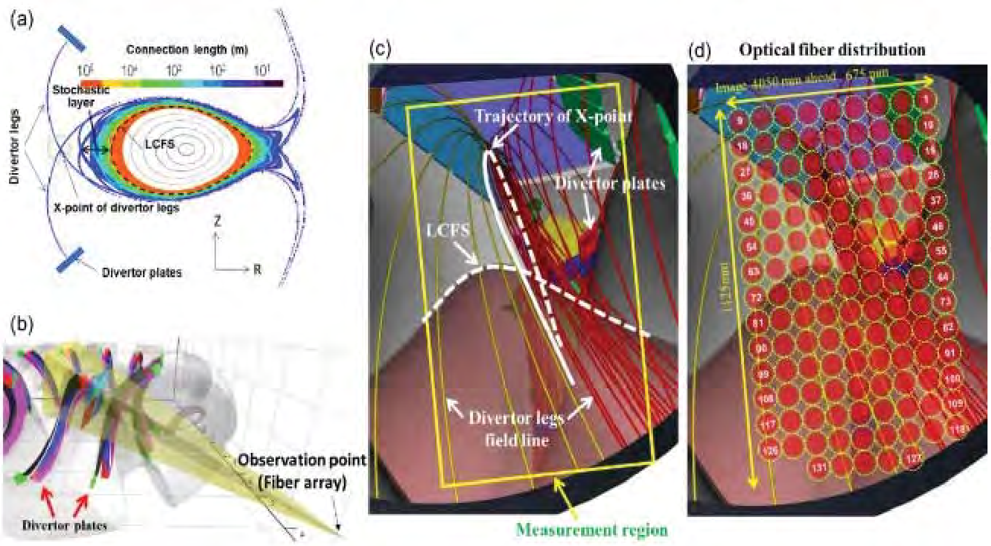



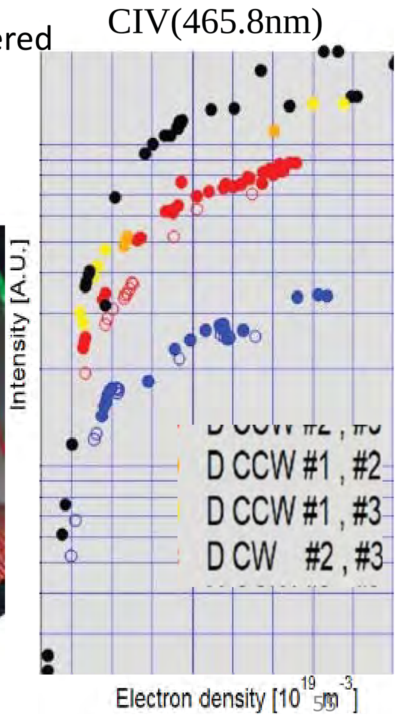

There are two time scales of the decay in D/(H+D) and H/(H+D) ratio
Fast decay (t < 5.29 sec)→ Profile relaxation
Slow decay (t >5.29 sec)→ particle confinement
H : 0.27sec and D: 0.39sec
Decay time of deuterium ion is longer than that of hydrogen
→ Better ion particle confinement in deuterium plasma

# Diagnostics at plasma periphery/divertor region

Influence on plasma periphery by the change of plasma ion species from hydrogen to deuterium is a great concern. To examine the influence, spectroscopy system and IR camera at divertor regions are improved.

Carbon impurity is increased by changing H to D. This is considered to be due to the increase of physical sputtering of carbon by D.




# Issues of Evaluation (2)

➢ **Results of initial experiments and future research development**

(3) Does the LHD project obtain high-performance plasma by the deuterium experiments and produce excellent research achievements with high academic value? (From the third mid-term plan)

(4) Does the LHD project obtain prospects for development of academic research toward a comprehensive understanding of toroidal plasmas? (From the third mid-term plan)

(5) Is preparation of necessary devices and facilities for the main device, heating systems, diagnostics, and others advanced appropriately according to the research plan of the deuterium experiments?

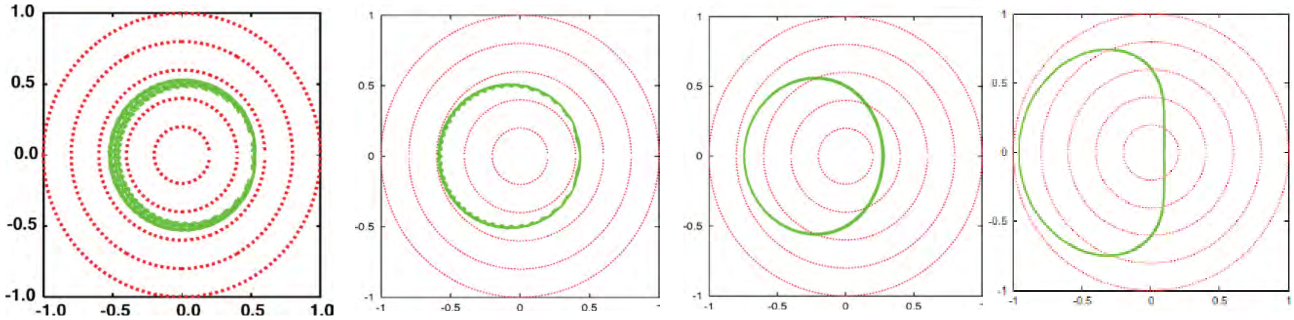
(6) Will the LHD project consider further research development towards the realization of a fusion reactor based on the achievements of the LHD project?
LHDプロジェクトの成果を踏まえて、核融合炉実現に向けた今後の研究展開を検討しているか。

In optimizing the Heliotron-type helical configuration, the choice of magnetic axis location is an important issue because its direction in optimization for the MHD stability and for the particle confinement is opposite to each other.

Small ← $R_{ax}$ → Large

MHD → **Stable**

**Good** ← **Particle Confinement**



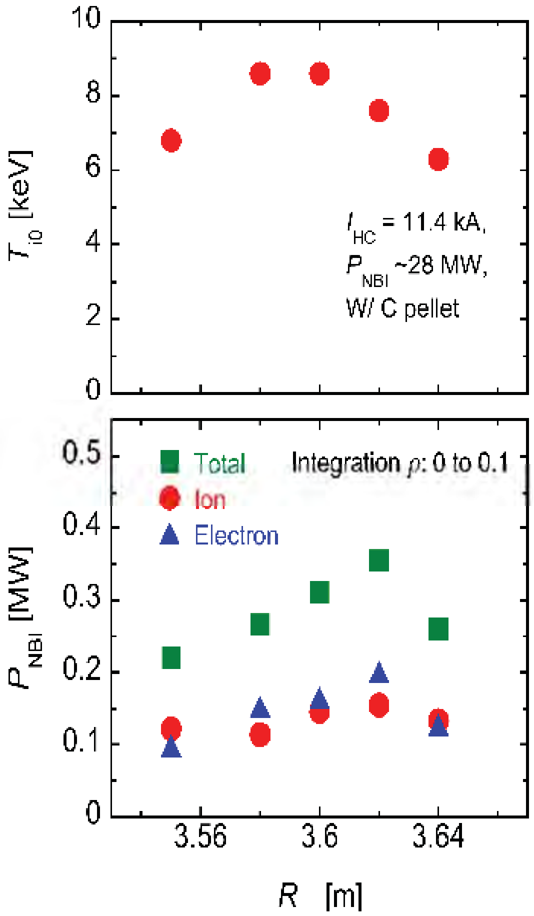
$R_{ax}$=3.53m (Neoclassically optimized*) | $R_{ax}$=3.6m (σ-optimized) | $R_{ax}$=3.75m (Standard) | $R_{ax}$=3.9m (Outwardly shifted)

Deviation of orbit's drift-surfaces are minimized as the magnetic axis locations are inwardly shifted. Triton burn-up experiments clearly show the benefit of neoclassically optimized configuration at around 3.53m.

* S.Murakami *et al.*, Fusion Sci. Technol. 46 (2004) 241



# Central ion temperature is peaked at around $R_{ax}$~3.59m



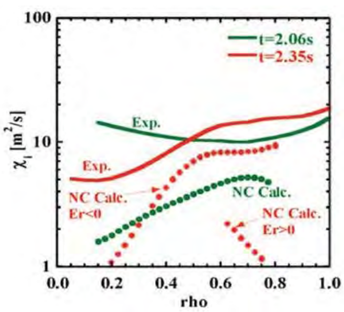

Generally speaking, the $T_{i0}$ degrades when the $R_{ax}$ becomes large.

- The degradation at $R_{ax}$ =3.55m can be explained by the degradation of heating efficiency because the tangency radius of negative-ion based NBIs are set at R=3.7/3.75m

This tendency makes sense if the bulk-ion transport is dominated by neoclassical transport.

$$\Leftrightarrow \chi^{exp} > \chi^{neo}$$

Indicating a link between neoclassical transport and anmalous transport.



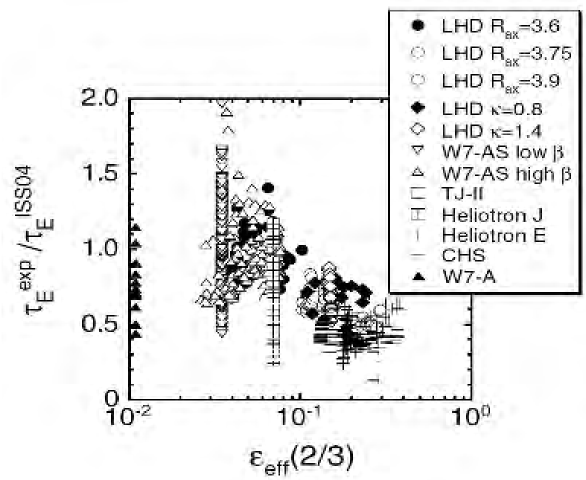

☜ Typical thermal diffusivity profile in a LHD high-Ti discharge where thermal diffusivities evaluated by the experiments (solid lines) is much larger than those by the neoclassical theory (dots).

Figure from K.Nagaoka *et al.*, Fusion Sci Technol. 46 (2004) 241

# Global transport analysis also indicate a link between anomalous transport and neoclassical transport.

H.Yamada *et al*., Nucl. Fusion 45 (2005) 1684

The confinement improvement factor ($\tau_E^{exp.}/\tau_E^{ISS04}$), which is the ratios of confinement times evaluated by experiments to these estimated by the ISS04 scaling law, seems to improve with the decrease of the effective helical ripples ($\varepsilon_{eff}$), which is a measure of neoclassical transport in helical device, i.e., smaller $\varepsilon_{eff}$ is better neoclassical transport in $1/\nu$ regime.

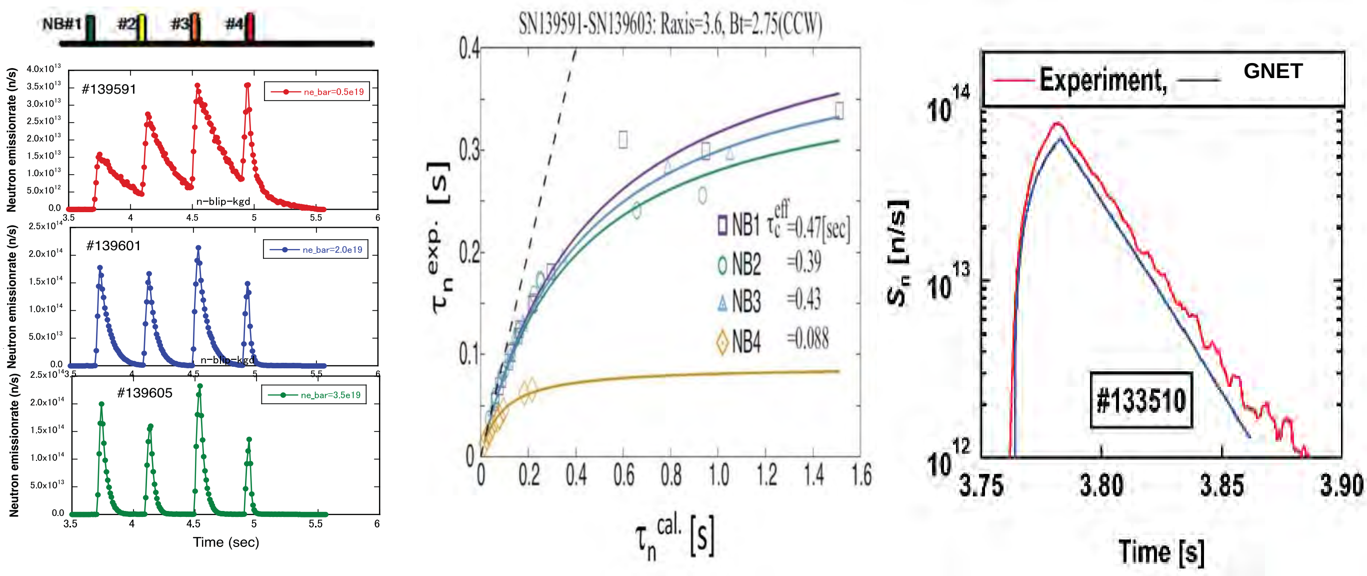



Experimental investigation on the link between neoclassical transport and anomalous transport is important to establish the comprehensive understanding in toroidal plasmas in addition to the isotope effect study.

- ✓ Comparison between the $\chi^{exp.}$ and $\chi^{neo.}$ for various configuration.
- ✓ Comparison of the measured turbulence level to $\chi^{exp.}$ and $\chi^{neo.}$
- ✓ Comparison of simulated turbulence level to the measurement, e.g., PCI, DBS and etc.



In the future fusion reactor, plasmas are sustained and controlled by fusion born a-particles. Thus, realtime estimation of energetic particle profiles will be necessary. For this purpose, FP model is ideal but the implementation of loss is necessary. To implement loss during slowing down process, effective confinement time of EP is evaluated, experimentally.




- The database construction of these effective confinement times ($\tau_c^{eff.}$) is ongoing. Systematic scan of magnetic configuration will provide the confinement database of EPs on magnetic ripples.
- The database will be extended to diffusive model ($D^{eff.}$) of the EP transport with EP driven instabilities[1], where, we can include the transport without instabilities by $D^{eff} = a^2/5.8\tau_c{}^{eff}$.
- The experimental results are also used to validate EP transport simulation, like GNET-code.

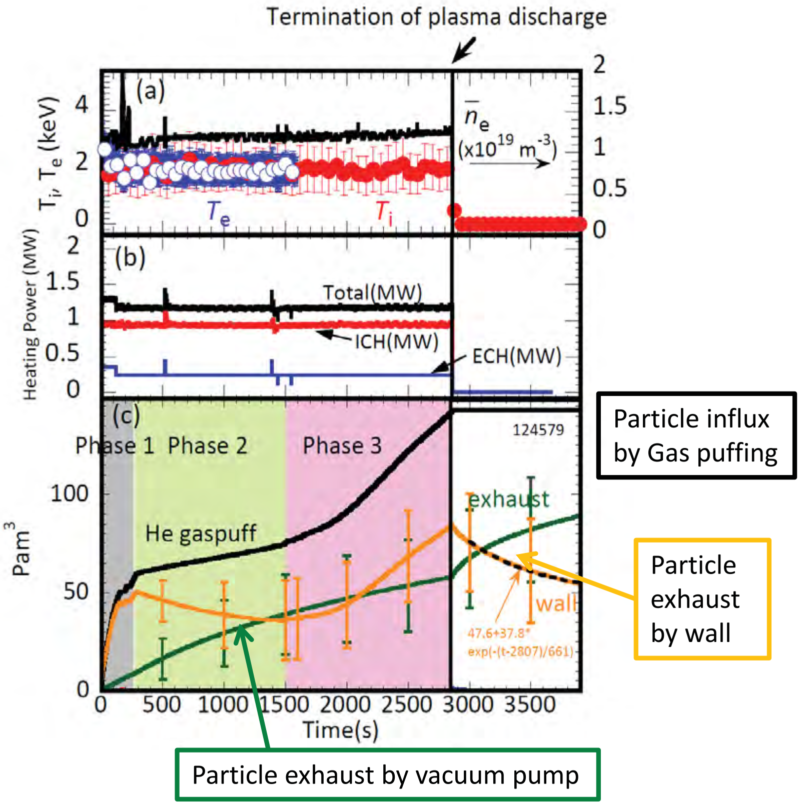


[1] W.W.Heidbrink et al., Nucl. Fusion **53**(2013) 093006

# PWI studies with long time scale is also important.

Revival of wall pumping was observed at the 48 min. long pulse operation in LHD

- Particle balance in LHD long pulse discharge is shown in Fig.(c)
- Particle exhaust by the wall is evaluated by the subtraction of the particle exhaust by vacuum pump from the particle influx by gas puffing.
- The particle pumping rate can be evaluated from the slope of the exhaust curve.
- Particle exhaust by wall:
  - ✓ Phase 1: ~ 0.2 Pa $m^3/s$
  - ✓ Phase 2: ~ -0.01 Pa $m^3/s$
    - Negative pumping rate !!
    - ☜ Emitting gas from the wall
  - ✓ Phase 3: ~ 0.04 Pa $m^3/s$
    - ☜ Revival of wall pumping
- From the analysis on the deposited layer on the diverter plate. Mixed material layer by carbon and iron seems to play a role on this revival.




The LHD steady state operation is suitable platform to explore the long time constant behavior in Plasma-Wall Interactions.



# Tungsten (W) related PWI studies will be enhanced.

As a material for divertor targets, tangsuten(W) is thought to be the best candidate.

To enhance the PWI study for future fusion reactor, a replacement of divertor target plate to bulk W and/or W coated Carbon tile is considered. To examine the influence of W on LHD operation, the W-coated Carbon divertor was installed at one toroidal section from FY2018.

W coated Carbon divertor

# PROMOTION OF COLLABORATION



# Issues of Evaluation (3)

**3. Promotion of collaboration**

共同研究の推進

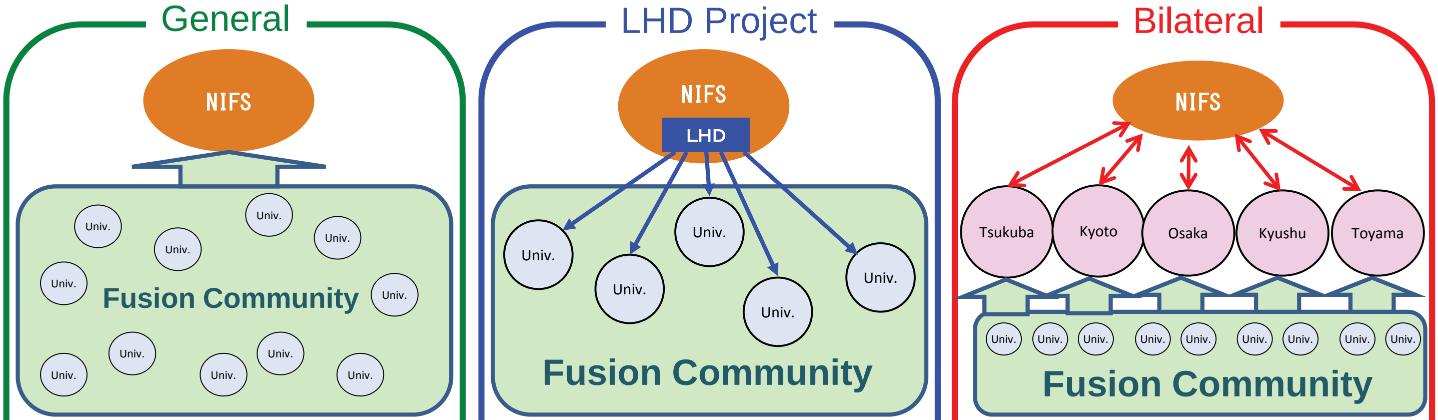
(7) Does the LHD project play the role of a global COE in the research with helical devices by constructing and using the research network among domestic and international universities and research institutes?

国内外の大学や研究機関との研究ネットワークが構築･活用され、ヘリカル型装置研究における国内外のCOEとしての役割を果たしているか。

(8) Does the LHD project promote cooperation with and contribute to ITER/BA? Further, does the LHD project contribute to the research and development of a reactor? (From the third mid-term plan)

# Domestic collaboration system

Three frameworks of domestic collaboration research are established




**General**

- Collaboration programs using experimental device or computer in NIFS
- Wide area from basic plasma to nuclear fusion
- Small-scale symposiums or workshops are supported
- 413 topics (2018)

**LHD Project**

- R&D programs in universities aiming at future application to LHD. Three-year program is accepted although other two category permit only single-year program.
- 24 topics (2018)

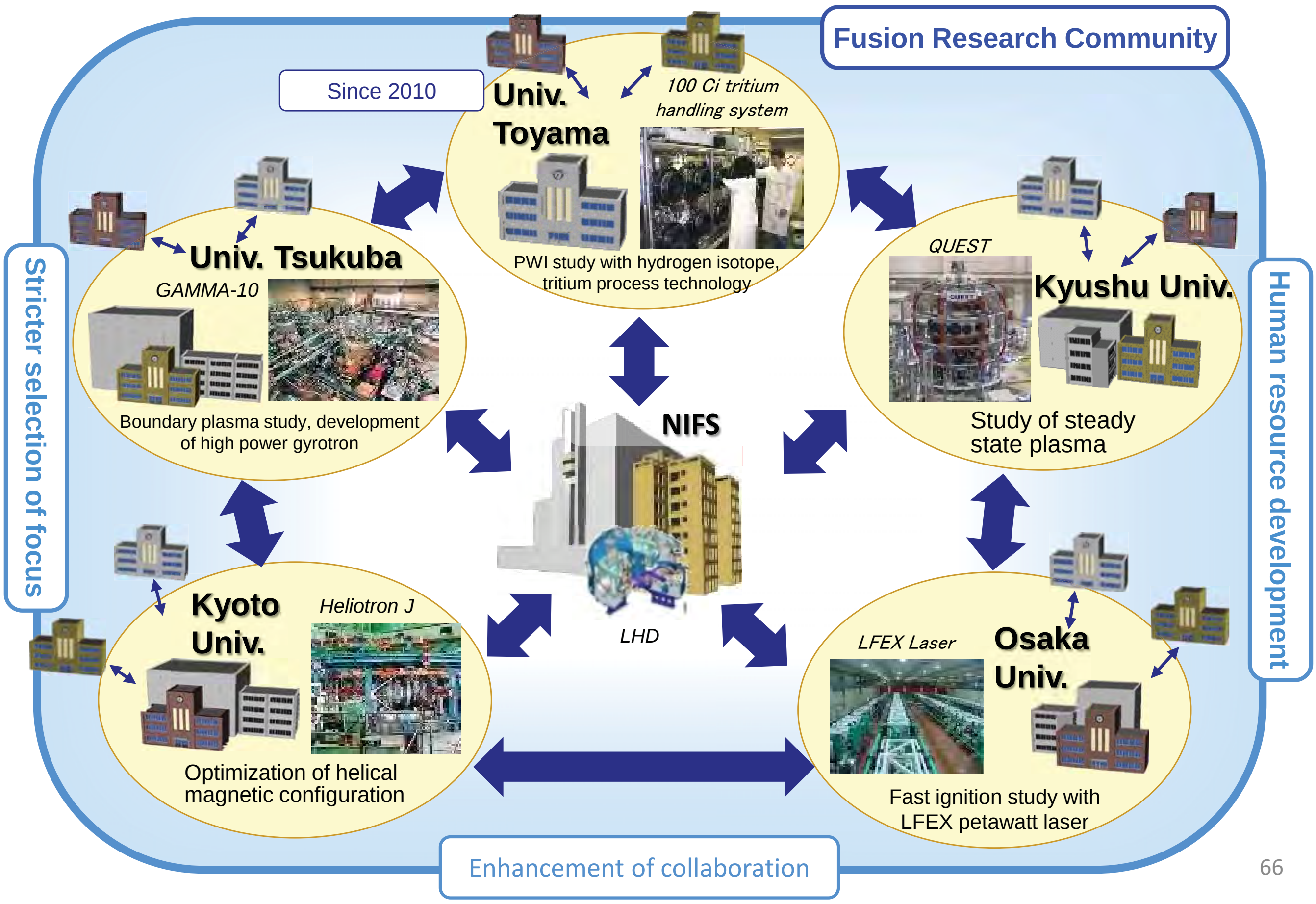
**Bilateral**

- Unique facilities in university research centers can be used by researchers across Japan, as if it were in NIFS.
- Each research center undertakes the research subjects among important common issues in the nuclear fusion research.
- 101 topics (2018)

223 universities/institutes, 1524 collaborators (2017)



# Bilateral collaboration research



# International Collaboration Researches

**Bilateral Coordination**

- US-Japan
- Korea-Japan
- China-Japan
- Russia-Japan
- Australia-Japan
- EU-Japan

*Activities in 3 Bilateral Coordination with intergovernmental agreements*

| Personnel exchange in FY2017 | J/China | | J/Korea | | J/US | |
|---|---|---|---|---|---|---|
| | man | day | man | day | man | day |
| to NIFS/Japan | 7 | 61 | 45 | 163 | 81 | 360 |
| from NIFS/Japan | 41 | 258 | 34 | 157 | 71 | 777 |

**Multilateral Coordination under IEA**

- Stellartor-Heliotron Concept (chair 2006-2015)
- Plasma Wall Interaction
- Spherical Tori
- (Steady State Operation)

*Improve physics base of the Stellarator-Heliotron concept and enhance the effectiveness and productivity of R&D efforts*

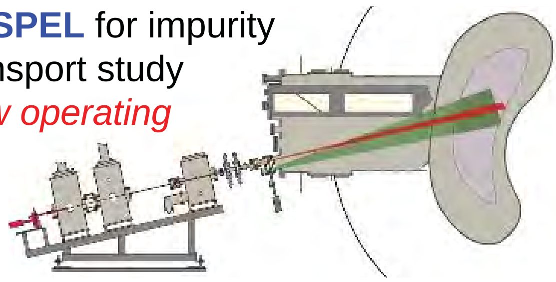

**Coordination with Other Institutes**

29 International Academic Exchange Agreements



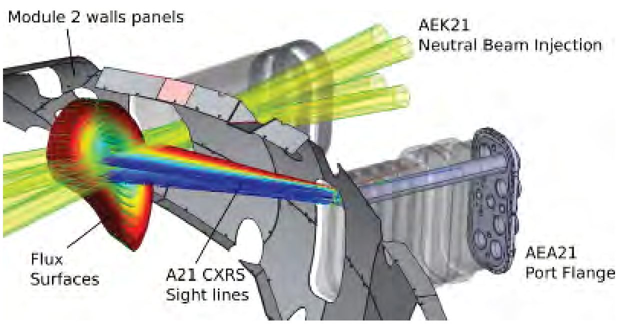
# Collaborations with IPP Greifswald (W7-X)

**TESPEL** for impurity transport study
*now operating*



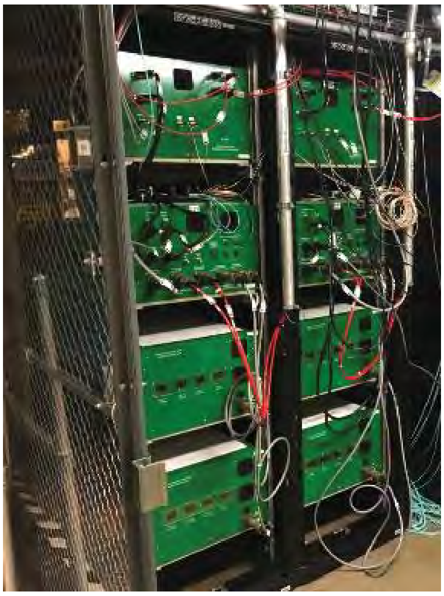
**Faraday cup** for high energy lost ion detection

**CXRS** for H/D ratio measurement

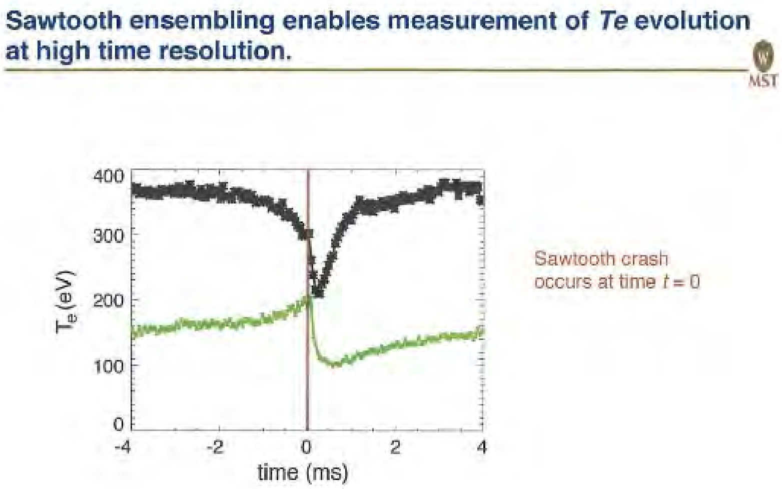



**Scintillating fiber detector** for secondary neutron measurement

# Collaborations with U. Wisconsin Madison



**High frequency power supply**
for high speed Thomson scattering system




Combination with high speed laser enables ~ 10 kHz measurement, which is useful for
- MHD study
- transient phenomena (L/H, attach/detach, ELM, etc.) observations



# Issues of Evaluation (3)

**3. Promotion of collaboration**

(7) Does the LHD project play the role of a global COE in the research with helical devices by constructing and using the research network among domestic and international universities and research institutes?

(8) Does the LHD project promote cooperation with and contribute to ITER/BA? Further, does the LHD project contribute to the research and development of a reactor? (From the third mid-term plan)

ITER計画・BA活動との連携、貢献が行われているか。また、原型炉研究開発に寄与しているか。（第三期中期計画より）

# Contributions to ITER/BA (1)

**Contract with JA-DA**

- **Performance examination of the ITER-TF coil connection**

**Contract with ITER-IO**

- **High power tube test for ITER ICH system**
  * 1.4MW/3s, 1.3MW/10s, 1MW/100s at 65 MHz using 4CM2500KG achieved
- **Negative ion source for NBI**
- **ITER Cryo-plant Process Study**
  * Dynamic simulation for the supercritical helium test loop experiment
  * Full-scale TF structure modelling with simulation under two base line scenarios, 15 & 17 MA, with Plasma disruption followed by the slow ramp down and the fast discharge
- **Design of the dispersion-interferometer**

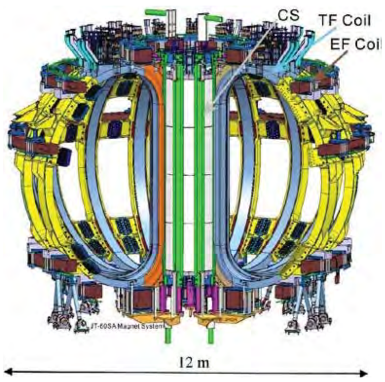

ITER TF joint



# Contributions to ITER/BA (2)

**Contributions to JT-60SA:**

- performance examination of the JT-60SA EF and CS coils
- development of diagnostics, fueling system
- making the JT-60SA Research plan
- management of collaboration




**BA collaborations:**

- DEMO design collaboration
- DEMO R&D collaboration
- Reduced-activation ferritic steel
- SiC/SiC composit
- JET ILW PWI research
- IFMIF/EVEDA collaboration
- management of BA
  * steering committee member
  * IFERC project leader

JT-60SA CS coil

# HUMAN RESOURCE DEVELOPMENT AND EFFORTS TOWARD UNDERSTANDING BY SOCIETY



# Issues of Evaluation (4)

**4. Human Resource Development and Efforts toward Understanding by Society**
人材育成、社会の理解へ向けた取り組み

（９）Does the LHD project contribute to the human resource development of researchers who are active internationally and lead the domestic and international fusion research?

国内外の核融合研究を牽引し、国際的にも活躍する人材の育成に貢献しているか。

（１０）Does the LHD project cooperate with local governments and engage in deepening the understanding of the deuterium experiments by local residents?

# Development of human resources through international collaborations

Developing human resources for fusion science is essential to keep and enhance the research potential for next generation

In order to perform it, NIFS has
- contributed to the education for graduate students via **SOKENDAI** (the graduate university for advanced studies)
- accepted graduate students and internship students from domestic and overseas universities and institutes
- has dispatched graduate students and young researchers to overseas institutes which have the academic exchange agreements

Graduate students in NIFS
- SOKENDAI: 15, including 6 from abroad (2018)
- Other universities: 38 (2017)

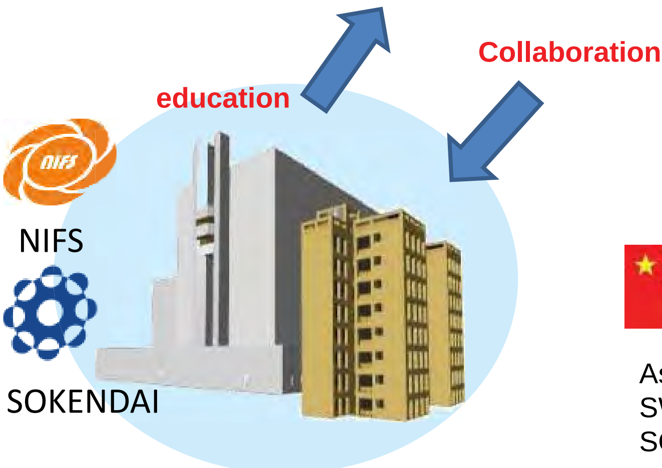


# Active Scientists raised locally, blooming globally

Prof. Y. Xu,
Southwest Jiaotong Univ.
JSPS fellow in NIFS

Dr. P. Drewelow
IPP Greifswald, Scientist,
Ph.D. thesis in LHD exp.

Prof. Y. Liang,
FZJ/HHU,Huazhong Univ.,
SOKENDAI




Assoc. Prof. S. Geng,
SWIP,
SOKENDAI

Dr. S.
General Atomics,
SOKENDAI

# Issues of Evaluation (4)

**4. Human Resource Development and Efforts toward Understanding by Society**

(9) Does the LHD project contribute to the human resource development of researchers who are active internationally and lead the domestic and international fusion research?

(10) Does the LHD project cooperate with local governments, and engage in deepening the understanding of the deuterium experiments by local residents?

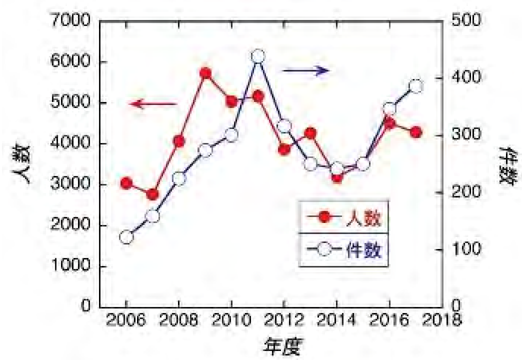
自治体との連携を図るとともに、重水素実験に対する地域住民の理解を深める取組みを行っているか。



# Public release of information (1)

**NIFS Tour**

- Throughout the year, NIFS welcomes visitors for the facility tour.
- Visitors can see several experimental facilities and hear a summary of NIFS research activities.
- Tour is on weekday and takes about 90 minutes.
- Three staffed specializing in NIFS tour.




**Open Campus**

- Once a year in autumn, since 1998
- 1500 visitors in 2018

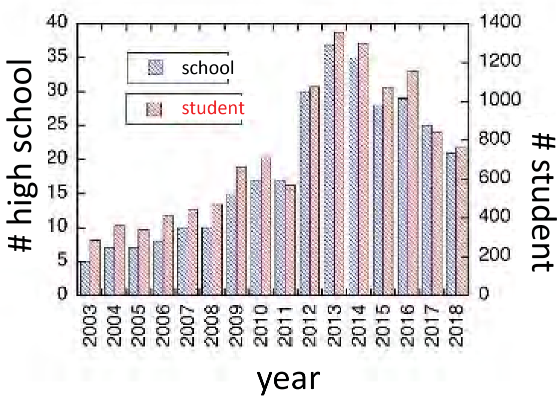
**Fusion Festa in Tokyo**

- Once a year in Tokyo as science event along the lines of Open Campus, since 2010
- Open lectures and experience-based event like scientific handcraft
- 2650 visitors in 2018


# Public release of information (2)

## Educational contributions

- Educational partnership activities of Super Science High School (SSH) :
  25 high schools, 842 students (2017).
- Visiting lectures: 8 high schools (2017)
- Internship programs for junior-high school, high school and technical college students:
  18 schools, 33 students (2017)




## Public Forum

- Explanation about LHD and deuterium experiment to increase local citizen's recognition of NIFS's scientific achievements
- Forums take place at community centers at Toki, Tajimi, and Mizunami, since 2006
- In FY 2018, 235 citizens joined the Forum
- Total: 5,365 (for 13 years)



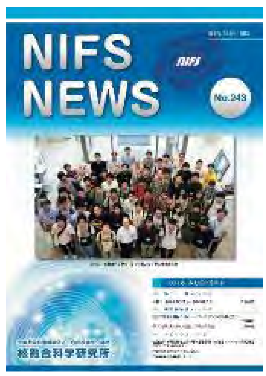
# Public release of information (3)

## Publications

- Design and publication of the PR magazines and leaflets:
  "Plasma-kun Dayori" (every 2 months)
  "NIFS NEWS" (every 2 months)
  "Fusion – Energy to Pave the Way for Future",
  "NIFS Do Research Aimed at Extracting Energy from Sea Water",
  "Introduction to NIFS and the NIFS Tour",
  and "Welcome to NIFS"

Autonom






## Web

- Introductions to fusion
- about NIFS
- about LHD
- about deuterium experiment
- Safety

# Cooperation with Local Autonomies

## Cooperation with local commission

- In 2013, NIFS concluded the agreement for D-D experiment with local autonomies
- Following the agreement, Gifu pref., Toki, Tajimi and Mizunami city established the Safety Surveillance Commission for National Institute for Fusion Science
- NIFS informs safety report and experimental schedule and status regularly to the commission.

## Collaboration Research with "Toki City Plasma Research Committee"

- In 1979, collaboration research started with Toki City Plasma Research Committee started, which consists of high and junior high school teachers
- Main activities are
  - holding lecture meetings on energy and environmental issues
  - measurement of environmental radio-activities at 18 locations in Tono area

# References

Table of Evaluation Results for the 2018 External Peer Review

# Table of Evaluation Results for the 2018 External Peer Review "Large Helical Device Project"

## Ⅰ. Points for Evaluation

(1)Is the implementation system built to achieve deuterium experiments with coordinating domestic and international researchers? (From the third mid-term plan)

(2)Are preparations of safety management equipment and of facilities and their countermeasures performed appropriately for starting the deuterium experiments? Was the safety management system built as planned? (From the third mid-term plan)

(3)Does the LHD project obtain high-performance plasma by the deuterium experiments and produce excellent research achievements with high academic value? (From the third mid-term plan)

(4)Does the LHD project obtain prospects for development of academic research toward a comprehensive understanding of toroidal plasmas? (From the third mid-term plan)

(5)Is preparation of necessary devices and facilities for the main device, heating systems, diagnostics, and others advanced appropriately according to the research plan of the deuterium experiments?

(6)Will the LHD project consider further research development towards the realization of a fusion reactor based on the achievements of the LHD project?

(7)Does the LHD project play the role of a global COE in the research with helical devices by constructing and using the research network among domestic and international universities and research institutes?

(8)Does the LHD project promote cooperation with and contribute to ITER/BA? Further, does the LHD project contribute to the research and development of the DEMO reactor? (From the third mid-term plan)

(9)Does the LHD project contribute to the human resource development of researchers who are active internationally and lead the domestic and international fusion research?

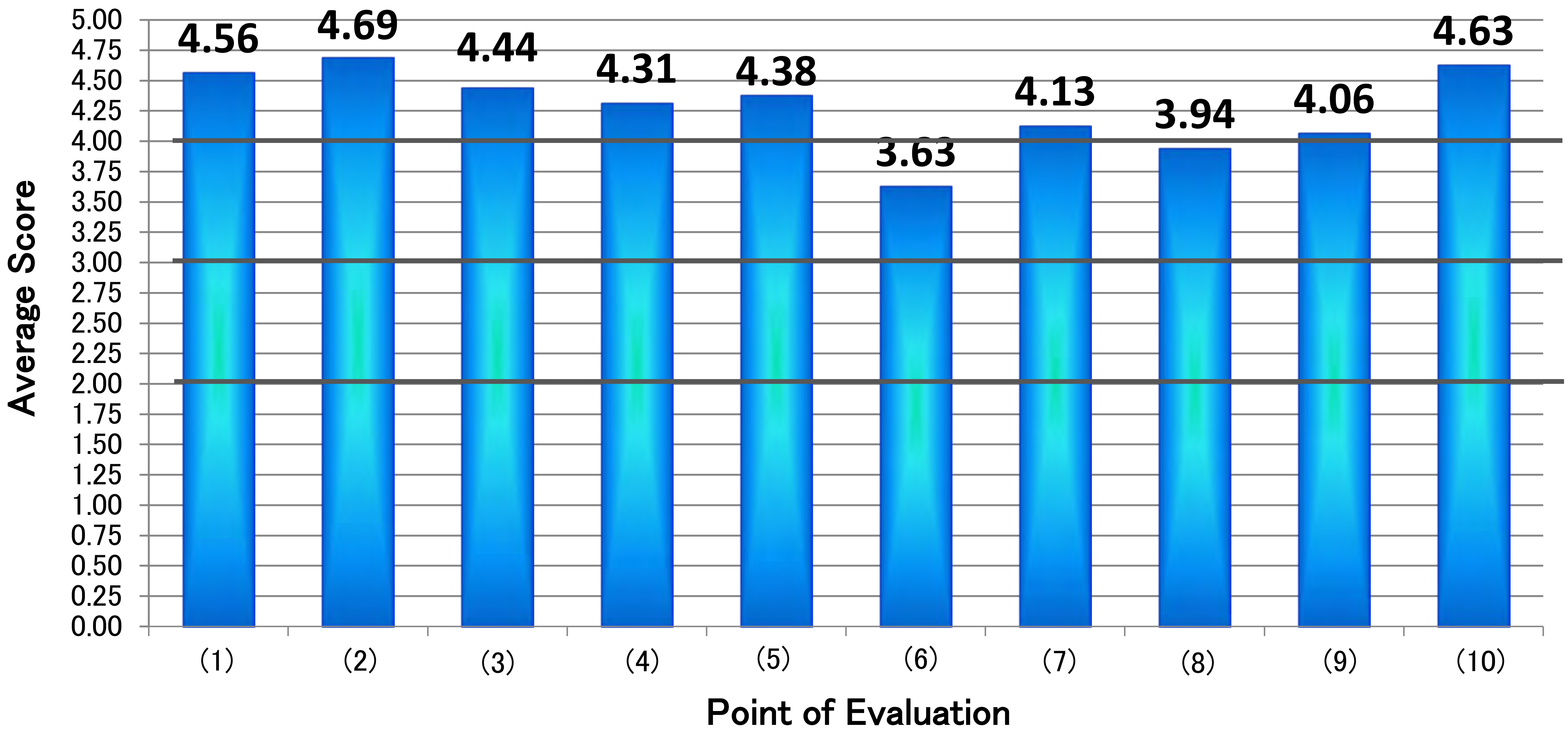
(10)Does the LHD project cooperate with local governments and engage in deepening the understanding of the deuterium experiments by local residents? Does the project also contribute to achieving a broad social understanding of fusion research?

## Ⅱ. Tabele of Evaluation

Number of persons

| Score \ Point of Evaluation | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|---|---|---|---|---|
| 5 (Extremely highly commmendable) | 10 | 12 | 9 | 5 | 9 | 1 | 3 | 4 | 4 | 10 |
| 4 (Highly commendable) | 5 | 3 | 5 | 11 | 4 | 8 | 12 | 7 | 9 | 6 |
| 3 (Commendable) | 1 | 1 | 2 | 0 | 3 | 7 | 1 | 5 | 3 | 0 |
| 2 (Adequate) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 (Inadequate) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Average Score** | **4.56** | **4.69** | **4.44** | **4.31** | **4.38** | **3.63** | **4.13** | **3.94** | **4.06** | **4.63** |

※The evaluation result is a combination of the results of domestic committee members (12 persons) and foreign committee members (4 persons).



Inter-University Research Institute Corporation
National Institutes of Natural Sciences
**National Institute for Fusion Science**
322-6 Oroshi-cho, Toki, Gifu, 509-5292, Japan
http://www.nifs.ac.jp/