National Institute for Fusion Science (NIFS)
National Institutes of Natural Sciences (NINS)

External Peer Review Reports in FY2014

March, 2015

External Peer Review Committee, NIFS Advisory Committee
Contents

Chapter 1  Background ......................................................... 1

Chapter 2  Reviews and Proposals ........................................ 5
  2.1 Summary of the External Peer Review ............................. 5
  2.2 Recommendations ..................................................... 9

Chapter 3  In Closing ......................................................... 11

Documents  2014 External Peer Review Presentation Materials

Appendix: Charts of review results
Chapter 1  Background

In order to advance fusion research in universities, the National Institute for Fusion Science (NIFS), as an Inter-University Research Institute, was established in 1989 with the Large Helical Device (LHD) as the main device. Planned to bear the collective opinion and expectations of the fusion community and with the special characteristic of generating a heliotron-type magnetic field using a superconductor, an idea developed in our country, the LHD, together with generating high-performance plasma by using the helical magnetic field configuration through high-power heating, is advancing experimental research that aims at clarifying physics and engineering issues in anticipation of the achievement of a toroidal magnetic field confinement fusion reactor. On the other hand, parallel with this, theoretical research utilizing large-scale simulations is essential in analysis of fusion plasmas of great complexity. At NIFS we have introduced the most advanced supercomputers, and having made these supercomputers available through joint-use with fusion theory scholars throughout Japan we thus have moved forward with pioneering research.

During this time, there have been changes in the domestic academic research system, and since 2004 NIFS, as an institute in the Inter-University Research Institute Corporation National Institutes of Natural Sciences, has advanced still further in countrywide joint use and joint research. Upon incorporation, we developed a six-year mid-term plan, and a system for receiving an annual evaluation regarding the state of our progress was introduced. This annual evaluation focuses primarily on management. Regarding research results, NIFS has determined that receiving an evaluation by external experts is important. Under the Advisory Committee, an external peer review committee is organized and each year an evaluation of research is conducted. The evaluation topics are decided by the Advisory Committee, and the evaluation is undertaken by the External Peer Review Committee, which is composed of the external Advisory Committee members and foreign experts appropriate for the evaluation topics. The External Peer Review Committee reports the results of its evaluation to the Advisory Committee, and NIFS respects those results, which become useful for improvement in the next fiscal year’s research activities.

At NIFS, upon the start of the second mid-term goals period that began in 2010, in order to further strengthen the centripetal force of NIFS as a Center of Excellence (COE) in the field of plasma and fusion research we designed research projects in three areas: the LHD, the Numerical Simulation Reactor Research, and the Fusion Engineering Research. Looking toward the realization of the fusion reactor, we then initiated research planning that would unify the results of these projects. For this reason, in FY 2010 we revised the research structure of NIFS. Placing all research staff members in one research department, we introduced a structure by which each researcher would freely select
the research project in which she/he would participate. Since then, coordination among the LHD Project, the Numerical Simulation Reactor Research Project, and the Fusion Engineering Research Project has become much closer, and we have become able to respond to new issues as occasion demands.

In the Advisory Committee meetings, in order to confirm results of the research project system, we conducted the external peer review on the LHD Project in 2011, the Numerical Simulation Reactor Research Project in 2012, and the Fusion Engineering Research Project in 2013. We then assigned the “Deuterium Experiment Implementation Plan” as the subject for external peer review in 2014. To serve as members of the external peer review, we selected ten members of the Advisory Committee who are outside of NIFS and four members from foreign countries. Furthermore, the Experts Committee on this topic was composed of the External Peer Review Committee and five specialists outside of NIFS. In this way, we composed the External Peer Review Committee and the Experts Committee and then conducted the evaluation.

At the first meetings of the External Peer Review Committee and the Experts Committee, which were held on September 12, 2014, we discussed how to move forward with this fiscal year’s external evaluation, and decided upon the perspectives and the specific issues for evaluation. We will introduce this information below. At the second meetings of the External Peer Review Committee and of the Experts Committee, which were convened on November 29, 2014, we received from each person in charge at NIFS a detailed explanation that used viewgraphs to treat the points for evaluation and materials regarding the reports of activities. A discussion session followed. Subsequently, on January 29, 2015, the third meetings of the External Peer Review Committee and the Experts Committee were held. Including further discussion with NIFS, these committees undertook evaluation duties that followed the points and items that had been determined at the committee meetings. With the draft version of the evaluation submitted, on February 24, 2015, the fourth External Peer Review Committee meeting and the Experts Committee meeting were held. The final report was compiled.

This report is composed of the following four parts: Part 1: The Particulars to Present; Part 2: Evaluations by Item; Part 3: Summary of the Evaluations, and Recommendations; and Part 4: Conclusion.

After this report is approved by the NIFS Advisory Committee, the Director General of NIFS will submit it to the President of the National Institutes of Natural Sciences (NINS). Subsequently, after approval by the Education and Research Council and the Administrative Council of NINS, this
The points for evaluation in the “Deuterium Experiment Implementation Plan” are composed of requisite items for evaluation of the research plan and the safety management plan, and of the readiness of the plans for the LHD Deuterium Experiment, which will advance as an important NIFS plan in the third mid-term plan that the Inter-University Research Institute Corporation National Institutes of Natural Sciences will formulate. The appropriateness and the level of achievement will be the basis of the points for evaluation.

Further, referencing the “Recommendation” in the external peer review regarding safety management that was implemented in 2009, the following two points were considered in this evaluation.

1. Are the training and the education of the people who will be responsible at the time of the deuterium experiment being conducted appropriately?
2. Are the Safety Committee and the Safety Surveillance Committee for Radiation Safety Management, the organization of the Radiation Control Office, and the systems for responses to emergencies being constructed appropriately?

The topics in the “Deuterium Experiment Implementation Plan” for the fiscal year 2015 evaluation are as follows below.

[1] Research Plan
(1) Is the goal of the deuterium experiment appropriate? Further, do the research plan and the implementation system for ensuring safety achieve those goals?
(2) Does this plan contribute to the promotion of a comprehensive understanding of toroidal plasma and heighten its academic value with regard to the realization of fusion energy?
(3) Regarding implementation of the plan, will this achieve a system of joint use and joint research that enables participation by a wide range of researchers?

[2] Deuterium Experiment Preparation System
(1) Moving toward the initiation of the deuterium experiment in 2016, is the preparation of
equipment and facilities being planned appropriately?
(2) Is the preparation system for the initiation of the deuterium experiment appropriate? Is preparation of the facilities and devices, including safety equipment, being advanced appropriately?

(1) Is the fundamental concept regarding safety management appropriate at the time of the formulation of the deuterium experiment implementation plan as also based upon the opinions of local residents?
(2) Are safety management equipment, facilities, and experiment equipment being planned appropriately for the safe accomplishment of the deuterium experiment and to be managed for maintenance?
(3) In order to safely accomplish the deuterium experiment, are various types of regulations being formulated appropriately?
(4) Are the operation manual, the radiation management manual, and the emergency measures manual being formulated appropriately?
(5) Are the organization of and the system for safety management while the deuterium experiments are being conducted constructed appropriately?
(6) Are education and training for the safe execution of the deuterium experiments, and nurturing of those responsible for safety management being undertaken appropriately?

[4] Understanding by Society and Citizens
(1) Is enhanced understanding of the safety of the deuterium experiment being advanced appropriately to local residents?
(2) Is promotion of the deuterium experiment plan being designed in conjunction with local governments?
(3) Is the importance and the safety of fusion research being widely disseminated in society?
Chapter 2 Reviews and Proposals

Points for evaluation results are summarized based on discussions by the External Peer Review Committee and the Experts Committee, and several important recommendations are proposed to promote the “Deuterium Experiment Implementation Plan.”

2.1 Summary of the External Peer Review

[1] Research Plan

(1) Is the goal of the deuterium experiment appropriate? Further, do the research plan and the implementation system for ensuring safety achieve those goals?

From the deuterium experiment, research in high-performativity through improvement of confinement, isotope effects, and confinement of high energy ions will advance, and contributions to the comprehensive understanding of toroidal plasmas are anticipated. Such goals as these are appropriate. This is a research plan, which together with expanding the plasma parameter regime through the improvement of confinement and the strengthening of heating devices, will expand toward new research realms through the maintenance of neutron diagnostics and high precision diagnostics, and maintenance of the closed divertor. And combined with the advances in the preparation of securing the safety of the deuterium experiments, we highly evaluate this plan.

Next, together with deepening further discussion regarding the formulation of concrete experimental planning, it is necessary to academically verify the isotope effect in improving confinement in helical devices and to contribute to a comprehensive understanding of toroidal plasma. The safety measures and the implementation system for advancing with this research are appropriate. In the future, while adding further examinations that include additional researchers, it will be desirable to advance while planning continuous revisions of the safety management system.

(2) Does this plan contribute to the promotion of a comprehensive understanding of toroidal plasma and heighten its academic value with regard to the realization of fusion energy?

Through confinement improvements and elucidation of physics, improvement of MHD stability and enlargement of the high beta region, confinement of high energy ions, optimization of the divertor, plasma wall interaction, and diversification of ICRF heating, this
is a plan that heightens the academic value in achieving fusion, and is highly evaluated. Through the closed divertor and by applying a perturbation magnetic field, the transport phenomenon in edge plasma will develop, and contributions to the control of particles in core plasma are expected. This is highly evaluated. Considering cases in which improved confinement through the isotope effect are insufficient, it is hoped that there will be elucidation of various confinement improvement methods and that there will be predictions regarding modeling.

(3) **Regarding implementation of the plan, will this achieve a system of joint use and joint research that enables participation by a wide range of researchers?**

Establishing links with research institutions in Japan and abroad through joint research projects aiming toward the deuterium experiment, results have been achieved in neutron diagnostics, tritium recovery, plasma wall interaction, and other fields. We highly praise the formation of a countrywide research network. That NIFS has held joint meetings for research planning for the deuterium experiment and for safety management planning with the Fusion Network as well as with the Experts Committee of The Japan Society of Plasma Science and Nuclear Fusion Research, and that NIFS has held discussions with a wide range of researchers at symposia and invited lectures in the case of academic society are also evaluated highly.

[2] **Deuterium Experiment Preparation System**

(1) **Moving toward the initiation of the deuterium experiment in 2016, is the preparation of equipment and facilities being planned appropriately?**

Aiming toward the deuterium experiment, NIFS is planning appropriately repairs and improvements to facilities for establishing the controlled area, reinforcement of the NBI, development and maintenance of neutron diagnostics, and planning and construction of a diagnostic for the tritium recovery. We highly evaluate this, and also evaluate that NIFS is advancing appropriately the maintenance execution plans by separating them into three stages.

(2) **Is the preparation system for the initiation of the deuterium experiment appropriate? Is preparation of the facilities and devices, including safety equipment, being advanced appropriately?**
Aiming toward the initiation of the deuterium experiment, we highly evaluate the establishment of the Division of Deuterium Experiments Management. Under its direction, preparation of manuals, preparation and improvement of facilities, and the preparation of safety facilities were implemented without delay.


(1) Is the fundamental concept regarding safety management appropriate at the time of the formulation of the deuterium experiment implementation plan as also based upon the opinions of local residents?

We judge the fundamental way of thinking regarding safety to be satisfactory. And implementing a system for monitoring the environment for very small amounts of tritium too can be praised from an academic perspective. Further, compliance is important, but because introducing excessive self-regulation together with hindering academic development will also affect the operation of other RI facilities, it is necessary to make NIFS regulations abundantly clear and to move forward so that these do not become standards.

(2) Are safety management equipment, facilities, and experiment equipment being planned appropriately for the safe accomplishment of the deuterium experiment and for their maintenance?

We judge and highly evaluate that the safety management instruments and facilities, and the experiment equipment will safely perform the deuterium experiment, and that operation and maintenance are being appropriately planned. Further, we would like the disposal of tritiated water to move forward in close cooperation with the Japan Radioisotope Association.

(3) In order to safely accomplish the deuterium experiment, are various types of regulations being formulated appropriately?

We highly evaluate that regulations have been sufficiently prepared for safe execution of the deuterium experiment. Further, regarding the handling of radioactivated materials, we seek sufficient study. Depending upon the material and the region in the LHD, radioactivated materials are subjects of research, and it is necessary to clarify that it is possible to transfer them according to law.
(4) Are the operation manual, the radiation management manual, and the emergency measures manual being formulated appropriately?

Manuals for the safe accomplishment of the deuterium experiments are being basically prepared, and these are highly evaluated. It may be stated that it is better for times of emergency to write the division/section and the telephone numbers to contact specifically. Further, as a more specific evaluation, in treating radioactivated materials, it is thought to be necessary to prepare a manual that includes concrete methods for measurement.

(5) Are the organization of and the system for safety management while the deuterium experiments are being performed being constructed appropriately?

The organization of safety management is highly evaluated for having been sufficiently prepared. However, so that inflexibilities due to bloated organization not occur, it likely will be necessary to operate while conducting appropriate reviews even after starting operation.

(6) Are education and training for the safe execution of the deuterium experiments and nurturing for those responsible for safety management being undertaken appropriately?

In addition to the lectures mandated by law, activities such as actually experiencing the handling of tritium conducted through cooperation with the Toyama University Hydrogen Isotope Research Center are highly evaluated. It is believed that training in communication in a time of emergency will be conducted and that cultivation of human resources for safely executing the deuterium experiment are being appropriately planned.

[4] Understanding by Society and Citizens

(1) Is enhanced understanding of the safety of the deuterium experiment being advanced appropriately to local residents?

In order to plan for enhancing understanding of safety, over nearly the past decade NIFS has held open meetings for local residents. These open meetings have been held each year at from 20 to 30 places and more than 4,000 people have attended. NIFS has explained the deuterium experiment and the results of research, and is advancing a shared understanding. And opinions raised at explanatory meetings are made available on the NIFS homepage. We very highly evaluate this. Further, NIFS is engaging in public relations such as through brochures and
leaflets, and is participating in science fairs and local events. In particular, in 2013 NIFS held a Science Classroom and more than 1,000 people participated. That NIFS is actively engaged in these efforts is highly evaluated.

(2) **Is promotion of the deuterium experiment plan being designed in conjunction with local governments?**

From around 1997, while continuing to consult with the nearby cities of Toki, Tajimi, and Mizunami, NIFS has deepened their understanding of its research activities and position regarding safety. And in 2013, NIFS concluded agreements with Gifu Prefecture and these three cities. Further, as joint activities with the Toki City Plasma Research Committee, we can evaluate extremely highly that NIFS is continuing local radiation measurements together with elementary and junior high school teachers.

We also highly evaluate the continuation of regular explanation meetings and research report meetings after the conclusion of the agreement. Further, training in information delivery together with local communities and the establishment at NIFS of the Regional Coordination Office, which is a system for coordination.

(3) **Is the importance of fusion research and its safety being widely disseminated in society?**

An Open Campus is held each year at NIFS, and this is becoming a large event with from 2,000 to 4,000 people attending each time. Further, NIFS conducts outreach not only in this area but also in other areas, too. NIFS holds the Fusion Festa in Tokyo at the National Museum of Emerging Science and Innovation. In 2014, more than 2,000 people attended, and that this has become a large event where people can learn about fusion research can be highly evaluated. In addition, the holding of academic lectures for local residents, the production of a mail magazine and of mail news, and visitors to NIFS exceeding 4,000 people indicates that NIFS is pouring strength into public relations activities. Moreover, through cooperation with the SSH activities and cooperation with internships for junior high and high school students NIFS is actively engaged in public relations toward youths who will support the next generations. This can be highly evaluated.

2.2 **Recommendations**

In this evaluation we have listed our recommendations regarding the path forward based upon the discussion of the Deuterium Experiment Implementation Plan.
(1) Regarding the improvement of confinement that will be accompanied by the deuterium experiment as well as the maintenance of heating devices and diagnostics instruments, together with the further deepening of discussion toward a concrete experiment plan formulation, and through enhancement of modeling we anticipate contributions toward a comprehensive understanding of toroidal plasma. We anticipate further continuation and maintenance of the countrywide research networks for neutron diagnostics, tritium recovery, and plasma-wall interaction that have been formed through collaborative research toward the Deuterium Experiment.

(2) To start the Deuterium Experiment on schedule, and under the Division of Deuterium Experiments Management we anticipate completion without delay of the preparation and maintenance plan formulation as well as the maintenance of equipment, reinforcement of facilities, and establishment of a safety management system.

(3) NIFS also summarizes fusion research performed at universities, and in safely achieving success in the deuterium experiment, completion also is extremely important. In particular, while respecting the law, respecting the opinions of local residents, and maintaining a well-balanced sense regarding the development of scholarship, one must respond with flexibility. Further, it is hoped that regarding actual safety management, NIFS will proceed safety management in a polite and reliable manner by the overlap of appointment terms for supervisors and by rotating their appointments.

(4) That NIFS has over a long period of time explained matters to local residents and has cooperated in communication activities with local governments can be highly evaluated. From now, too, through results from safety management and continuous practice it is hoped that NIFS will work toward receiving understanding and support of fusion.
Chapter 3 In Closing

At the National Institute for Fusion Science, from the beginning of the second mid-term goals period in 2010, in order to strengthen further the centrifugal power of NIFS as a Center of Excellence in the plasma-fusion field, NIFS composed research projects in the following three fields: the LHD Project, the Numerical Simulation Reactor Research Project, and the Fusion Engineering Research Project. Aiming toward realization of the fusion reactor, we started research planning toward integrating these results. For this purpose, in 2010 NIFS undertook a revision of the research structure within the Institute. All of the research education staff were set in one research division, and each researcher could freely choose to participate in one of the three projects. These are the LHD Project, the Numerical Simulation Reactor Research Project, and the Fusion Engineering Research Project, and their coordination was promoted. It is anticipated that expedient responses will occur as occasions demand.

The NIFS Advisory Committee introduced external peer reviews for the LHD Project in 2011, for the Numerical Simulation Reactor Research Project in 2012, and for the Fusion Engineering Research Project in 2013. Then, in the fiscal year 2014 NIFS initiated an external peer review of the Deuterium Experiment Implementation Plan. The external peer review members include 10 Advisory Committee members from outside the Institute and four foreign researchers. The Experts Committee is composed of the External Peer Review Committee and five specialists for the topics. They have undertaken the evaluation.

At the First External Peer Review Committee and Experts Committee meetings held on September 12, 2014, there was discussion of how to proceed in conducting this year’s external evaluation. It was decided that the committees would evaluate the following points.

[1] Research Planning

(1) The appropriateness of the deuterium experiment’s goals; the implementation system for a research plan that will achieve its goals and an implementation system for safety protection
(2) Plans for raising the academic value
(3) Joint use; joint research system

[2] Deuterium Experiment Preparation System

(1) Maintenance planning for equipment and facilities
(2) The preparation system and facilities and equipment maintenance
(1) Fundamental ways of thinking about safety management
(2) Safety management equipment and facilities; planning regarding experiment equipment
(3) Appropriate formulation of regulations
(4) Appropriate formulation of manuals
(5) Formulation of organization and system
(6) Education and training as well as appropriate planning for the nurturing of the person in charge for safety management

[4] Understanding by Society and Citizens
(1) Enhancing the understanding of the safety of the deuterium experiment among local residents
(2) Coordination with local governments
(3) Informing society of the importance and the safety of fusion research

Subsequently, at the second External Peer Review Committee and Experts Committee meetings held on November 29, 2014, members received a detailed point-by-point explanation of the evaluation’s perspective and the points for evaluation from the person in charge at NIFS, and a question-and-answer session was held subsequently. Moreover, on January 29, 2015, the third External Peer Review Committee and Experts Committee meetings were held. Including additional discussions with NIFS, there also was a point-by-point discussion that followed the topics of evaluation decided by the External Peer Review Committee, and a summation. When all of the texts for the evaluation had been gathered, on February 24, 2015, the fourth meetings of the External Peer Review Committee and the Experts Committee were held and the final report compiled.

A result of this external evaluation of the deuterium experiment plan is the conclusion that, regarding all of the items above, nearly all of the items may be highly evaluated. In particular, regarding the enhancement of the understanding of safety and cooperation with local governing bodies, we evaluate this extremely highly. This may be called a result of the Institute’s continuous efforts. In the future, we look forward to continuing activities. We can highly evaluate the ongoing composition and preparation of appropriate regulations and manuals as well as the construction of organizations and systems, but we anticipate further effort.

Furthermore, at the third External Peer Review Committee and Experts Committee meetings held on January 29, 2015, there was further discussion regarding ways of thinking about safety management
and the treatment of radioactivated materials. In addition to receiving explanations of the Institute’s approaches to safety management, we received an explanation through additional materials regarding negotiations with local governments and citizens. In addition, we received several days later a report that summarized the fundamental way of thinking regarding the treatment of radioactivated materials, too. As a result of discussions that referenced these explanations and materials, we have concluded that the fundamental way of thinking regarding safety management and the treatment of radioactivated materials is appropriate.

Finally, we have summarized below recommendations regarding how to move forward from now with the deuterium experiment implementation planning.

(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.

(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.

(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.

(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
Documents

2014 External Peer Review Presentation Materials
The Deuterium Experiment
Implementation Plan

Yasuhiko Takeiri
National Institute for Fusion Science

2014 NIFS External Review (Nagoya, November 29, 2014)

Large Helical Device (LHD) Project

- The world-largest helical system, and the world-largest SC fusion machine
- Intrinsic advantage and engineering capability of steady-state operation
- Complementary/alternative role to tokamak approach

The goal of the Large Helical Device project
- Establish scientific basement for a helical fusion reactor
- Comprehend physics of toroidal plasmas
Objectives of Large Helical Device Project - defined in the basic plot in 1989 -

To clarify the physics and engineering problems important for helical fusion reactor plasmas by studying currentless plasmas in the next large-scale fusion experimental device of the university program.

(1) Realize plasma with a high fusion triple product and conduct extensive confinement study requisite for 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.

LHD has worked very well for 16 years.

- Operation for 16 years
- Engineering base of a large-scale superconducting and cryogenic system for fusion reactor development

Heating capability
- NBI 28 MW
- ECH 4.6 MW
- ICH 3.5 MW

< LHD basic dimension >
- Outer diameter: 13.5 m
- Cold mass: 820 ton
- Total weight: 1500 ton
- Magnetic field: 3 T
- Magnetic energy: 0.77 GJ

Several-month-long operation, 17 times since 1998
- Operational time of He compressor: 75,000 hours
  - Duty > 99%
- Coil excitation number: 1,545 times
- Plasma discharges: 122,000 shots
  (Plasma generation every 3 min)

A large number of opportunities for diversified collaboration on physics
Demonstration of steady-state-operation of high-performance fusion plasma

LHD has shown steady and encouraging development of plasma performance in these 16 years since the initial operation.

Two major keys to realize fusion energy
1. Control of burning plasmas
   ➔ ITER
2. Steady-state operation
   ➔ LHD and JT-60SA

Achieved plasma parameters encourage the further next step.

<table>
<thead>
<tr>
<th>Plasma parameters</th>
<th>Achieved</th>
<th>Target</th>
<th>Fusion condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion temperature</td>
<td>8.1 keV at 1x10^{19}m^{-3}</td>
<td>10 keV at 2x10^{19}m^{-3}</td>
<td>&gt; 10 keV &gt; 1x10^{20}m^{-3}</td>
</tr>
<tr>
<td>Electron temperature</td>
<td>20 keV at 2x10^{18}m^{-3}</td>
<td>13.5 keV at 1.4x10^{19}m^{-3}</td>
<td></td>
</tr>
<tr>
<td>Denisty</td>
<td>1.2x10^{21}m^{-3}</td>
<td>4x10^{20}m^{-3}</td>
<td>Steady-state (1 year)</td>
</tr>
<tr>
<td></td>
<td>with T_e of 0.25 keV</td>
<td>with T_e of 1.3 keV</td>
<td></td>
</tr>
<tr>
<td>Beta</td>
<td>5.1% at 0.425 T</td>
<td>5% at 1-2 T</td>
<td>&gt; 5% at &gt; 5 T</td>
</tr>
<tr>
<td></td>
<td>3.7% at 1 T</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steady-state operation</td>
<td>54min. 28sec (500kW)</td>
<td>1 hour (3,000 kW)</td>
<td>Achieved in 2013</td>
</tr>
<tr>
<td></td>
<td>(1keV, 4x10^{19}m^{-3})</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>47min. 30sec. (1,200 kW)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2keV, 1x10^{19}m^{-3})</td>
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Innovative discovery to enable breakthrough ➔ acceleration of research
✓ Steady and stable high beta due to self-stabilization of instability
✓ Super-high density plasmas beyond 10 times the conventional fusion condition
✓ Impurity hole to pump out impurity automatically, etc.
Objectives of the LHD deuterium experiment

1. To realize high-performance plasmas by confinement improvement and to provide a wide range of plasma parameter space relevant to the reactor plasmas.
   As a consequence, scientific research area will be expanded with an increase in the variety of experiments.

2. To study the mass dependence (isotope effect) in the plasma confinement, leading to the establishment of a model for the burning experiment using deuterium and tritium.

3. To demonstrate that the confinement capability of high-energy ions is relevant to the burning plasmas in helical systems.

Annual Plan for LHD Deuterium Experiment

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

LHD deuterium experiment will start after the supposed 3-years preparation.

Post-LHD project will be directed to researches for the basic plasma science and the plasma application as well as the reactor design, with hydrogen plasma experiments.
Schedule for LHD deuterium experiment (tentative)

- Concluding the Agreements for the LHD deuterium experiment with local government bodies on March 28, 2013.
- Deuterium experiment will start in 2016, and during the planned 9-years’ experiments, 10keV of the $T_i$ should be achieved.

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<tbody>
<tr>
<td>Preparation for D-exp. (3 years)</td>
<td>H-Exp.</td>
<td>H-Exp.</td>
<td>Deuterium Experiments (9 years)</td>
<td>$T_i = 10\text{keV}$ at $2 \times 10^{19} \text{m}^{-3}$</td>
</tr>
<tr>
<td>Upgrade for Heating System (NBI, ECH, ICRF)</td>
<td>Upgrade for Diagnostics System (Neutron diagnostics, etc.)</td>
<td>Upgrade of Vacuum Pumping System</td>
<td>NBI: 18MW (60–80keV, 2sec) 14MW (180keV, 2sec)</td>
<td>$W_p = 3.8\text{MJ}$ at $1 \times 10^{20} \text{m}^{-3}$</td>
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<td></td>
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<td></td>
<td>ECH: 6MW–3sec, 1MW–CW (77GHz &amp; 154GHz)</td>
<td>$&lt;\beta&gt; \sim 3%$ at $T(0)\sim 5\text{keV}$</td>
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<td></td>
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<td></td>
<td>ICRF: 6MW–5sec, 2–3MW–CW</td>
<td>$nT_\tau \sim 1.4 \times 10^{20}$</td>
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<td></td>
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<td></td>
<td>Neutron Diagnostics</td>
<td>3MW Heating for 1 hour</td>
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<td>High–Energy Particle Measurement</td>
<td>3-Dimensional Measurement</td>
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<td></td>
<td>High–Accuracy Measurement</td>
<td>Divertor Diagnostics</td>
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<td>Steady–State Data Acquisition</td>
<td>PWI Laboratory</td>
</tr>
</tbody>
</table>
Towards Realization of Fusion Energy by Magnetic Confinement

**Issues of Evaluation (1)**

**1. Research Plan**

(1) Is the goal of the deuterium experiment appropriate? Further, do the research plan and the implementation system for ensuring safety achieve those goals?

(2) Does this plan contribute to the promotion of a comprehensive understanding of toroidal plasma and heighten its academic merit with regard to the realization of fusion energy?

(3) Regarding implementation of the plan, will this achieve a system of collaborative use and collaborative research that enables participation by a wide range of researchers?
2. Deuterium Experiment Preparation System

(1) Moving toward the initiation of deuterium experiments in Heisei 28 [2016], is the preparation of equipment and facilities being planned appropriately?

(2) Is the preparation system for the initiation of deuterium experiments appropriate? Is preparation of the facilities, including safety equipment, and machinery being advanced appropriately?

3. Safety Management Planning

(1) Is the fundamental concept regarding safety management appropriate at the time of the formulation of the deuterium experiment execution plan as also based upon the opinions of local residents?

(2) Are safety management equipment, facilities, and experiment equipment being planned appropriately for the safe accomplishment of the deuterium experiment and to support management?

(3) In order to safely accomplish the deuterium experiment, are various types of regulations being formulated appropriately?

(4) Are the operation manual, the radiation management manual, and the emergency measures manual being formulated appropriately?

(5) Are the organization and the system for safety management when the deuterium experiments are being conducted being constructed appropriately?

(6) Are education and training for the safe execution of the deuterium experiments, and nurturing for those responsible for safety management being undertaken appropriately?
4. Understanding by Society and Citizens

(1) Is enhanced understanding of the safety of the deuterium experiment being advanced appropriately to local residents?

(2) Is promotion of the deuterium experiment plan being designed in conjunction with local governments?

(3) Is the importance of fusion research and its safety being widely disseminated in society?

Note from the review of the safety management in 2009

Referencing the “recommendation” regarding the safety management plan at the time of the deuterium experiment in the external review of the safety management undertaken in 2009, the two points below, too, are to be considered in this evaluation.

1) Has the cultivation and the education training of those responsible at the time of the deuterium experiment been conducted appropriately?

2) Are the organization of the safety committee for radiation safety management, the safety observation committee, the radiation management office, and others, and the structure at the time of an emergency being appropriately constructed?

→ Reflect to “3. safety management planning”
1. Research Plan

(1) Is the goal of the deuterium experiment appropriate? Further, do the research plan and the implementation system for ensuring safety achieve those goals?

(2) Does this plan contribute to the promotion of a comprehensive understanding of toroidal plasma and heighten its academic merit with regard to the realization of fusion energy?

(3) Regarding implementation of the plan, will this achieve a system of collaborative use and collaborative research that enables participation by a wide range of researchers?
1. To realize high-performance plasmas by confinement improvement and to provide a wide range of plasma parameter space relevant to the reactor plasmas. As a consequence, scientific research area will be expanded with an increase in the variety of experiments.

2. To study the mass dependence (isotope effect) in the plasma confinement, leading to the establishment of a model for the burning experiment using deuterium and tritium.

3. To demonstrate that the confinement capability of high-energy ions is relevant to the burning plasmas in helical systems.

---

Improvement of the plasma confinement (Isotope effect) is clearly observed in deuterium experiments in the world-major devices.

<table>
<thead>
<tr>
<th>Device</th>
<th>Nation</th>
<th>Improvement factor in D-exp</th>
</tr>
</thead>
<tbody>
<tr>
<td>JFT-2M</td>
<td>Japan</td>
<td>1.1–1.4</td>
</tr>
<tr>
<td>JT-60U</td>
<td>Japan</td>
<td>1.2–2</td>
</tr>
<tr>
<td>Alcator C</td>
<td>USA</td>
<td>1.5</td>
</tr>
<tr>
<td>DIII-D</td>
<td>USA</td>
<td>1.4–2</td>
</tr>
<tr>
<td>ISX-B</td>
<td>USA</td>
<td>1.4</td>
</tr>
<tr>
<td>TFTR</td>
<td>USA</td>
<td>1.2</td>
</tr>
<tr>
<td>ASDEX</td>
<td>Germany</td>
<td>1.3–2</td>
</tr>
<tr>
<td>ASDEX-U</td>
<td>Germany</td>
<td>1.5</td>
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<tr>
<td>TEXTOR</td>
<td>Germany</td>
<td>1.4</td>
</tr>
<tr>
<td>JET</td>
<td>UK</td>
<td>1.2–1.4</td>
</tr>
<tr>
<td>FTU</td>
<td>Italy</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Isotope effect is a major issue to be identified for the burning plasmas.
Main subjects in the LHD deuterium experiment (1)

(a) Confinement improvement and related physics
   Research on the isotope effect in the plasma confinement and the related confinement improvement in the deuterium experiments, toward systematic understanding of the toroidal plasmas.

(b) Improvement of MHD stability and expansion of high-\(\beta\) regime
   Research on the MHD equilibrium and stability in high-\(\beta\) regime of collisionless plasmas realized by the confinement improvement and the increase in the heating power in the deuterium experiment.

(c) Confinement of high-energy ions
   Research on the confinement of high-energy ions, such as ICRF accelerated ions and 1-MeV triton with a high-accuracy diagnostic of neutrons (utilizing T+D \(\rightarrow\) n(14MeV)+\(\alpha\) as the secondary reaction of D+D \(\rightarrow\) T(1.0MeV)+p).

Main subjects in the LHD deuterium experiment (2)

(d) Optimization of divertor
   Research on the particle and heat control in the peripheral plasma region with the closed helical divertor and improvement of the steady state plasma performance.

(e) Plasma wall interaction (isotope effects)
   Research on the isotope effects in the plasma wall interaction including the fuel recycling, to understand the behavior in the burning plasmas.

(f) Expansion of experimental approaches
   Ion heating experiments by the ICRF heating schemes of H-minority/D-majority and \(3^\text{He}\)-minority/D-majority.
**Expected plasma parameters and the resulted neutron and tritium yields**

- Heating condition: NBI 32MW (perp.: 80keV-18MW, tang.: 180keV-14MW)
  ICH+ECH 3MW
- Assumed energy conf. time: 2 times ISS95 (Achievement: x1.6)
- Magnetic field: 3T

\[
\begin{align*}
T_i(0) &= 10\text{keV at } n_e = 2 \times 10^{19} \text{ m}^{-3} \\
W_p &= 3.8\text{MJ at } n_e = 1 \times 10^{20} \text{ m}^{-3} \quad <\beta> \sim 3\%, \quad T(0)\sim5\text{keV} \quad nT \sim 1.4 \times 10^{20} \text{ m}^{-3} \text{keV s} \\
\text{if } T_E \sim 3T_E^{\text{ISS95}}, \quad Q \sim 0.3
\end{align*}
\]

### Maximum neutron and tritium yields
- Line-averaged density: \(2.5 \times 10^{19} \text{ m}^{-3}\)
- Total abs. heating power: 27.7 MW
- Central temperature: 9.5 keV
- Plasma stored energy: 1.77 MJ
- Neutron yield rate: \(1.91 \times 10^{16} /\text{s}\) (yield rate by thermal plasma: \(5.98 \times 10^{14} /\text{s}\))
- Pulse length: 3sec → Neutron yield: 5.7 \(\times 10^{16}\), Tritium yield: 1.0 \(\times 10^8\) Bq (2.7 \(\times 10^{-3}\) Ci)

### Annual Plan for LHD Deuterium Experiment

<table>
<thead>
<tr>
<th>FY</th>
<th>First 6 years</th>
<th>Second 3 years</th>
<th>After 10th year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiments</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preliminary Exp. (Commissioning)</td>
<td></td>
<td>Integrated High-Performance Exp.</td>
<td>Post-LHD Project</td>
</tr>
<tr>
<td>Plasma Exp. For Target Parameters</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum Annual Yield of Tritium</td>
<td>3.7(\times 10^{10}) Bq (1 Ci) (Integrated yield)</td>
<td>5.55(\times 10^{10}) Bq (1.5 Ci) (Integrated yield)</td>
<td>---</td>
</tr>
<tr>
<td>Maximum Annual Discharge of Tritium</td>
<td>3.7(\times 10^{9}) Bq (0.1 Ci) (Integrated yield)</td>
<td></td>
<td>---</td>
</tr>
<tr>
<td>Maximum Annual Yield of Neutron</td>
<td>2.1(\times 10^{19}) (Integrated yield)</td>
<td>3.2(\times 10^{19}) (Integrated yield)</td>
<td>---</td>
</tr>
</tbody>
</table>

LHD deuterium experiment will start after the supposed 3-years preparation.

Post-LHD project will be directed to researches for the basic plasma science and the plasma application as well as the reactor design, with hydrogen plasma experiments.
NBI upgrade plan for deuterium experiment

Low-energy positive-NBI: 2 (perp. inj.) 18MW
High-energy negative-NBI: 3 (tang. inj.) 14MW

- NBI upgrade for raising the beam energy of positive-NBIs has been completed.
ECH upgrade plan for deuterium experiment

77GHz/154GHz  6 systems
6MW/3sec, 1MW/cw

- Three 77GHz- and two 154GHz-ECH systems, each of which injects >1MW for a short pulse and >300kW for CW, have been installed. (an 84GHz- and an 82.7GHz-ECH systems will not be available in the D-experiment.)
- One 154GHz-ECH system is planned to be installed after the start of the deuterium experiment.

ICH upgrade plan for deuterium experiment

3 sets with 6 antennas 6MW/5sec, 2~3MW/cw

- Each antenna injects >1MW for pulse and >0.5MW for CW.
- 2 straps of HAS (HAsu-Seigyo) antenna
- 2 straps of FAIT (Field-Aligned Impedance-Transforming) antenna
- 2 straps of PA (Poloidal Array) antenna
- Frequency will be fixed at 38.5 MHz.
- PA antennas will be removed before the deuterium experiment.
- **Armor** was installed to protect vessel wall from the increased NB power.

- Baffles to form **closed helical divertor** configuration have been installed (9 modules completed).

Tiles are made of tungsten or carbon fiber composite materials.

Cryopumps are being installed under the dome.

---

**Upgrade plan for diagnostics (1)**

**Extension of confinement study for high-energy particles**

**Neutron-γ-ray diagnostics**
- Neutron flux monitor based on $^{235}$U fission chamber
- Neutron activation system
  - Capsule for activation foil
  - High-pure Ge detector
- γ-ray camera
- Neutron camera
- $^{252}$Cf neutron source
- Rail & train system

**High-energy particle diagnostics**
- LHD plasma
- Escaping fast-ion diagnostics
  - Scintillator array
  - Image fibers
- Collective Thomson scattering diagnostics
- Gyrotron
- Receiver
- High-sensitivity CCD camera
- Gyroradius
- Pitch angle

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13/47
Upgrade plan for diagnostics (2)

Enhancement of anomalous transport study

High precision transport diagnostics system

Microwave reflectometry imaging

Multichannel ECE imaging

Beam emission spectroscopy (BES) imaging

High-energy neutral beam

Toward deeper understanding of divertor physics

Upgrade of divertor, edge plasma diagnostics

Divertor plate

Dome

Cooling pipe

Fast ion gauge

YAG laser

Polychromator

Edge Thomson scattering diagnostics

Steady state, fast data acquisition and management system

- Fast DAQ for fluctuation measurements with high-time and space resolutions
- Data analysis computing cluster for real-time analysis and monitoring
- Real-time operability for steady-state plasma measurement and control

Schedule for LHD deuterium experiment (tentative)

- Concluding the Agreements for the LHD deuterium experiment with local government bodies on March 28, 2013.
- Deuterium experiment will start in 2016, and during the planned 9-years’ experiments, 10keV of the $T_i$ should be achieved.

<table>
<thead>
<tr>
<th>FY2013</th>
<th>FY2014</th>
<th>FY2015</th>
<th>FY2016 – FY2024</th>
</tr>
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<tbody>
<tr>
<td>H-Exp.</td>
<td>H-Exp.</td>
<td>FY2015</td>
<td>Deuterium Experiments (9 years)</td>
</tr>
</tbody>
</table>

**Deuterium Experiments**

Closed Helical Divertor with Pumping System

- NBI: 18MW (60–80keV, 2sec)
- ECH: 6MW–3sec, 1MW–CW
- ICRF: 6MW–5sec, 2–3MW–CW

Neutron Diagnostics

- High-Energy Particle Measurement
- 3-Dimensional Measurement
- High-Accuracy Measurement
- Divertor Diagnostics
- Steady-State Data Acquisition

W_p = 3.8MJ at $1\times10^{20}$ m^{-3}

$\beta$ < 3% at $T(0)$~5keV

$\nT_\tau \sim 1.4\times10^{20}$ m^{-3} keV s

3MW Heating for 1 hour

Target in D-Exp.

$T_i = 10keV$ at $2\times10^{19}$ m^{-3}
Research schedule plan for deuterium experiments

### Agreements for D-exp
- Legal license
- Device upgrades
- Safety installation
- Inspection
- Preliminary experiments

### First 6 years
- 2013
- 2014
- 2015
- 2016
- 2017
- 2018
- 2019
- 2020
- 2021

#### Preparations
- Isotope effect
- Control of edge plasma
- Stability of high-\(E\) plasma
- Plasma flow and stability
- Impurity control
- High fusion products
- Integrated plasma research
- Establishment of academic basis
- Super-dense plasma
- Extension of high-\(\beta\)
- Long pulse discharge
- High-energy ion confinement
- Extension of parameter regime
- Establishment of academic basis

### Second 3 years
- 2022
- 2023
- 2024

### After
- Post LHD

### Implementation system for LHD deuterium experiment (1)

#### LHD Experiment Board
- chaired by Executive Director

#### LHD Operation Group
- LHD Device Engineering Meeting
  - Technological examination of devices
  - Arrangement and planning of installation

#### LHD Experiment Group
- LHD Experiment Group Meeting
  - Preparation and planning of experiment
  - Report of experimental results
  - Discussion of researches
  - Dry-run for presentation

#### Division director of health and safety promotion
- Watches and supervises the safety of experiments

#### Radiation Control Office
- Checks the radiation safety of the experiments

---

**LHD team**
- LHD experiment board is responsible for management of the LHD experiment.

- Experiment plans are verified and finalized by the board including the safety management.

- Division director of health and safety promotion watches and supervises the safety for experiments as a board member.

- Head of radiation control office checks the radiation safety in the experiments.

- Safety regulation and roles in the emergency are confirmed at the morning meeting before the experiment.

(1) Is the goal of the deuterium experiment appropriate? Further, do the research plan and the implementation system for ensuring safety achieve those goals?

1. Deuterium experiment is expected to greatly extend the LHD plasma parameter regime to the reactor-relevant regime, which should lead to the firm design of a helical fusion reactor by establishment of an academic basis for toroidal plasmas.

2. Main subjects in the LHD deuterium experiment should contribute to achievement of the goal of the deuterium experiment through the confinement improvement due to the isotope effect, extension of high-\(E\) regime, intensive research on enhanced high-energy ions, optimization of divertor, and research on the isotope effects in the peripheral region and the plasma wall interaction, as well as expansion of ICRF heating schemes.

3. Machine upgrade is planned to maximize the heating capability in the deuterium experiments, to improve the diagnostic accuracy for precise physics research, and to install the closed helical divertors, and the research schedule is also planned along the main subjects.

4. LHD experiment board should conduct the deuterium experiment to achieve the goal, through well-organized research and safety management system.
(1) Is the goal of the deuterium experiment appropriate? Further, do the research plan and the implementation system for ensuring safety achieve those goals?

(2) Does this plan contribute to the promotion of a comprehensive understanding of toroidal plasma and heighten its academic merit with regard to the realization of fusion energy?

(3) Regarding implementation of the plan, will this achieve a system of collaborative use and collaborative research that enables participation by a wide range of researchers?

---

**High-Temperature Plasmas with ITB formation**

- High electron temperature plasmas with Electron ITB/CERC
  - Upgrade of ECH power and fine control of deposition
  - Transport improvement due to the bifurcation of $E_r$

- High ion temperature plasmas with ion ITB
  - Wall conditioning enhances the transport improvement
  - Impurity exhaust (Impurity Hole formation)

- High temperature plasmas with comparable Ti and Te
  - Integration of ion ITB and electron ITB
  - Control of temperature profile
Neutral beam Injectors (NBIs) will be upgraded for deuterium beam injection, which have higher ion heating efficiency

Positive NBI (40kV, 6MW, H\text{\textsubscript{0}}) + (40kV, 6MW, H\text{\textsubscript{0}}) \Rightarrow (60kV, 9MW, D\text{\textsubscript{0}}) + (80kV, 9MW, D\text{\textsubscript{0}})

Negative NBI (180kV, 5MW, H\text{\textsubscript{0}}) \times 3 \Rightarrow (180kV, \sim3.5MW, D\text{\textsubscript{0}}) \times 3

In LHD deuterium experiment, \(T_{i0} = 10\) keV will be achieved with deuterium beam injection and further improvement of confinement due to the isotope effect

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**Extension of High Beta Regime**

\(<\beta> > 5\%\) is required for realization of economical helical fusion reactor and was achieved in high collisional regime, which clarify the following characteristics of MHD equilibrium and stability:

- Activities of resistive interchange modes are mitigated in collisionless regime with high magnetic Reynolds number
- Plasma is well confined in stochastic region

Confinement improvement in DD experiments expects to

- access to low-collisional high beta regime, which enable us to studies of equilibrium, stability and transport in new regime.
- clarify collisionality dependence of plasma confinement in the stochastic region
Subjects of MHD Studies

MHD studies are required for maintenance of stable plasma

The studies of the following subjects are ongoing:
- Beta limits due to equilibrium and stability
- Change of magnetic topology
- Equilibrium, stability and transport in stochastic region
- Response of 3D field to plasma
- Non-linear growth of MHD instabilities
- H mode physics and ELM control

Further understanding of MHD physics is expected through DD experiments

High-energy ions

Neutron profile based on FIT3D code

- Neutron is mainly due to fast-ion-plasma reaction.
- Neutron measurement expands the fast-ion study.
  - NFM reveals global confinement of fast ion.
  - NPM reveals radial profile of fast ion.
- Further progress of study on fast-ion confinement changing due to magnetic field configuration or MHD instability will be promising.
Closed Helical Divertor

Particle and impurity control by divertor pumping
→ Suppression of plasma cooling due to gas and removal of impurity
→ Improvement of plasma performance

Reduction of heat and particle load in divertor
→ Achievement of high-power and long-pulse plasma
→ Divertor design of helical reactor

Divertor Studies

Strategy of edge plasma control: **combination of Closed Helical Divertor (CHD) and Stochastization with RMP**

- Particle recycling is controlled with *closed helical divertor (CHD) with pump*
- RMP-controlled stochastic layer is utilized for *radiative cooling* and *impurity shielding*
- RMP-controlled stochastic layer is expected to enhance the *divertor detachment*
- Radiative cooling in stochastic layer *mitigates heat load* to divertor plates
- Isotope effect and neutral particle transport including He should be investigated
Plasma Wall Interaction

Distribution of the heat loading and its global balance towards the FFHR-d1 is estimated in the LHD D-D plasma with long pulse operation.

Particle transport

- Quantitative analysis of H isotopes on the entire wall surface is estimated by material probe experiment. Then, the data is applied to estimation of the total T inventory in the large fusion system.

Material transport

- Erosion and deposition profile of the plasma facing components on entire wall surface in LHD is evaluated by material probe experiment.

Tritium Study

~ tritium mass balance and safety handling technology ~

- Application of tritium as a tracer
  - Study of tritium behavior in the large system
- Tritium mass balance in LHD
  - Total amount of tritium by neutron measurement
    = Tritium inventory in/on the first wall and the diverter tile [PWI study]
    + Tritium analysis in the vacuum exhaust gas
- Tritium safety handling technology
  - Validation of the tritium decontamination factor in the large scale tritium removal system

Fusion reaction:
\[ D + D \rightarrow \text{He} (0.82\text{MeV}) + n (1.45\text{MeV}) \]
\[ D + d \rightarrow T (1.01\text{MeV}) + p (3.03\text{MeV}) \]
Helium will be replaced by deuterium in ICRF heating

Minority ion heating (D(H) plasma)
- Applicable to a variety of plasmas if deuterium is usually used
- Optimal minority ratio may differ from tokamak devices

Second harmonic heating of deuterium
- Effective with high temperature and/or high energy deuterium ions
- Simultaneous heating with minority heating in D(H) plasma

Other heating and physics experiment
- D(He3) heating
- Study about high energy ion and fusion products generated by ICRF heating

Steady state experiment
- Comparison with deuterium and helium plasmas
- Effect of actual fuel in steady state discharge on engineering and operation and so on

Comparison of charge-exchange spectra in D(H) plasma of PLT tokamak

Research on Isotope Effect

- Isotope effect is a long-standing mystery
- The one of missions of LHD deuterium experiment
  ✓ key to realize confinement improvement
  ✓ Academic base for physics towards burning plasmas

Previous experiments in tokamaks and helical systems have indicated the importance of low-recycling for improved confinement

→ Hypothesis:
  recycling control and its impact on core confinement (through core-edge coupling)
  Increased understandings through integrated view

- Non-local phenomenon
- Multi-scale turbulence
- Impacts of ion mass on poloidal flow \( \rightarrow M_p \)
- Residual zonal flow level: \( D > H \)
Isotope Effect from the viewpoint of impurity

Isotope effect should be also considered from impurity
• JET: ITER like wall experiment (Maddison NF2014)
• JT-60U Zeff is larger in D compared to H (T.Nakano)
• Impacts of wall material on H mode (Itoh, Itoh, PPCF1995) and so on

Impact of impurity on ion heat confinement in LHD (Osakabe, PPCF2014)
• 4 different-size C pellets into in high-Ti plasmas
• Indicating the existence of threshold of C density for ion heat confinement improvement

→ Isotope effect will be considered also from the viewpoint of impurity

(2) Does this plan contribute to the promotion of a comprehensive understanding of toroidal plasma and heighten its academic merit with regard to the realization of fusion energy?

1. NBI upgrade for the deuterium beam injection effectively enhances the ion heating power, and should raise the ion temperature to $T_{i0} = 10$ keV with confinement improvement due to the isotope effect.

2. Confinement improvement in the deuterium experiments should extend high-$\beta$ regime to low-collisional regime extrapolated to a reactor plasma, and clarify collisionality dependence of confinement in the stochastic region.

3. Precise measurement of neutrons should clarify the fast ion confinement and reveal the fast-ion induced MHD instability foreseen in a reactor plasma.

4. Particle control with closed helical divertor and control of stochastic region with RMP should lead to divertor optimization for a reactor.

5. Deuterium experiments greatly expand the PWI study with regard to the heat transport, the particle transport, and the material transport, contributing to the reactor design.

6. Deuterium experiments expand the heating scenario with ICH, leading to high-performance of long-pulse discharges, which extend the reactor relevant PWI study.

7. Research on the isotope effect contributes to establishment of academic basis for comprehensive understanding of toroidal plasmas.
1. Research Plan

(1) Is the goal of the deuterium experiment appropriate? Further, do the research plan and the implementation system for ensuring safety achieve those goals?

(2) Does this plan contribute to the promotion of a comprehensive understanding of toroidal plasma and heighten its academic merit with regard to the realization of fusion energy?

(3) Regarding implementation of the plan, will this achieve a system of collaborative use and collaborative research that enables participation by a wide range of researchers?

---

Research plan has been discussed by a wide range of researchers through collaboration.

- Research plan for the LHD deuterium experiment has been discussed and proposed in workshops organized in frameworks of the NIFS collaboration system. Eight workshops have been held, and various kinds of subjects have been discussed, such as device development, divertor study, PWI study, isotope effect, fast ion confinement, tritium study, and environmental radiation.

- Also, in academic meetings of the fusion community, such as meetings held by the Fusion Network and symposiums held in annual conference of The Japan Society of Plasma Science and Nuclear Fusion Research, the research plan related with the deuterium experiment has been proposed and discussed by a wide range of researchers.

- Through these discussions among the fusion community, the research plan for the LHD deuterium experiment has been established.
Workshops with collaborators toward deuterium experiment from 2010 to 2014

- Eight workshops have been held at NIFS to discuss on the deuterium experiment plan and the tritium safety.

<table>
<thead>
<tr>
<th>No.</th>
<th>Framework</th>
<th>Date</th>
<th>Place</th>
<th>Workshop</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Joint Sponsorship of NIFS General Collaboration &amp; JSPF Expert Committee</td>
<td>August 31, 2010</td>
<td>NIFS</td>
<td>Trinitium safety and handling &quot;LHDにおけるトリチウム安全研究の展望&quot;  &quot;LHD重水素実験における重水素吸気バランスとトリチウム回収・除去&quot;  &quot;核融合炉の運転制御の基礎となるトリチウム研究・技術の開発&quot;</td>
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<tr>
<td>2</td>
<td>NIFS General Collaboration</td>
<td>December 13, 2011</td>
<td>NIFS</td>
<td>Trinitium safety and handling &quot;LHD重水素実験における重水素吸気バランスとトリチウム回収・除去&quot;</td>
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<td>3</td>
<td>NIFS General Collaboration</td>
<td>March 22, 2012</td>
<td>NIFS</td>
<td>Deuterium experiment plan &quot;LHDにおける重水素実験計画の検討&quot;</td>
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<td>4</td>
<td>Joint Sponsorship of NIFS General Collaboration &amp; JSPF Expert Committee</td>
<td>December 6, 2012</td>
<td>NIFS</td>
<td>Trinitium safety and handling &quot;ヘリカル型核融合システムのトリチウム安全性&quot;  &quot;重水素吸気バランスと関連研究&quot;  &quot;持続的燃料供給のためのトリチウム研究・技術開発&quot;</td>
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<td>5</td>
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<td>June 21, 2013</td>
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<td>Deuterium experiment plan &quot;LHDにおける重水素実験計画の検討&quot;</td>
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<td>August 8, 2013</td>
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<td>Trinitium safety and handling &quot;核融合炉システムにおけるトリチウムの取り扱いと安全性&quot;  &quot;核融合炉燃料計量管理の基礎となるトリチウム研究・技術開発&quot;</td>
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<td>April 25, 2014</td>
<td>NIFS</td>
<td>Deuterium experiment plan &quot;LHD重水素実験研究計画の策定&quot;  &quot;重水素実験に関する核融合ネットワーク会合&quot;</td>
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<td>8</td>
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<td>Trinitium safety and handling &quot;核融合炉システムにおけるトリチウムの取り扱いと安全性&quot;  &quot;核融合炉燃料計量管理の基礎となるトリチウム研究・技術開発&quot;</td>
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Symposiums on deuterium experiment plan in academic meetings

- Deuterium experiment plan has been discussed with collaborators in symposiums of academic meetings.
- It has been also discussed in a question and answer time of plenary talk and invited talk.

<table>
<thead>
<tr>
<th>No.</th>
<th>Classification</th>
<th>Date</th>
<th>Academic meeting and symposium</th>
<th>Place</th>
<th>Agenda and title</th>
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</table>
| 1   | Symposium      | November 25, 2011 | Plasma Conference 2011 (PLASMA 2011) | Kanazawa | 1. はじめに（主催談話）M. Sasao (Tohoku Univ.)  
2. LHD重水素実験計画の概要 Y. Takeiri (NIFS)  
3. 構想例のプラズマにおける吸気エネルギー効率の意思決定 T. Nishitani (JAERA)  
4. 燃料リサイクルを行うLHD重水素実験 T. Tanihara (Kyushu Univ.)  
5. LHDプラズマ中での流動制御に関する核融合研究 T.H. Watanabe (NIFS)  
6. 発表討論 M. Sasao (Tohoku Univ.) |
| 2   | Symposium      | December 6, 2013 | JSPP 30th annual meeting Symposium IV | Tokyo | 1. はじめに M. Sasao (NIFS)  
2. LHD重水素実験における流動制御に関する研究 K. Isu (NIFS)  
3. LHDにおける核融合研究を支える研究 K. Eriyama (Tokyo Univ.)  
4. JT60UからのLHD重水素実験における核融合研究 Y. Kusaka (JAERA)  
5. 論文発表会に関連するプラズマ技術に関する各会議 H. Sugama (NIFS)  
6. 総合討論 |
| 3   | Plenary talk   | June 19, 2014 | 10th Joint Conference on Fusion Energy | Tsukuba | ヘリカル型核融合炉への向けた大型ヘリカル装置の実用化研究の進展 Y. Takeiri (NIFS) |
2. JT60Uからのヘリカルプラズマ実験における核融合研究 K. Urano (JAERA)  
3. 動力学的な理解およびプラズマを用いた核融合研究 T. Fujita (Nagoya Univ.)  
4. 流動制御に関する核融合研究の開発アップ T.S. Hahn (Seoul National Univ.)  
5. 流動制御に関する核融合研究の開発アップ K. Sasao (Kyoto Univ.)  
6. LHD重水素実験計画の関連特性に関する核融合研究 M. Osakabe (NIFS) |
All Japan fusion neutron diagnostics development team has been organized toward the LHD deuterium project.

**Nagoya Univ./Dr. H. Tomita, Prof. T. Iguchi**
- Neutron spectrometer
- Nuclear emulsion

**JAEA/Drs. T. Nishitani, K. Ochiai, M. Ishikawa, and K. Shinohara**
- FNS
- Neutron camera on JT-60U
- ITER Micro FC

**National Institute of Technol., Toyama College/Prof. E. Takada**
- Neutron camera detector

**Kyoto Univ./Dr. S. Murakami**
- Fast-ion modeling
- Prediction of fusion output

**Hokkaido Univ./Dr. J.H. Kaneko**
- Triton burnup/NPA-CVD diamond

**Kinki University/Dr. H. Yamanishi**
- Reactor UTR-KINKI

**Kyoto University/Prof. T. Misawa**
- Reactor KUCA

**Fission reactor collaboration**

**NIFS collaboration**

**JAEA collaboration**

**NIFS-Univ. collaboration**

**Collaboration with Nagoya University**
~ Joint work for neutron flux monitor development ~

**Neutron transport study by MCNP**

The LHD is fairly complicated.
→ A program generating an input file of 3D machine geometry for MCNP has been developed.

**Test operation of wide dynamic range DSP unit prototype at KUCA**

KUCA is flexible in changing thermal neutron flux

FC for NIFS

Thermal neutron flux up to $10^7$ nv in the reactor core

An example of test operation at KUCA

A satisfactory prospect was obtained toward manufacture of NFM-DSP unit for LHD

Tritium behavior in ground water at the NIFS site

- To understand the background tritium level at the NIFS site and the tritium behavior released from the facility to the environment, two component separation analysis was carried out.
- The tritium concentrations in rain was 0.09-0.78 Bq/L, and the tritium concentrations of stream water and ground water were almost constant, 0.34 Bq/L and 0.25 Bq/L, respectively.
- The two component separation analysis gave good agreement between isotopic ratio and conductivity.


Two component separation of flow rate using $\delta^{18}$O, conductivity and tritium concentration at the rain event. The black bar represents the ground water component and the slash bar is the rain component.

S. Sugihara, et al., Fusion Science and Technology 60 (2011) 1300-1303

Simulation model of hollow fiber polymer membrane

- A simulation model was developed for transient response of a hollow fiber membrane for the tritium removal system.
- The mass transfer processes such as sorption and desorption, diffusive transfer of gases are treated in the model.
- This model represents well not only separation factors and recovery ratio at the steady state but also responses to the multi-step wise change in the sweep gas rate.

Water vapor separation model with the hollow fiber membrane module.

Characterization of surface morphologies of first wall

- Characterization of the surface morphologies were clarified by microstructural observation.
- Formation of the microscopic defects such as dislocation loops and helium bubbles were formed on the subsurface region. Impurity deposition was also observed on the top surface.
- These surface morphologies can act as the strong trapping site of the hydrogen isotopes.

Cross-sectional TEM images of stainless first wall sample after exposed to single LHD campaign
LHD deuterium experiment project promotes research activities in universities through the collaboration.

- Number of NIFS collaboration related with the deuterium experiment is counted to around 40 every year.

**Statistics of published papers**

- Through the NIFS collaboration, number of papers have been published related with the deuterium experiment project.
1. Research plan for the LHD deuterium experiment has been discussed and proposed by a wide range of researchers through the collaboration.

2. Toward the LHD deuterium experiment, all Japan fusion neutron diagnostics development team has been organized based on collaborative research.

3. Tritium-related studies important for the deuterium experiment, such as research on the environmental tritium and technology development for the tritium removal system, have been conducted in collaborative researches with universities.

4. PWI studies, such as the retention properties of hydrogen isotopes and the characterization of surface morphologies of the first wall, have been accelerated toward the LHD deuterium experiment, leading to establishment of a wide range of collaboration network.

5. Selected subjects related with the deuterium experiments are counted to around 40 every year in the NIFS collaboration system, and 47 papers have been published.
2. Deuterium Experiment
Preparation System

(1) Moving toward the initiation of deuterium experiments in Heisei 28 [2016], is the preparation of equipment and facilities being planned appropriately?

(2) Is the preparation system for the initiation of deuterium experiments appropriate? Is preparation of the facilities, including safety equipment, and machinery being advanced appropriately?
Device Upgrade Plan for the LHD Deuterium Experiment

Preparation plan of equipment and facilities for safety for the start of deuterium experiment

<table>
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<tr>
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<tbody>
<tr>
<td>Legal Licenses</td>
<td>H-exp</td>
<td>H-exp</td>
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<td>Installation of</td>
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<td>(LHD Application)</td>
<td>Start of D-exp</td>
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<tr>
<td>Safety Equipment</td>
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<td>(Inspection)</td>
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<td>System</td>
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</tbody>
</table>

- Neutron and RI radiation monitoring systems
- Integrated radiation monitoring system
- Access control system
- Tritium removal system
- Filling wall holes, Remote control
- Neutron shielding of devices
- Remodeling of building and facilities
- Legal regulation, Manuals, Training

Preliminary Experiments

Test of Equipment in H-exp.

In-situ Calibration of NFM
Preparation schedule of machine upgrade for the start of deuterium experiment

H25 (2013)  
H-exp  
Installation (Step by Step)  
NBI(BL4) Upgrade  
ECH Gyrotron (154GHz)  
ICH Antenna  
Neutron diagnostics, High precision & 3D diagnostics  
Neutron shielding, Remote control, Categorizing diagnostics for necessity (Removal of unnecessary devices)

H26 (2014)  
H-exp  
NBI system modification and adjustment for D-injection  
ICH Antenna & Oscillator

H27 (2015)  
H-exp  
ECH Gyrotron (154GHz)

H28 (2016)  
D-exp

Upgrade of NBI for deuterium experiments

- Optimum beam current will be reduced to 70% by D-ion extraction:
  - Beam optics is governed by the Child-Langmuir law.

\[
J_{si} = \frac{4e_0 V^{3/2}}{9 d_s^2 \sqrt{\frac{2Ze}{m_i}}}
\]

- Strategy of NBI for deuterium operation
  - Positive-ion based NBIs:
    - Beam energy will be increased from 40 to 60/80keV and their power will be increased from 6MW to 9MW.
  - Negative-ion based NBIs:
    - No significant upgrade is planned.
    - Beam power will be deteriorated at the initial phase of D-operation.
    - The beam power will be recovered by the optimization of grids after D-operation.
Neutron Diagnostics

Fusion reaction producing neutrons in deuterium plasmas:
\[ d + d \rightarrow n \ (2.5 \text{ MeV}) + ^{3}\text{He} \ (0.82 \text{ MeV}) \]
\[ \rightarrow p \ (3.0 \text{ MeV}) + t \ (1.0 \text{ MeV}) \]
Secondary reaction: \[ d + t \rightarrow n \ (14 \text{ MeV}) + \alpha \ (3.5 \text{ MeV}) \]

DD neutron rate expected in LHD is \( >10^{16}\text{n/s} \), comparable to JT-60U, TFTR, and JET.

Role of neutron diagnostics
1. Measurement of fusion output, which estimates amount of tritium
2. Study on beam-ion behavior
   - Global confinement property and slowing down of beam ions
   - Radial profile of beam ions
   - Effect of Alfvénic modes on radial transport of beam ions
3. Confinement study of MeV tritons isotropic in velocity space

\[ ^{235}\text{U fission chamber satisfies} \]

- 1. Wide dynamic range
  -> Pulse counting mode
  + Campbelling mode
- 2. Fast time response (~1 ms)
- 3. Good n-\(\gamma\) discrimination capability
- 4. Long-term high reliability

Tritium Removal System

Two types of tritium recovery system are installed.
- Molecular sieve type for exhausted gas in the vacuum pumping
- Polyimide membrane type for purged gas in the maintenance

Recovering Rate: >95 %
1. After the conclusion of the Agreement for the LHD deuterium experiment with local government bodies on March 28, 2013, the preparation schedule for the machine upgrade, the installation of safety equipment, and the equipment for building and facilities was defined, including the establishment of safety management system, toward the start of the deuterium experiment in 2016.

2. NBI systems has been upgraded for the deuterium beam injection with a high priority to enhance the ion heating power in the deuterium experiment.

3. Neutron flux monitor system development has firstly been started as the most important diagnostics for the deuterium experiment, and as a primary safety equipment, the tritium removal system has been designed and constructed.

4. Neutron shielding is designed for individual devices, and devices are listed, which should be removed due to weakness against neutrons and less necessity.

5. Building and facilities have been remodeled for the radiation controlled area.

6. Legal license procedure and preparation of various kinds of operation and safety manuals are scheduled.

2. Deuterium Experiment Preparation System

(1) Moving toward the initiation of deuterium experiments in Heisei 28 [2016], is the preparation of equipment and facilities being planned appropriately?

(2) Is the preparation system for the initiation of deuterium experiments appropriate? Is preparation of the facilities, including safety equipment, and machinery being advanced appropriately?
Preparation system for the initiation of the LHD deuterium experiment

- Division for deuterium experiments management is responsible for the preparation for the LHD deuterium experiment.
- D-exp management division mainly consists of division directors of NIFS including the safety-related divisions, which enables fast decision and top-down implementation.
- Under the D-exp management division, LHD upgrade team 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.

Preparation items executed by LHD upgrade team

Preparation items and schedule for the initiation of the LHD deuterium experiment

Conducted by LHD upgrade team

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<thead>
<tr>
<th>Item</th>
<th>2013</th>
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<th>2015</th>
<th>2016</th>
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<tr>
<td>Tritium removal system</td>
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<td>Neutron diagnostic system</td>
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<tr>
<td>Integrated radiation monitoring system</td>
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<td>He gas tank</td>
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<tr>
<td>Filling holes</td>
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<td>Neutron shielding &amp; Remote control</td>
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<td>Gas puffing system</td>
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<td>Vacuum pumping &amp; Gas exhaust system</td>
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<td>Device modification against radiation</td>
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<td>Device removal</td>
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<td>Plasma monitoring &amp; control system</td>
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<td>Reinforcement against earthquake</td>
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Strategy to select removed and/or reformed devices which are weak against radiation

**Step 1: Check list submission for existing devices in the LHD torus hall and basement**
- Status of existing devices and their robustness against radiation were checked.
- Diagnostics and/or control systems which are obviously weak against radiation were picked up, and were decided to be removed.
- Done in October, 2013.

**Step 2: Manual preparation for operation and radiation safety**
- Manuals for operation and radiation safety were prepared for each device and maintenance work.
- Device has to be removed if manual is not prepared.
- Done in May, 2014.

**Step 3: Implementation plan submission**
- Suitability and feasibility of the plan were checked.
- Done in June, 2014.

All devices are now being classified into three groups according to the implementation plan, for the judgement of removal or reformation.

---

**Removal of devices that are weak against radiation is ongoing**

List of devices that were and will be removed according to stages classified based on the check list

An example: X-ray PHA based on Si detector

*Before*

*After*
Reduce the neutron/gamma-ray streaming

- Effective dose outside the controlled area < 1.3mSv/3weeks
- We will have ~2,100 shots per year. -> effective dose < 0.6μSv/shot
- Some holes made for diagnostic/controlling at the basement level should be filled to satisfy the effective-dose limit.
- Now, filling holes at the northern side was completed.
- This work will be finished before the start of the deuterium experiment.

Example of shielding

Effective dose at the basement level by calculation (after shielding)

Effective dose (μSv/shot)
- Northern side: 0.13
- Eastern side: 0.29
- Southern side: 0.16
- Western side: 0.06

Filling holes of northern wall in basement

Filling holes of the floor between the heating equipment room and the trench with polyethylene beads

Filling holes of the wall between the basement and the trench with polyethylene plates and beads
Removed/reformed devices which are weak against radiation

- Last year, all systems equipped with LHD were classified into three groups based on the check list: “remove”, “reform”, and “satisfy”.
- Devices classified into “remove” are now antecedently removed.
- Implementation planning sheet is submitted and defined this year.
- Removing/reforming devices will be done according to the planning sheet.

PHA diagnostics

After removing PHA diagnostics

Exhaust gas processing system

~ Tritium removal systems ~

- Exhaust gas processing system
  - Two types of tritium removal system
    - Molecular Sieves [MS] type and Permeable Membrane [PM] type

- Schedule of construction and commissioning
  - Completion: PFD, P&ID, design of components and layout
  - Next step: Control system design, construction and commissioning

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<thead>
<tr>
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<th>2014</th>
<th>2015</th>
<th>2016</th>
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<tr>
<td>Operation</td>
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</table>
Absolute calibration of neutron flux monitor using $^{252}$Cf neutron source

- To measure the total number of neutrons, the neutron flux monitor system needs to be absolutely calibrated.
- Calibration will be carried out along the guide line decided in the WS on the neutron calibration*.
- To avoid rescue circumstances of the source, the train and track system should be reliable.
- We have developed a train that can run continuously at least for three days.
- Test installation of the track inside the vacuum vessel has already been performed twice to measure the time necessary to install, and to find points at issue for the installation.


Refurbishment of LHD Building

- Preparation of rooms in LHD building, such as access control room, material research labs., and maintenance room.
- Maintenance of air conditioning machine
- Installation of an emergency power generator of 100 kW providing for 10 days
Air Balance of LHD Building

Application Procedure for the Licenses

<table>
<thead>
<tr>
<th>Apparatus etc.</th>
<th>Act</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Cf-252 sealed source (800MBq)</td>
<td>Act on Concerning Prevention from Radiation Hazards due to Radioisotopes, etc. (Radiation Hazard Prevention Act)</td>
<td>Radio-isotope (sealed source)</td>
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<td>LHD</td>
<td>Given above</td>
<td>Radiation Generating Device (Plasma Generator)</td>
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<tr>
<td>Material for the first wall and the plasma irradiation</td>
<td>Given above</td>
<td>Radio-isotope (unsealed source)</td>
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</table>

Some licenses have to be obtained before starting the LHD deuterium experiment.
### Schedule for obtaining the Licenses

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<td>(1) Fission Chamber</td>
<td>Agreement for environmental safety (Mar.)</td>
<td>Approval</td>
<td>Order</td>
<td>Delivery</td>
<td>Set the control area (Dec.)</td>
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<tr>
<td>(2) Cf-252</td>
<td>Application</td>
<td>Approval</td>
<td>Order</td>
<td>Delivery</td>
<td>Set in the LHD hall Calibration</td>
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<td>(3) LHD &amp; unsealed radioactive materials</td>
<td>Hearing</td>
<td>Application</td>
<td>Hearing</td>
<td>Facilities inspection &amp; First Plasma</td>
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<td>(4) Accounting Provision</td>
<td>Application</td>
<td>Approval</td>
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<td>Notification</td>
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</table>

LHD deuterium experiment will start after the facilities inspection preparation.

(2) Is the preparation system for the initiation of deuterium experiments appropriate? Is preparation of the facilities, including safety equipment, and machinery being advanced appropriately?

1. Division for deuterium experiments management was established, which is responsible for the preparation for the initiation of deuterium experiments, and conducts and accelerates the preparation of the facilities and the establishment of the safety management.

2. LHD upgrade team for the deuterium experiment has carried out the design and construction of the safety equipment and the device upgrade required for the deuterium experiments.

3. Along the planned schedule, the device upgrade and the preparation of the safety equipment including the establishment of the safety management have progressed under the organized preparation system.

4. Filling holes of walls for reduction of the neutron streaming has been completed to 80%. Devices which are weak against the radiation are classified for the judgement of removing/ reforming based on the submitted implementation plan, and the removal has partly started.

5. Tritium removal systems and the neutron diagnostic system as the safety equipment are now under construction, and the preparation for the absolute calibration of neutron flux monitor has successfully progressed.

6. Refurbishment of the LHD building for setting the radiation controlled area has been completed, and the related facilities, such as the exhausted water and the air conditioning system, are under construction.

7. Procedure for the legal licenses proceeds without any problem, and the required licenses should be obtained before the start of LHD deuterium experiments.
[3] Safety management planning

(3-1) Is the fundamental concept regarding safety management appropriate at the time of the formulation of the deuterium experiment execution plan as also based upon the opinions of local residents?

重水素実験の目的は適切か、またその目的を達成する研究計画及び安全を確保する実施体制となっているか。

(3-2) Are safety management equipment, facilities, and experiment equipment being planned appropriately for the safe accomplishment of the deuterium experiment and to support management?

安全管理機器・設備、実験機器等は重水素実験を安全に遂行し、維持管理するために適切に計画されているか。

(3-3) In order to safely accomplish the deuterium experiment, are various types of regulations being formulated appropriately?

重水素実験を安全に遂行するために、規則類は適切に策定されているか。

(3-4) Are the operation manual, the radiation management manual, and the emergency manual being formulated appropriately?

運転マニュアル、放射線管理マニュアル、緊急時マニュアル等は適切に策定されているか。

(3-5) Are the organization and the system for safety management when the deuterium experiments are being conducted being constructed appropriately?

重水素実験を実施する際の安全管理のための組織、体制等は適切に構築しているか。

(3-6) Are education and training for the safe execution of the deuterium experiments, and nurturing for those responsible for safety management being undertaken appropriately?

重水素実験の安全な遂行に向けた教育・訓練及び安全管理責任者の養成は適切に計画されているか。
Fundamental Concept for Safety management

Deuterium Experiment
Neutron Tritium Radio-active Materials

LHD Plasma Generating Device

Regulation for Safety Management

- Act Concerning Prevention from Radiation Hazards due to radioisotopes, etc. (Legal Level)
- Final report of the Deuterium Experiment Security Evaluation Committee (NIFS management Level)
- Arbitration proposal by the Environmental Dispute Coordination Commission (in deference)

Basic Concept

- Minimize quantity of occurring tritium.
  ⇒ Examination of the experiment parameter
- Limit the quantity of tritium remaining in a VV which does not exceed a management level, even if a gross quantity is released.
  ⇒ Examination of the experiment plan
- Keep the management level of the radiological generations which have a possibility to give influence on the environment.
  ⇒ Preparation of exhaust, drainage, the ventilation equipment
- Pay attention severely about a leak of the tritium component water.
  ⇒ Preparation of a safekeeping method, safekeeping facilities

the Safety Management Plan Evaluation Committee

Management of low level radiation
  ⇒ Develop and establish the measurement technique and is useful for the Fusion Reactor in Future
(3-1) Is the fundamental concept regarding safety management appropriate at the time of the formulation of the deuterium experiment execution plan as also based upon the opinions of local residents?

The basic concept for the safety management, such as the NIFS management level been set severer than laws and ordinances, is considered to be excessive as the standard for general facility treating with radiation. However, this was based on an Arbitration proposal by the Environmental Dispute Coordination Commission and on a local opinion. Furthermore, from the Safety Management Plan Evaluation Committee, “The NIFS management value is sufficiently low compare with that of laws and ordinances, but research of a such small amount radiation promotes the development of its measurement equipment and a research to establish its measurement technique.” is evaluated to be appropriate.

(3-2) Are safety management equipment, facilities, and experiment equipment being planned appropriately for the safe accomplishment of the deuterium experiment and to support management?

安全管理機器・設備、実験機器等は重水素実験を安全に遂行し、維持管理するために適切に計画されているか。

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(3-4) Are the operation manual, the radiation management manual, and the emergency manual being formulated appropriately?

運転マニュアル、放射線管理マニュアル、緊急時マニュアル等は適切に策定されているか。

(3-5) Are the organization and the system for safety management when the deuterium experiments are being conducted being constructed appropriately?

重水素実験を実施する際の安全管理のための組織、体制等を適切に構築しているか。

(3-6) Are education and training for the safe execution of the deuterium experiments, and nurturing for those responsible for safety management being undertaken appropriately?

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重水素実験の目的は適切か、またその目的を達成する研究計画及び安全を確保する実施体制となっているか。

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---

**Neutron and tritium measure and control**

\[
\begin{align*}
D + D & \xrightarrow{50\%} T + p \\
& \xrightarrow{50\%} ^3\text{He} + n
\end{align*}
\]

Number of Tritium = Number of Neutron

To manage these safely, it is necessary to grasp quantity of the neutron production precisely

The *fission chamber* detectors are used to grasp quantity of neutron precisely. (See §2.3.3.1)

1. N, \(\gamma\)-ray protection
2. Provision for tritium (One of the most important issue)
3. Management of Exhaust, drain water, RI and RA-waste
4. Radiation Controlled Area & Security
5. Integrated Radiation Monitoring System
1. Neutron and γ-ray Protection

**Reduction of radio-activation by neutron**

- Concrete under the LHD machine will be strongly radio-activated.
- To reduce the radio-activation of concrete, we have a plan to cover the concrete with 5 cm thick borated polyethylene (PE).

*This year, covering concrete on one-torus section with PE was done.*

- We will finish covering concrete at the other torus sections before starting deuterium experiment.

2. Provision for tritium

- **Exhaust gas processing system**

  **Specifications of tritium removal systems**
  - Type of tritium removal system:
    - Oxidation catalyst + absorbent [MS type]
    - Oxidation catalyst + polymer membrane [PM type]
  - Maximum flow rate:
    - MS type: 20 Nm³/h
    - PM type: 300 Nm³/h
  - Detritiation factor [DF] : > 20

  ![Tritium removal systems diagram](image)

  Maximum tritium production: 55.5 GBq/y

  Collection and delivery to JRIA

  Oxidation catalyst → Recovery of HTO

  Chemical form of tritium HTO

  Detritiation factor > 20

  Environmental monitoring

  Stack

  Tritium active sampler

  Dilution by room air (24610 m³/h)
- MS type tritium removal system -

**Features of system**
- Catalysts: Pt-Al₂O₃ for hydrogen, Pd-Al₂O₃ for hydrocarbons
- Low throughput [< 20 m³/h]
- High tritium concentration
- Operation: period of plasma exp.

- PM type tritium removal system -

**Features of system**
- Catalyst: Pt-Al₂O₃ for HT
- Application of polymer membrane => **Merits of membrane:**
  - No regeneration system
  - High throughput
  - Continuous operation
  - Compact system
  - Control of performance
  - Ease maintenance
- High throughput [< 300 m³/h]
- Low tritium concentration
- Operation: period of maintenance

Tritium decontamination factor: > 20 (Tritium recovery rate: > 95 %)
3. Management of Exhaust, drain water, RI and RA-waste

[Exhaust and Ventilation]

- Since Ar in air is activated during Deuterium Experiment, we have to minimize the ventilation of the main experiment hall keeping negative pressure.

- To keep the concentration of Ar-41 below the limit in law, we vent air with 500Nm$^3$/h.

- A ventilation systems of ACU-6 and ACU-14 have ability to keep the pressure in the main hall and the maintenance workroom negative.

- Radio-active dusts are removed by the pre-filter and hepa-filter before exhausting.

-Air ventilation system of the LHD building -
3. Management of Exhaust, drain water, RI and RA-waste 2

[Drain water and Recovered water]

- All drainage that occurred in Controlled Area except the recovered water is kept in a retention tank temporarily and discharged after confirmation the radio-activity concentration below NIFS management level (tritium: 0.6 Bq/cm³). (Legal level: 60 Bq/cm³)

- Drainage that exceeds NIFS management level (0.6 Bq/cm³) is treated as same as recovered water described below.

- Recovered water, which produces by the tritium removal system and contains the triated water (HTO), is contained in an exclusive safekeeping container and asks Japan Radio-Isotope Association (JRIA) for taking care of.
3. Management of Exhaust, drain water, RI and RA-waste

[Radio-Active Waste]

Radio-Active wastes are classified into 8 categories as follows and put in the metal-container (50L) of the JRIA designation. These are kept at one time in a Disposal-by-Storage Facility and are asked JRIA for processing.

1) combustibles (type1)
2) incombustibles
3) incompressible incombustibles
4) combustibles* (type2)
5) filters
6) Ion-exchange resin (consultation required)
7) inorganic substances
8) organic substances
1) combustibles (type1)
   - flammable waste such as work gloves, the mask, a paper towel, cloth Wes, etc.
2) incombustibles
   - a glass vial, glassware vinyl chloride, silicon, china, aluminum foil, Teflon fit, etc.
3) incompressible incombustibles
   - the soil, a steel frame, a pipe, a concrete piece, a casting, etc.
4) combustibles* (type2)
   - plastic, a poly-vial, a poly-seat, rubber gloves, Styrofoam, etc.
5) filter
   - Pre-filter, hepa-filter to arrange to exhaust facilities
6) ion-exchange resin (consultation required)
   - Ion-exchange resin such as primary cooling facilities
7) inorganic substances
   - Be in 25L of poly-container, and it is held by 50L of metal-container
8) organic substances
   - With liquid scintillation waste fluid, etc.
   - Be in 25L of poly-container, and it is held by 50L of metal-container

[Radioisotope]

(1) The radioisotope which is used as a radiation detector and for the calibration
   - Enriched U-235 (fission chamber) : Neutron measurement
   - Cf-252 : Source for calibration of the neutron measurement

(2) The materials which are activated by a neutron or absorb Radioisotope
   - SUS sample, carbon sample, silicon sample : used for PWI studies
   - Main radionuclide
     - Graphite : T, C-14, Be-7
     - SUS316 : T, C-14, Cr-51, Mn-53, Mn-54, Fe-55, Fe-59, Co-56, Co-57, Co-58, Co-60, Ni-59, Ni-63, Zr-95, Nb-95m, Nb-94, Nb-95, Nb-93m, Mo-93, Tc-99

These materials are controlled in the Storage Facility.
4. Controlled Area & Security

- Controlled Area -

Access Control
- Gates and Security Code (SQRC) -

Access Gates and SQRC (Security QR Code) for authentication

SQRC seal are affixed on personal dosimeters. Then, no one can enter the controlled area without personal dosimeter.

SQRC reader
Access gates
Personal dosimeter with SQRC
Access control room and rocker room
- Exit Flow and Contamination Test Apparatus -

Access gates

Contamination monitor

From LHD hall

Survey meter

Access gates for LHD hall

Access Control room

Contamination inspection room

Expiration inspection device

LHD deuterium experiment will start after the supposed 3-years preparation.

5. Integrated Radiation Monitoring System

Access gates

Contamination monitor

Access Control room

Exhaust gas monitor

Drainage monitor

Gas and dust monitor

Environmental monitors

Unification

Interlock

Integrated radiation monitoring system

LHD central control

Control room

Enhancement of monitoring system of LHD building
Example of Monitoring Displays

DRAINAGE CONTROL SYSTEM  RMSAFE (SITE BOUNDARY)

STACK and LHD HALL GAS MONITOR  RMSAFE (LHD HALL)

Measuring Instruments (1)

Measuring equipment
- prepared and started operations to get BG data

Stack gas monitors  $^3$H sampler for stack gas  Low background Liquid scintillation counters (LSC-LB7)

Drainage tanks  Drainage monitor  Ultra Low Level Liquid Scintillation Spectrometer (1220 QUANTULUS)  Auto Well Gamma System (AccuFLEX 7000)
Measuring Instruments (2)

Air monitors for the LHD hall

Monitoring post of RMSAFE

hand-foot-clothing monitors

Survey meters

Renovated LHD Building to apply D-experiments

Exhaust Gas Processing System

Access Control Area

RI storage Area

RI Analysis Area

B2F

B1F

1F
Cumulative dose were monitored by glass dosimeter installed in the site (1) and site boundary (2-8).
Data shows the flat background dose.

Environmental background of radioactivity

It is need to estimate the influence of the deuterium experiments

Following environmental background is being measured.

- Radioactivity in the Stack Gas
- Atmospheric tritium
  Three chemical type of tritium was measured separately
  water vapor (HTO), molecular hydrogen (HT) and hydrocarbons (CH₃T)
- Tritium in the river water (HTO)
  Recent date is under 0.5 Bq/L.
- Tritium in plant samples (FWT and OBT)
  Pine needles at NIFS and Shiomi-park
- Environmental radionuclides
  rain, atmospheric dust, atmospheric deposition and surface soil
Background of Radioactivity

Radioactivity in the stack gas is measured as background data in order to estimate the influence of the deuterium experiments.

Radioactive concentration in the stack gas: 2012.6~2014.9
- Tritium monitoring in the atmosphere -

- Tritium monitoring in the river water -

- Tritium monitoring in the atmosphere -

- Tritium monitoring in the river water -

**Atmospheric tritium concentrations of three chemical forms such as HTO, HT and CH$_3$T had been measured since 2004.**

- Tritium concentrations of HTO, HT and CH$_3$T were distributed around 2-23 mBq/m$^3$, 5-11 mBq/m$^3$ and 0.5-3 mBq/m$^3$.

- The HTO concentration depends on humidity in air.

- Recent decreasing rate of HT concentration to half was estimated **19.4 years**.

Atmospheric tritium was separately collected as water vapor (HTO), molecular hydrogen (HT) and hydrocarbons (CH$_3$T) by using this sampling system.

**Atmospheric tritium concentration is gradually decreasing year by year.**

**Recent date is under 0.5 Bq/L.**

**This result is similar to background tritium concentration in Japan.**
- Tritium monitoring in plant samples -

We monitored tritium concentration in pine needle samples. Shiomi park is located about 5km south of NIFS. FWT and OBT concentrations are gradually decreasing, and recent data is background level.

- Environmental monitoring of radionuclides -

In order to understand the background level of radionuclides, we stated the rain, atmospheric dust, atmospheric deposition and surface soil collection. We also started the passive type sampling of HTO in atmospheric water vapor. A passive type sampler which does not require any power supply is more effective for the study on atmospheric HTO behavior around the LHD.
(3-2) Are safety management equipment, facilities, and experiment equipment being planned appropriately for the safe accomplishment of the deuterium experiment and to support management?

In the deuterium experiment, a neutron and tritium are produced, and this neutron activates the surrounding materials. Activated materials radiate the secondary Gamma-ray. To manage these safely, it is necessary to grasp quantity of the neutron production precisely. To measure the quantity of neutron precisely, the fission chamber detectors are used. To ensure this measurement, the calibration using 252-Cf will be carried out in LHD.

The deuterium experiment is limited by the quantity of the neutron production and the experiment is planned not to exceed the maximum neutron budget.

Protection against the neutron and gamma-ray are designed using the DORT-code and FISPACT-code. In this calculation, some shielding materials and some through holes are taking account. To reduce the radio-activation by the neutron, some holes are buried by the polyethylene and floor concrete under the LHD machine will be covered with the Borated Polyethylene brocks.

To minimize the influence of the radiation and tritium to the environment, NIFS management levels, which are lower than the levels in law, are set. Exhaust, ventilation, drain and their monitoring system are equipped to keep the NIFS management level. The radiation monitoring system is also equipped.

Radio-Active wastes are classified into 8 categories and put in the container of the JRIA designation. These are kept at one time in a Disposal –by-Storage Facility and are asked JRIA for processing.

To reduce the tritium in the exhaust, 2 type of tritium removal systems are designed and equipped as the exhaust gas processing system. Tritium concentration is control 1/25 lower than that in law. Recovered water from the tritium removal systems is contained trebly in the JRIA container and is kept in the waterproof storage section. Some tritium monitors are set to get the background data.
Control area is set in the LHD building. To reduce unguarded expansion of the radiation contamination, entrance of this area is only one. Rocker room, contamination inspection room, decontamination room, etc. are set taking account the flow line. Key of each room is electric lock and controlled at the access control room.

Radiation related equipment is connected to the Integrated Radiation Monitoring System and be monitored their conditions on this system. Some date is connected to the LHD interlock system.

(3-1) Is the fundamental concept regarding safety management appropriate at the time of the formulation of the deuterium experiment execution plan as also based upon the opinions of local residents?

(3-2) Are safety management equipment, facilities, and experiment equipment being planned appropriately for the safe accomplishment of the deuterium experiment and to support management?

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(3-4) Are the operation manual, the radiation management manual, and the emergency manual being formulated appropriately?

(3-5) Are the organization and the system for safety management when the deuterium experiments are being conducted being constructed appropriately?

(3-6) Are education and training for the safe execution of the deuterium experiments, and nurturing for those responsible for safety management being undertaken appropriately?

Present NIFS Regulations for Experiment

Followings are present NIFS regulations for LHD experiment

※ [NIFS Regulation of Prevention of Radiation Hazards ] is revising to fit the Deuterium Experiment now

NIFS Safety and Health Regulation
核融合科学研究所安全衛生管理規則

NIFS Regulation of Prevention of Radiation Hazards (revising for D-experiment)
核融合科学研究所放射線障害防止規程(案)

NIFS Detailed Regulation of the Vacuum Maintenance on LHD
核融合科学研究所大型ヘリカル装置真空維持管理細則

NIFS Detailed Regulation of the Heavy Ion Beam Probe
核融合科学研究所重イオンビームプローブ装置の維持管理細則

NIFS Detailed Regulation of Experimental Devices
核融合科学研究所における実験装置等の維持管理細則

NIFS Detailed Regulation of the X-rays Device
核融合科学研究所におけるエックス線装置の維持管理細則

NIFS Detailed Regulation of the Ion Beam Analyzer
核融合科学研究所イオンビーム解析装置の維持管理細則

- General Hierarchy of Law related to Radiation -
We establish internal rules and manuals before starting Deuterium experiment.

- Examples of NIFS Regulation –
NIFS Regulation of Prevention of Radiation Hazards
例のNIFS規制

NIFS詳細な処置規則による極微量放射性物質開発
**- Procedure for in-Vessel Work –
* Prevent the tritium exposure**

One should pass through anterior chamber to enter LHD vacuum vessel

**Anterior chamber has**
- isolated air conditioning system
- 2 level control areas divided by barriers
- survey system for fist check

**One should**
- wear protective clothing depending on work level
- check radiation level, oxygen concentration before entering vacuum vessel

- 2 level control areas divided by barriers
- survey system for fist check before entering vacuum vessel

- check radiation level, oxygen concentration before entering vacuum vessel

---

**- Procedure for port Work (Vacuum related) –
* To prevent the tritium exposure**

- One should minimize tritium leak to LHD hall
- Staffs who completed the training of tritium handling in Toyama Univ. can conduct port work.

- LHD vacuum vessel is kept in a negative pressure during port work

  **with gate valve**
  - Measure residual tritium using a tritium monitor
  - After confirming non-existence of residual tritium, port work is conducted with a proper curing
  - If residual tritium cannot be decontaminated, port work is stopped

  **w/o gate valve**
  - Port work is conducted in a temporal work room with a ventilation equipment
- NIFS management level 1 –

- Controlled Area (Working area)
  - 1 mSv/week (100 mSv/5 years)
  - 40 Bq/cm²

- Boundary of Controlled Area
  - 1.3 mSv/3 month
  - 4 Bq/cm²

- Site Boundary
  - 50 μSv/year

- Tritium production
  - 37 GBq/year (former 6 years)
  - 55.5 GBq/year (later 3 years)

- Maximum Tritium release into environment
  - 3.7 GBq/year

- NIFS management level 2 –

- Tritium Concentration in Working Environment (Law)

<table>
<thead>
<tr>
<th>Types of Radioisotopes</th>
<th>Limit in Working environment (Bq/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isotope</td>
<td>Chemical form</td>
</tr>
<tr>
<td>³H</td>
<td>Gaseous tritium</td>
</tr>
<tr>
<td></td>
<td>1 × 10⁴</td>
</tr>
<tr>
<td>³H</td>
<td>triated water or vapor</td>
</tr>
<tr>
<td></td>
<td>8 × 10⁻¹</td>
</tr>
</tbody>
</table>

- Tritium Concentration in Exhaust (NIFS management level)

<table>
<thead>
<tr>
<th>Types of Radioisotopes</th>
<th>Limit in Air or Exhaust (Bq/cm³)</th>
<th>Limit in Drainare or Waste water (Bq/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isotope</td>
<td>Chemical form</td>
<td></td>
</tr>
<tr>
<td>³H</td>
<td>Gaseous tritium</td>
<td>7 × 10¹</td>
</tr>
<tr>
<td>³H</td>
<td>triated water or vapor</td>
<td>2 × 10⁴ (5 × 10⁻³)</td>
</tr>
</tbody>
</table>

( ) : Concentration Limit in Law
**- Communication to the local government -**

NIFS must report the emergency occurrence to the fire department, the police station and the hometown local government (Toki, Tajimi, Mizunami cities and Gifu Prefecture).

Following items are considered and discussed with the local governments.

- Communication means
  - satellite phone (facsimile), electric generator, bicycle, etc.

- Working time of the communication system
  - 24 hours

- Matters needing reports
- the Important matter which should be reported **without delay**
- the Matter which should be reported in advance or without delay
- Report of the disaster occurrence which scale is less than that of former matter
[Communication Means]
NIFS maintains satellite phones (facsimiles) which possessed battery.
In addition, these are connected to the non-common use generation facilities which is available for 7 days.
When a satellite phone (facsimile) is cut off, NIFS dispatches person in Toki city hall, Tajimi city hall, Mizunami city hall and the Tounou Promotion Bureau.

[the Communication System]
Because the monitoring system is operating all day, some person work as a responsible person by turns.
A responsible person communicates to the local government and to the other staff.

[Matter Needing Reports]
When the accidents such as fires
When the recovered water containing tritium more than the limits of laws and ordinances leaked out in the facility by accidents
When the annual dose of radioactivity at the site boundary exceed the limit in law
When tritium or Argon-41 more than the limits of law and ordinances was exhausted
When the recovered water more than the limits in laws and ordinances was drained away
The earthquake that occurs after caution declaration based on a law, and earthquakes which level exceeds five minus
When the situation that might have an influence on the neighboring environment by the disasters and stopped deuterium experiment
[the Important matter which should be reported without delay]
- Quantity of annual production of a neutron and tritium exceeds the NIFS management level
- When the keeping recovered water leaked out in an facility by accidents
- The annual dose of radioactivity of the site border is time beyond the NIFS management level
- When tritium or Argon-41 more than the NIFS management level was exhausted
- When the recovered water more than research institute management level was drained away
- When a deuterium experiment is stopped by the disasters such as earthquakes, and repair of the major equipment became the necessary for the experiment reopening

[the Matter which should be reported in advance or without delay]
- The start time of the deuterium experiment in each fiscal year and end time (notify the assembly)
- When there are the maintenance plan of the research facility, a research plan and research contents and these changes (prior communication)
- Results of research (regularly)
- A certain matter of the publication duty
- After the deuterium experiment of each fiscal year, annual production quantity of a neutron and tritium, annual exhausted quantity of tritium to environment, the annual cumulative dose at the site boundary
[Report of the disaster occurrence which scale is less than that of former matter]

NIFS reports the following cases to the local governments.
- When the Meteorological Agency announces that there was rolling more than seismic intensity 4 caused by the earthquake in Toki-city, Tajimi-city and Mizunami-city
- When, by a typhoon and/or a seasonal rain front, the disasters such as a landslide and the large-scale fallen tree may occur

In addition,
- Publication to the homepage
  NIFS uploads on the homepage.
- Reporting means, reporting time zone
  It is decided after local discussion with local government.

(3-3) In order to safely accomplish the deuterium experiment, are various types of regulations being formulated appropriately?

On starting the deuterium experiment, NISF is pushing forward the change of the rule and the establishment according to the Industrial Safety and Health Law, the Atomic Energy Basic Act and the Civil Protection Law in addition to the present safety regulations.

"NIFS Regulation of Prevention of Radiation Hazards" was submitted to the Supervisory Authority as a regulation relating to the radiation generator due to the incorporation of 2004. Since the RI for the calibration and the radioactive materials for PWI research is used in the deuterium experiment, this regulation is revised. This regulation is in the top priority, and the various manuals are maintained to push forward the deuterium experiment while checking the consistency with this regulation.

For the works which have a possibility to contact with tritium, such as in-vessel working and port working, work procedures are provided to keep a safety work. For the in-vessel work, the anterior chamber is provided as an entrance of the vacuum vessel and prevents spread of tritium contamination to the outside.
The NIFS management levels for the dose at the site boundary and the tritium concentration for the exhaust and the drainage are set to control the safety by NIFS. In addition, the management values of the neutron and tritium production and of the environmental dose are set, and their measuring methods and position to ensure these values are set. Measurement of the background level before the deuterium experiment is started about the possible measuring equipment.

In the event of an emergency, communication means, such as a satellite phone, to the local governments are secured, and the reporting matters and the announcement of their data are established.

(3-3) In order to safely accomplish the deuterium experiment, are various types of regulations being formulated appropriately?

(3-1) Is the fundamental concept regarding safety management appropriate at the time of the formulation of the deuterium experiment execution plan as also based upon the opinions of local residents?

(3-2) Are safety management equipment, facilities, and experiment equipment being planned appropriately for the safe accomplishment of the deuterium experiment and to support management?

(3-3) In order to safely accomplish the deuterium experiment, are various types of regulations being formulated appropriately?

(3-4) Are the operation manual, the radiation management manual, and the emergency manual being formulated appropriately?

(3-5) Are the organization and the system for safety management when the deuterium experiments are being conducted being constructed appropriately?

(3-6) Are education and training for the safe execution of the deuterium experiments, and nurturing for those responsible for safety management being undertaken appropriately?
We are preparing the following three manuals.

- Facility Operation Manual
- Radiation Management Manual for Facility
- Emergency Manual

These manuals stimulate revision to better things while using them.

**- Facility Operation Manual -**

- Preparing the Operation Manual for the Facilities which will be used in the Deuterium Experiment.

- This manual is prepared as one of materials which we decide whether this facility should remove before deuterium experiment or not.

- Each facility is checked its rating, usefulness and the resistivity against neutron exposure.

- Facility which is not submitted these materials and not cleared check is removed before the Deuterium Experiment.
### Model of the Facility Operation Manual

<table>
<thead>
<tr>
<th>項目</th>
<th>内容</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 目的</td>
<td>このマニュアルは、安全に運転を行うための必要な手順を定めるものである。</td>
</tr>
<tr>
<td>2. 運転・監視体制について</td>
<td>運転に携わる責任体制を明確にしておくこと。</td>
</tr>
<tr>
<td>3. 定期点検について</td>
<td>別途定める項目に従い、定期点検を実施すること。</td>
</tr>
<tr>
<td>4. 運転開始の手続きについて</td>
<td>4-1. 始業前点検</td>
</tr>
<tr>
<td></td>
<td>4-1-1. 放射線総合監視システムが動作していることを確認する。</td>
</tr>
<tr>
<td></td>
<td>4-1-2. 始業点検表に基づき機器・設備の点検を実施する。 (機器毎に、その必要性に応じて項目を設ける。)</td>
</tr>
<tr>
<td>5. 運転中について</td>
<td>5-1. 運転中は常に機器を安全に操作すること。</td>
</tr>
<tr>
<td>6. 運転終了時の手続きについて</td>
<td>6-1. 停止作業</td>
</tr>
<tr>
<td></td>
<td>6-2. 運転後の点検</td>
</tr>
<tr>
<td></td>
<td>終了点検表に基づき機器・設備の点検を実施する。</td>
</tr>
<tr>
<td>7. 異常時の対応について</td>
<td>別途定める異常時対応マニュアルに従って、行うこと。</td>
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<tr>
<td>8. その他</td>
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</table>

### Operation Manual for Vacuum Evacuation System

<table>
<thead>
<tr>
<th>項目</th>
<th>内容</th>
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<tbody>
<tr>
<td>1. 目的</td>
<td>このマニュアルは、真空操業の管理基準であることを明確にすることが目的。</td>
</tr>
<tr>
<td>2. 設計構想</td>
<td>真空操業システムによるフラクタル構造を考慮した。</td>
</tr>
<tr>
<td>3. 安全対策について</td>
<td>3-1. 事故防止のために利用者に対して注意を促す。</td>
</tr>
<tr>
<td>4. 運転中について</td>
<td>4-1. 運転中の注意点を明確にする。</td>
</tr>
<tr>
<td>5. 運転終了時の手続きについて</td>
<td>5-1. 運転終了時の注意点を明確にする。</td>
</tr>
<tr>
<td>6. その他</td>
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</tbody>
</table>

63/91

64/91
Deuterium Experiment: We have to keep the NIFS management level for an exhaust, drainage and dose level at the site boundary.

Port related Work: We have to minimize the tritium leakage into the environment.

In addition to the Facility Operation Manual, we push forward the preparation of the Radiation Management Manual in the viewpoint of the radiation management every apparatus.
We are preparing the Emergency Manual during the Deuterium Experiment to keep the consistency with the conventional disaster prevention manual.

**Basic way of thinking to an emergency and a disaster**

We have to pay attention to a neutron and tritium which have a possibility to give influence to environment, when a disaster and/or an accident occurs.

Followings are basic way of thinking to the deuterium experiment safety at an emergency and a disaster.

1) Minimize the quantity of occurring tritium,
2) Limit the quantity of tritium remaining in a VV which does not exceed the management level, even if a gross quantity is released,
3) Keep the management level of the radiological generations, such as Ar-41, which have a possibility to give influence on the environment
4) Pay attention severely to a leak of the recovered water.
- Network at Emergency -

- Self Fire Brigade (Plan at D-experiment) -
(3-4) Are the operation manual, the radiation management manual, and the emergency manual being formulated appropriately?

Since the equipment was installed in the LHD hall and the LHD basement and these area is set as the Controlled Area after the start of the deuterium experiment, "Radiation Management Manual", "Facility Operation Manual" and "Radiation and equipment controlled area management Manual" are provided and revised for each equipment. Each manual has been written in a uniform format along the model that has been created by the Development Task Force Team for LHD Deuterium Program.

"Radiation and equipment controlled area management Manual " is written for the radiation source handling, radiation generating device, and the devices that generate radiation in operation even when LHD is not operating. This manual is developed to control the safety even during non-experimental period.

“Emergency Manual” is written about the communication system, the disaster prevention system, the responsibility at the time of the experiment, etc. taking into account the conventional disaster prevention manual. In particular, the security about a radiation and tritium is ensured by setting the top priority to check the RI safekeeping facilities and the tritium recovery system in the Emergency Manual for the deuterium experiment. For example, workers’ safety is ensured to set the time that worker can stay in the LHD hall, when worker enters into the LHD hall, in the view point of the radiation exposure.
(3-1) Is the fundamental concept regarding safety management appropriate at the time of the formulation of the deuterium experiment execution plan as also based upon the opinions of local residents?

(3-2) Are safety management equipment, facilities, and experiment equipment being planned appropriately for the safe accomplishment of the deuterium experiment and to support management?

(3-3) In order to safely accomplish the deuterium experiment, are various types of regulations being formulated appropriately?

(3-4) Are the operation manual, the radiation management manual, and the emergency manual being formulated appropriately?

(3-5) Are the organization and the system for safety management when the deuterium experiments are being conducted being constructed appropriately?

(3-6) Are education and training for the safe execution of the deuterium experiments, and nurturing for those responsible for safety management being undertaken appropriately?

the organization and the system for safety management

NIFS Safety Promoting Organization

Director General organizes the Safety and Health Committee as a general safety and health manager based on the Industrial Safety and Health Law.

Member of the S&H Committee are the safety officer, the health officer, industrial physician and a few selected NIFS staff.

Meeting is held once in a month and things about safety and health are discussed.

Division of Health and Safety Promotion, which has 10 offices, carries out the safety and heath related matter pointed out by the above committee.

Radiation Control office is expanded and performs the administrative task in the deuterium experiment while getting support of the Radiation Safety Committee (plan).
NIFS Radiation Safety System

Control office which will be expanded to deal with the deuterium experiment performs the administrative.

The Safety Monitoring Committee is organized by the local government as a third party organization independent of NIFS, and performs monitoring about the security of the deuterium experiment.

After the deuterium experiment begins, the Monitoring of various apparatuses, facilities is performed for 24 hours in a whole year.
(3-5) Are the organization and the system for safety management when the deuterium experiments are being conducted being constructed appropriately?

Safety management system of NIFS is established based on the Industrial Safety and Health Law and is consist of the General Safety and health manager, who is the Director General, the Health Officer, the Safety Officer and the Industrial Physician. The Safety and Health Committee is organized above member and a few additional members, and discuss the things related to health and safety on a meeting once a month. Furthermore, Division of Health and Safety Promotion with 10 offices is organized by the Director General. This division is carrying out matters pointed out by this committee and makes plan for improvement of the safety and prevention the work-related accident.

After the start of the deuterium experiment, the Radiation Control Office is expanded and deals with the safety management. In addition, the Radiation Safety Committee (tentative name) is established as a radiation management section other than the Radiation Control Office. And Safety Monitoring Committee (tentative name) is established by the local government and monitors the safety.
Monitoring the equipment and management of the Disposal-by-Storage Facility are parts of the function of the Integrated Radiation Monitoring System, and these are carried out in 24-hours both experimental and non-experimental period. When there is an abnormality, necessary staff is assembled in accordance with emergency contact network and deals with correspondence.

(3-1) Is the fundamental concept regarding safety management appropriate at the time of the formulation of the deuterium experiment execution plan as also based upon the opinions of local residents?

(3-2) Are safety management equipment, facilities, and experiment equipment being planned appropriately for the safe accomplishment of the deuterium experiment and to support management?

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(3-6) Are education and training for the safe execution of the deuterium experiments, and nurturing for those responsible for safety management being undertaken appropriately?
Education
- **General Safety Lectures** and **Radiation Safety Lectures** are held twice for each in the end of fiscal year for the workers including students to renew the permission of working in the next fiscal year.

- **Radiation Safety Lectures after the deuterium experiment start** are also held twice in a year. For a person who enters the radiation controlled area, new lecture of the non sealed RI treatment is opened.

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Education for the visiting co-researchers

- **Safety education**
  - All the co-researchers are requested to take a safety lecture and a radiation safety lecture before they start the collaboration work.
  - A guide line is presented in the “NIFS Safety Handbook”
  - A covenant should be signed after the lecture.

- **Radiation safety control**
  - Co-researchers who want to engage in the controlled area (ex. LHD hall) should be registered as radiation worker before they start the research
    - Registration should be carried out at their own universities
    - If their university could not go through the registration procedure, NIFS would do it instead
  - A card key to access the controlled area is issued to the radiation worker
Education for the foreign co-researchers

- Safety education for the foreign co-researchers is carried out in English by their caretaker.
  - All the co-researchers are requested to take a safety lecture before start of their collaboration work in the controlled area.
  - A guide line is presented in the “NIFS Safety Handbook”
  - A covenant should be signed after the lecture.

- Warning signs are presented in English.
- English version of NIFS Safety Handbook is available.

Training and Nurturing for Safety Responsible Manager

Training

For a person who want to work in LHD, it is necessary to take class not only for "a vacuum work in LHD" but also for "the tritium safely handling course" which is held in the Hydrogen Isotope Research Center in Toyama University. In this class, students learn the actual tritium handling.

The contents of the training are as follows.

- knowledge about tritium
- the lecture about the radiation preventive rule
- the tritium measurement using the tritium detecting device
- tritium decontamination
- training of safe port work

Identification of completion is conferred on a person of completion by the center.
Disaster Drill in NIFS
Disaster prevention drill in LHD is held once a year. Toki south fire department participates this drill. The training includes the report to the local governments.

The radiation control office which is incorporated in the self-defense disaster prevention team supports the radiation-related correspondence.

Fire Drill in LHD
Fire Drill in LHD during experiment period is performed some times in a year.

These Drills are opened to the governments and the media.
Nurturing for Safety Responsible Manager

Detailed knowledge about the radiation is necessary on pushing forward a deuterium experiment safely.

Therefore NIFS recommends to be qualified the license of "first class chief responsible for handling of radioactive substances" to several people every year.

Eight people passed it and were able to acquire a qualification so far. Seven qualified people already exist.
Nine people passed a subject examination this year and they can get a qualification when they receive the technical training.
NIFS is going to increase qualified people in future.

(3-6) Are education and training for the safe execution of the deuterium experiments, and nurturing for those responsible for safety management being undertaken appropriately?

As same as before, education and training system is maintained after the start of the deuterium experiment, and the fresh training course and field education is conducted for new workers and update course for the continuators. However, the fresh training course are performed for two days incorporating the training using unsealed RI handling.

In NIFS, the disaster drill for the entire Institute is currently conducted once in a year combined with the report training to the local government, and has the participation of the Toki south fire department. Also, in LHD, the Fire Drill is conducted at least once a year assuming fire and earthquake during the experimental period.

The Radiation Control Office is incorporated in the work squad of the private disaster prevention brigade, and supports the radiation related step according to their duties. For the deuterium experiment, it is planned to increase the ripeness of the training by increasing the number of training and performing it regularly and to perform a necessary action as far as possible.
In order to get a knowledge of radiation safety in many researchers and technical officers, NIFS encourages the qualification of “first-class radiation protection supervisor” to a few people every year, as an effort of nurturing the safety responsible reader. 8 person got this qualification by this effort. Including the existing qualified personnel, there are 9 researchers and 7 technical officers who have been qualified. Also, 9 person has passed the written test, and it is possible to qualify when receiving the technical training. In the future, It is planned to go to increase the qualified person in future.

Tritium is produced during the deuterium experiment same as a neutron. There is a possibility to contact with tritium in the works such as in-vessel working and port working. To accomplish such work safely, it is necessary a responsible person who has a knowledge and an experience to treat tritium safely. In order to nurture such a responsible person, “the tritium safely handling course” is held in the Hydrogen Isotope Research Center in Toyama University as a part of the research collaboration. The contents of the training are knowledge about tritium, the lecture about the radiation prevention regulations, the tritium measurement, tritium decontamination, and safely port work using the device which really handles tritium. An identification of completion is conferred on a completed person by the center. 17 people have completed the training so far.
4. Understanding by Society and Citizens

(1) Is enhanced understanding of the safety of the deuterium experiment being advanced appropriately to local residents?

(2) Is promotion of the deuterium experiment plan being designed in conjunction with local governments?

(3) Is the importance of fusion research and its safety being widely disseminated in society?
NIFS has been focusing on the following activities with a view to increase social recognition of the necessity of fusion research and also NIFS’s scientific achievements.

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 City, Tajimi City, and Mizunami City, since 2006
- In FY 2014, 309 citizens joined the Forum
- Total: 4,190 (for 9 years)

Web
- Release of information by web pages
- Upgrading of Q&A web page
- Creation of special website featuring scientific events, symposia and conferences

Outreach activities to increase social recognition (2)

Publications
- Design and publication of the PR magazines and leaflets: “Plasma-kun Dayori” and “NIFS NEWS” issued 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”

Participation in the local events and festivals
- Science Fair in Mizunami City
- Toki Pottery Festival in Toki City
- Orosihi Pottery Festival in Toki City
- Tajimi Pottery Festival in Tajimi City
- Tajimi Festival in Tajimi City
- Children’s Art Festival in Tajimi City etc.

• Achievement in FY 2013
  - Scientific Handcraft: 29 times
  - Scientific Experiments: 6 times
  - Participants: about 1,100 children
(1) Is enhanced understanding of the safety of the deuterium experiment being advanced appropriately to local residents?

1. Public forum has been held at 23 – 30 places every year since 2006 to explain the LHD deuterium experiment, and the total participants were counted to 4,190 for 9 years, leading to increasing in the local citizen’s recognition of the NIFS’s scientific achievements and the safety of the deuterium experiment.

2. Safety information and the Q&A on the deuterium experiment are uploaded on the NIFS Web site.

3. PR magazines and leaflets are constantly published to the local residence, and public visitors are positively accepted to show LHD, counted to over 4,000 people per year.

4. Understanding by Society and Citizens

(1) Is enhanced understanding of the safety of the deuterium experiment being advanced appropriately to local residents?

(2) Is promotion of the deuterium experiment plan being designed in conjunction with local governments?

(3) Is the importance of fusion research and its safety being widely disseminated in society?
Cooperation with Local Autonomies

Agreement for the LHD Deuterium Experiment
- 1997: NIFS makes mention on tritium generation in D-D experiment
- 1998: Consultation on letter of agreement starts with local autonomies
- 2000: NIFS advances letter of agreement to councils and citizens
- 2001: Citizens take the case to council for common nuisance for abort of D-D experiment
- 2003: Adjustment of common nuisance unsuccessful
- 2006: Public forums start at local community centers
- 2007: Committee of Safety Evaluation of D-D experiment organized
- 2011: Great Higashi-Nihon earthquake
- 2012: NIFS asks conclusion of letter of agreement to local autonomies
- 2013: Concluded the Agreement for D-D experiment with local autonomies

Collaboration Research with “Toki City Plasma Research Committee”
- In 1979 move of IPP Nagoya Univ. to Toki City makes collaboration research start
- Mainly with elementary, junior-high and high school teachers at Toki City, and occasionally with science teachers at Tajimi City and Ena City
- Activity contents are as follows:
  - holding of lecture meeting on energy and environment
  - measurement of environmental radio-activities at 18 locations in Tono region

(2) Is promotion of the deuterium experiment plan being designed in conjunction with local governments?

1. Negotiation with local governments is fluently made to establish mutual understanding for the NIFS activities including the deuterium experiment.

2. Public forums held by NIFS have been supported by the residents’ associations, as well as the local governments.

3. Agreement for the deuterium experiment was concluded with the local governments, and based on this agreement the safety monitoring committee is organized for the deuterium experiment by the local governments.

4. Collaboration research with “Toki-City plasma research committee” is carried out on measurement of environmental radio-activities, and promotes the understanding of the safety of the deuterium experiment.
4. Understanding by Society and Citizens

(1) Is enhanced understanding of the safety of the deuterium experiment being advanced appropriately to local residents?

(2) Is promotion of the deuterium experiment plan being designed in conjunction with local governments?

(3) Is the importance of fusion research and its safety being widely disseminated in society?

Release of Information to Public (1)

NIFS has been conducting various events and activities for the purpose of informing the public about our research activities.

Open Campus
- Once a year in autumn, since 1998
- More than 40 events such as NIFS introduction, science experiments, and open lecture

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

<table>
<thead>
<tr>
<th>Year</th>
<th>Open Campus</th>
<th>Fusion Festa in Tokyo</th>
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<td>2015</td>
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Open Lectures for Local Residents
- Every year in July and during the International Toki Conference, two academic lectures are given for city residents.
- Showing panels and LHD model at NINS Symposium

Release of information by Mailing Lists
- “Mail News”: release of event information in accordance with holding period (registered number: 1,157)
- “Mail Magazine”: research activities of NIFS disseminated twice a month (registered number: 361)

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.

Release of Information to Public (3)

Educational contributions
- Educational partnership activities of Super Science High School (SSH):
  22 high schools, 809 students participated.
- Visiting lectures: 7 high schools
- Internship programs for junior-high school, high school and technical college students:
  7 schools, 21 students

Press Release
- 10 times in FY2013
- Providing news to Japan Science and Technology Agency (JST) Science Portal, Science Media Center of Japan, The American Association for the Advancement of Science (AAAS) “Eurek Alert!” both at home and abroad.
(3) Is the importance of fusion research and its safety being widely disseminated in society?

1. Open campus has been held every year since 1998, showing the NIFS research activities, and the participant is over 2,000.

2. “Fusion Festa in Tokyo” has been held every year since 2010, for showing the importance of the fusion energy development widely to public people, and the participant is over 2,100.

3. Open academic lectures are given for city residents twice a year.

4. NIFS research activities are disseminated as a “Mail Magazine” twice a month.

5. Super Science High School (SSH) activities and the internship programs for students should contribute to public science education.

6. These activities, as well as the frequent press releases, contribute to wide dissemination of the importance of fusion research in society.
## Results of the Evaluation through the 2014 External Evaluation of the “Deuterium Experiment Implementation Plan”

<table>
<thead>
<tr>
<th>Items</th>
<th>(1)Implementation system to conduct research plan and to manage safety</th>
<th>(2)Research plan to heighten academic value</th>
<th>(3)System for joint research and joint use</th>
<th>(2)Maintenance of equipment and facilities</th>
<th>(3)Preparation system and maintenance system</th>
<th>(3)Fundamental way of thinking for safety management</th>
<th>(3)Plan of safety-related equipment and facilities</th>
<th>(3)Appropriate formulation of regulations</th>
<th>(3)Appropriate formulation of manuals</th>
<th>(3)Appropriate formulation of organization and system</th>
<th>(2)Education and training, and nurturing of personnel in charge of safety</th>
<th>(4)Enhancement of understanding and the importance and the safety of fusion research toward it</th>
<th>(4)Coordination with local governments and promotion of safety and safety education</th>
<th>Number of persons</th>
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<td>Avg.</td>
<td>4.32</td>
<td>4.11</td>
<td>4.26</td>
<td>4.26</td>
<td>4.42</td>
<td>4.06</td>
<td>4.32</td>
<td>4.00</td>
<td>3.89</td>
<td>4.05</td>
<td>4.37</td>
<td>4.63</td>
<td>4.53</td>
<td>4.42</td>
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### Evaluation Response Table

<table>
<thead>
<tr>
<th>Points for Evaluation</th>
<th>S</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluation Response Table</td>
<td>Evaluate extremely high</td>
<td>5</td>
<td>Evaluate highly</td>
<td>4</td>
<td>Praised</td>
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※ The evaluation results combine the results from the members based in Japan and the members based abroad. As there are committee members who did not respond to all items, the number of responses differs for each item.

## Points for Evaluation

### (Research Plan)

1. Are the purposes of the deuterium experiment appropriate? Further, is this a research plan that will achieve its goals and an implementation system that will protect safety?

2. Is this a plan that will contribute to advancing our comprehensive understanding of toroidal plasmas and that will heighten the academic value toward achieving fusion?

3. Is this a plan that upon implementation will develop a system for joint use and joint research that enables the participation of a wide range of researchers?

### (Deuterium Experiment Preparation System)

1. Aiming toward the start of the deuterium experiment in 2016, is this plan appropriate for the preparation of equipment and facilities?

2. Is the preparation system leading toward the start of the deuterium experiment appropriate? Is the preparation of facilities and instruments including safety equipment advancing appropriately?

### (Safety Management Plan)

1. Is the fundamental way of thinking regarding safety management appropriate for the formulation of a deuterium experiment implementation plan that considers the opinions of local residents?

2. Will the safety management instruments and the equipment, and the experiment equipment be appropriately planned to safely perform the deuterium experiment and be appropriately planned for operation and maintenance?

3. In order to safely accomplish the deuterium experiment, are regulations being appropriately formulated?

4. Are the operation manual, the radiation management manual, and the emergency manual being appropriately formulated?

5. Are the organization of and the system for safety management upon the implementation of the deuterium experiment being appropriately constructed?

6. Are education and training for the safe performance of the deuterium experiment and the nurturing of the person in charge for safety management being appropriately planned?

### (Society and Understanding)

1. Toward local residents, is enhancement of their understanding of the safety of the deuterium experiment being appropriately advanced?

2. Is communication with local governments being planned in promoting the deuterium experiment plan?

3. Is the importance and the safety of fusion research being spread widely throughout society?
Average Score by Evaluation Item

**Average Score per Item**

- **1.00** to **5.00**

<table>
<thead>
<tr>
<th>Evaluation Item</th>
<th>Avg. Score</th>
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<tbody>
<tr>
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<td>4.32</td>
</tr>
<tr>
<td>[2] Research plan to heighten academic value</td>
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</tr>
<tr>
<td>[4] Preparation system and maintenance system</td>
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<tr>
<td>[6] Plan of safety-related equipment and facilities</td>
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<tr>
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<tr>
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<td>[9] Education and training, and nurturing of persons in charge of safety</td>
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<tr>
<td>[12] Maintenance of equipment and facilities</td>
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<td>[13] System for joint research and joint use</td>
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**Average Score by Evaluation Item**

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