Fusion in the Context of Future Energy Sources

Fusion Power Associates

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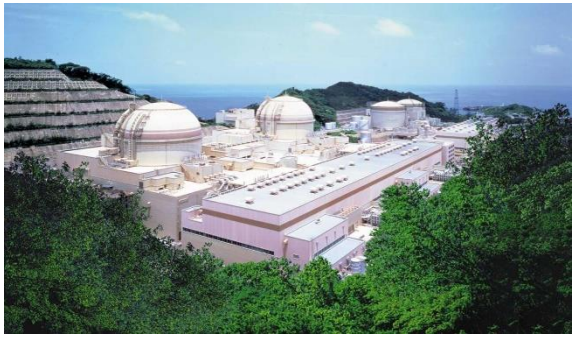
What are necessary conditions for the sustainable development of the world?

They include less CO_2 emission, a culture of Nuclear Safety, an abundance of fuel, recycling of the material, low cost capability, public acceptance, sufficient contributions by private sectors, etc.

These suggest that we are given our life in the world with enough complexity.

Severe environmental destruction is proceeding
Ice of Arctic sea is continuously melting

You must feel some stress



Atomic Plant

This is our ancestors' home. We feel our progress, relief and satisfaction

But if we fail to develop new energy system, our descendants will have to live again

Note; The circulatory system has a larger economic value. The price of the water in a pet-bottle is more expensive than the gasoline

Energy and Environment : A major challenge for the 21st century to realize our sustainable world

Today: ~ 80 % of primary energy comes from fossil resources

Demand for Energy increases from developing countries

But fossil reserves except for coal are low ➔ cost increase

- **Green house gases ➔ big impact on climate**
- **Japanese Satellite 'Ibuki detected that CO_2 concentration exceeded 400ppm in December 2015**

Need to replace fossil sources by renewables, nuclear (fission and fusion) before the end of the century

Renewables cannot do it alone: intermittency / storage

➞ ***This is our common motivation and objective to show the viability of fusion energy to realize our sustainable world, disseminating our successful scientific and technological output***

➞ ***To this end, further understanding of innovative development of Fusion Science and Technology is necessary***

Roles and Functions of Fusion Research

In general; our longtime dream has been to realize that fusion energy is alive, and nowadays, it has become a real target as indicated by worldwide investments and the progress of the ITER project

- **Achieving long-term integration of physics and engineering necessary for energy development**
- **Promoting the development of research that follows the critical path**
- **Securing the basic sciences and supporting technologies necessary for fusion research**
- **Continually disseminating scientific results and leading the development of advanced science and technology in the field of nuclear fusion**
- **Steadily training necessary human resources**
- **Convince world leaders to have a long-ranged view for the Future Energy Mix for the sustainable development of the World**

Our Dream is Alive
Now Fusion Energy is an Achievable Goal!

ITER is now 10 years old

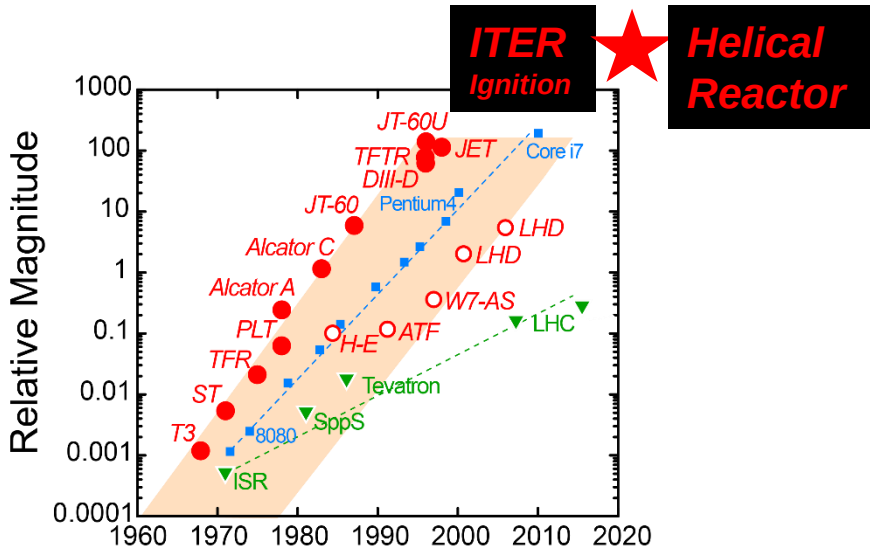
From ITER Newsline October/ITER Communication

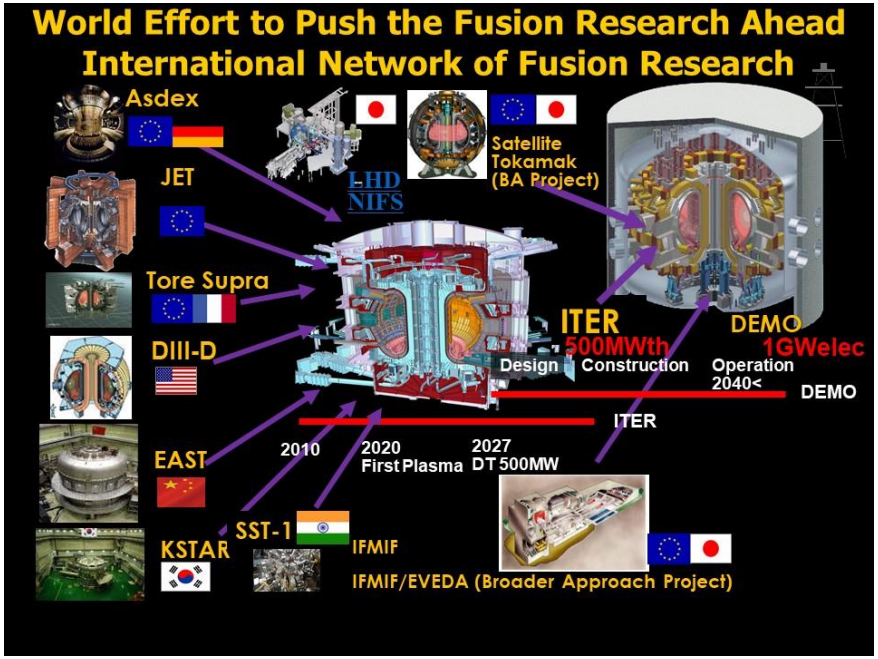
Director-General Nominee Kaname Ikeda (left) and his second-in-command Norbert Holtkamp unveil the ITER Organization plaque at the entrance of the prefabricated building that already accommodated 170 ''ITER people.'' in the fall of 2007

The ITER Organization was established ten years ago, on 24 October 2007. A week ahead of the official anniversary, part of the ITER staff, now numbering 800, gathered for a "family photo" on the edge of the construction site. Photo: Gérard Lesenechal

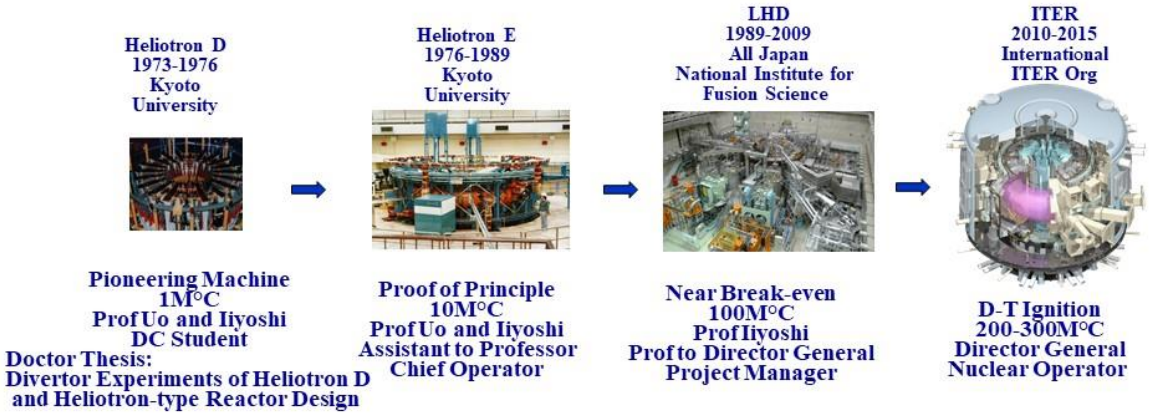
Puy d'amour bakery in Puyricard

Noriko





My Small Personal History of Fusion Research



I am very glad to extend my charrier of a researcher together with Fusion's constant progress.

I would like to thank all of my colleagues and collaborators in this opportunity

Since the ITER project will clarify a future direction of fusion research and development after its successful demonstration of 500MW thermal output showing the viability of fusion energy, achievements of longtime public investment will generate more interest from the private sector, i.e., energy industries and the world economics. We should recognize this fact more positively

In this context; I make note of two points:

1) **It is necessary to always have our widespread views, and try not to fall into science's deflation spiral**
2) **Therefore it is necessary to promote more interest in the non-Tokamak line to increase the robustness of the fusion development.**
3) **A good example is the Stellarator/Heliotron research. Recently Stellarator/ Heliotron devices have entered into a new era. The W7-X device conducted its first operation, and the LHD device started D-D experiments, which extend the capabilities of the Stellarator/ Heliotron concepts. They will demonstrate the plasma capability of Q=0.1-1.0, playing a role to complement the ITER non-oriented regime, such as Broader Approach (BA) among Japan and EU (IFMIF-EVEDA, JT-60SA). Therefore, we should not forget the excellent Property of Stellarator/Heliotron**

In other words;

Economics theory defines that the deflation spiral is caused by the price adhesion; as a simple example, when people buy goods at a cost of $95 by paying with a $100 bill, they do not spend the $5 change. As a result the economy slows down

The same risk exists for science; i.e., the subject adhesion occurs and the function of the research community starts to self-organize for itself

How to avoid this?

1) **We should keep practicing self-assessment. If not, as our fusion research is reaching a more mature phase, this could unfortunately result in a deflation spiral in our science**

2) **Otherwise at the end of deflation spiral, the research community might face the moratorium, and the forced restructuring might happen inevitably**

3) **As stakeholders, we should begin preparing for this restructuring, if we wish to stay on our successful track**

In this context, it is clear that the ITER project should be concentrating their efforts all around the world to avoid the moratorium of fusion research

World Wide Fusion Research by Stellarator/Heliotrons

Theory and theorists play an important role

Note:

- **<u>Strong competition</u> exists among fusion community and against other areas of physics, which is the destiny of the most advanced sciences**
- **Required a necessary and consistent high level of <u>originality</u>**
- **<u>Effective decision making</u> with a long ranged view**

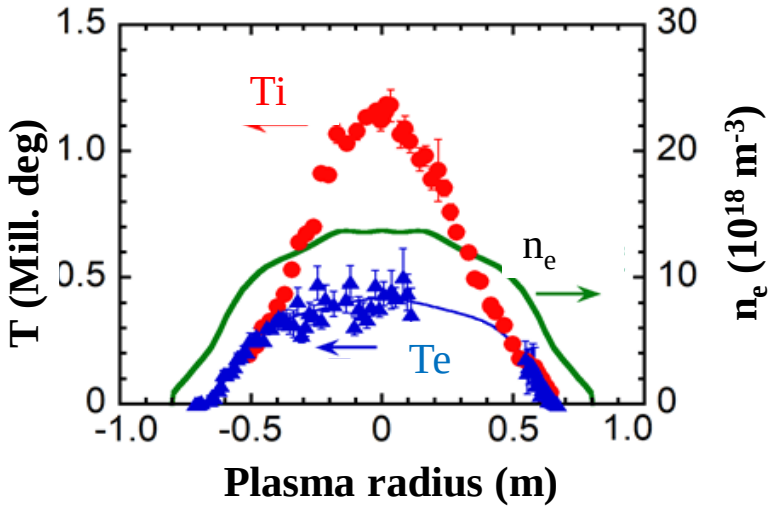
21st International Stellarator-Heliotron Workshop (ISHW2017) October 2nd-6th, 2017, Kyoto, Japan

- "Overview of Initial Results of LHD Deuterium Experiment", T. Morisaki (NIFS)
  - Ion temperature, T_i =10 keV has been achieved in deuterium experiment
- "Results from first operation and outlook for future performance in W7-X", T. Sunn Pedersen (IPP-Greifswald),
  - T_e = 8 keV, τ_E = 100 msec has been achieved at $n_e = 4.5 \times 10^{19}$ m^{-3}
- "Recent Results from HSX and New Directions", D. Anderson (Univ. Wisconsin)
  - Reduction of viscosity and heat/particle transport was demonstrated in a quasi-helical symmetry configuration of the HSX device
- "Study on isotope effect has been reported by some researchers"
  - M. Nakata (NIFS) , U. Losada (CIEMAT), S. Ohshima (Kyoto Univ.)

❑ **Progress was made on configuration optimization from the viewpoint of not only NC transport and MHD stability but also turbulence**

151 Participants, 13 countries

First DD Plasma7 March 2017



Achievement of Ti=10keV in LHD

The Four Excellent Properties of Stellarator/Heliotron

- **Steady State (Intrinsically)**
- **Plasma Current-less or Minimized Plasma Current**
- **Built-in Divertor**
- **No- or High Density limit**

Rotational transform was invented by Prof. Lyman Spitzer, Jr., PPPL in 1951 by the Figure 8 Stellarator

These are well highlighted as the major mission by the present day big project LHD and W-7X

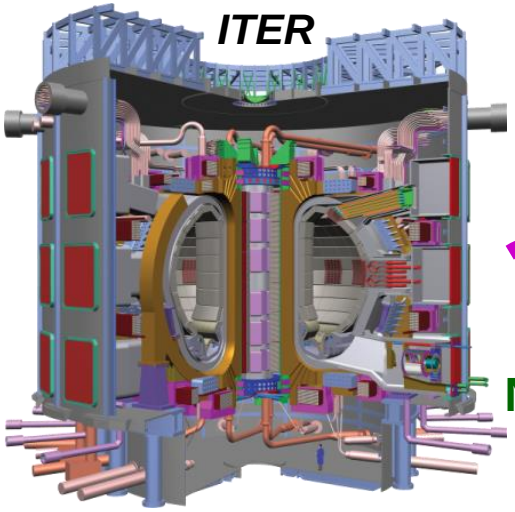
At the same time, these are shared by or illustrated as the major challenges of ITER which must be overcome for its success (Current-Disruption, Steady Operation, ELM Control, Mitigation of Divertor Heat-flux etc)

Nowadays, the Stellarator/Heliotron line is establishing its own roadmap to DEMO, in which the outputs of the ITER project have been adopted

Roadmap to Heliotron DEMO Reactor

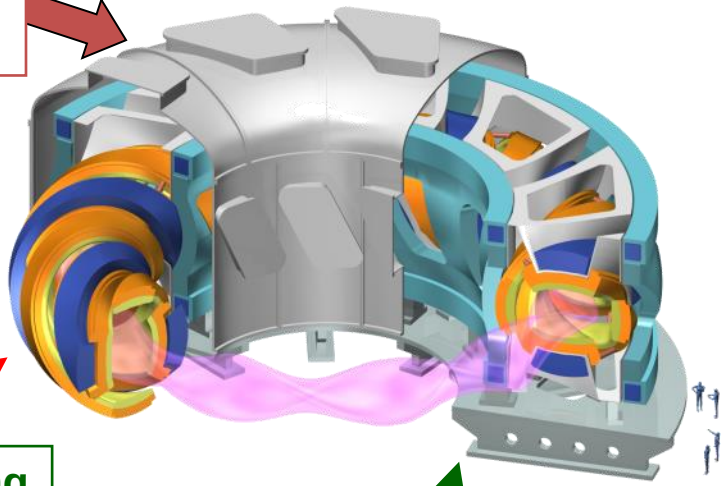
Tokamak Experimental Rector

ITER



SC magnet technology, blankets, and divertor.

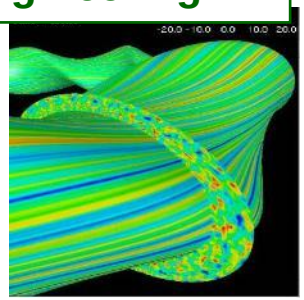
Heliotron Demo Reactor



Physics of burning plasmas

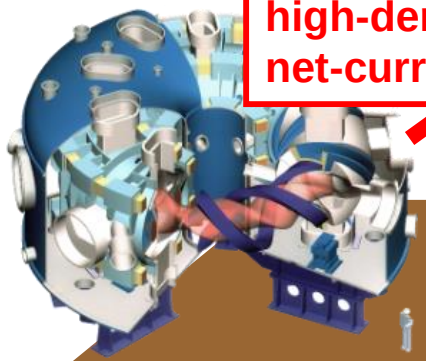
Numerical Test Reactor

Multi-layer models covering physics and engineering



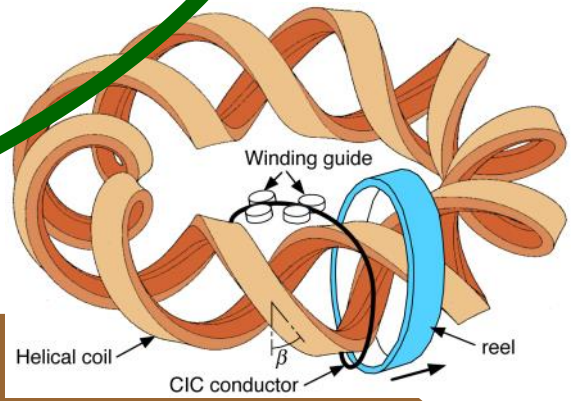
Deuterium experiment

Demonstration of steady-state, high-temperature, high-density, and high-beta by net-current free plasmas



LHD

Helical winding tech.



Basic Science

Next step is to launch the DEMO Reactor Project

- **Develop the ITER generation and move along the roadmap**
- **Maximize the achieved intellectual properties by ITER**
- **Use the expertise in industry and community developed during ITER construction (huge investment, long lead time to rebuild)**
- **Strong industry involvement including substantial prototypes**
- **Near term benefits beyond fusion with enough attractive examples (Spin-off)**

Keys are:

1) To Develop Low Activation Material

2) To Establish Scenario for Heat Removal by Divertor

3) Investment by the Private Sector

Steady promotion of research in the current phase as “Scientific and Technological Feasibility” of the fusion research and development

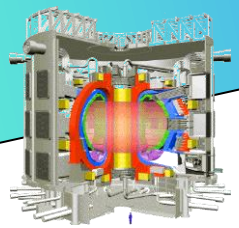
Scientific Feasibility

-To achieve break-even plasma condition

JT-60 (QST)

Scientific & Technological Feasibility

-To realize burning plasma and long-duration burning
-To establish physical and technological basis for DEMO



ITER
(Experimental Reactor)

JT-60SA (QST)

IFMIF

Technological Demonstration & Economic Feasibility

-To demonstrate electric power generation
-To Improve economic efficiency

DEMO Reactor

- 7 Members (EU, JA, CN, IN, KO, RF, US) collaboration
- Demonstrate burning plasma (Q>10, 300-500sec)
- ITER Organization assembles components as in-kind contribution by 7 Members (JA: Toroidal Field Coils etc.)

ITER Project

BA Activities

- EU – Japan Bilateral Collaboration in Japan supporting ITER and DEMO R&D comprising following activities:
  - IFERC (DEMO design and R&D)
  - IFMIF/EVEDA (Engineering Validation for fusion material irradiation facility)
  - Satellite Tokamak Programme (JT-60SA)
- Discussing activities from 2020 onwards

Academic Research

FIREX
(Osaka Univ.)

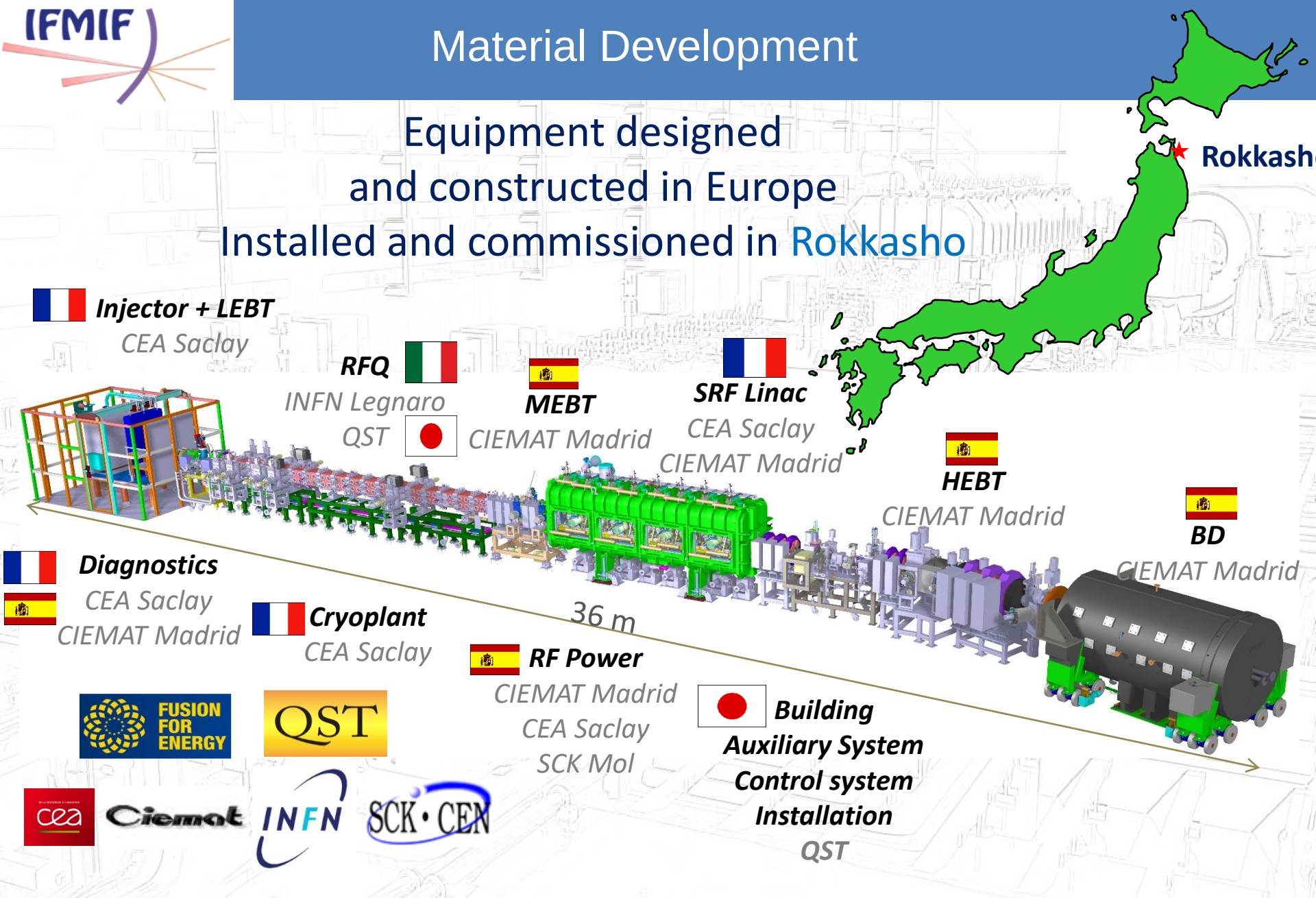
LHD(NIFS)

QST: National Institutes for Quantum and Radiological Science and Technology
NIFS: National Institute for Fusion Science

MEXT MINISTRY OF EDUCATION, CULTURE, SPORTS, SCIENCE AND TECHNOLOGY-JAPAN

Material Development

Equipment designed and constructed in Europe Installed and commissioned in Rokkasho



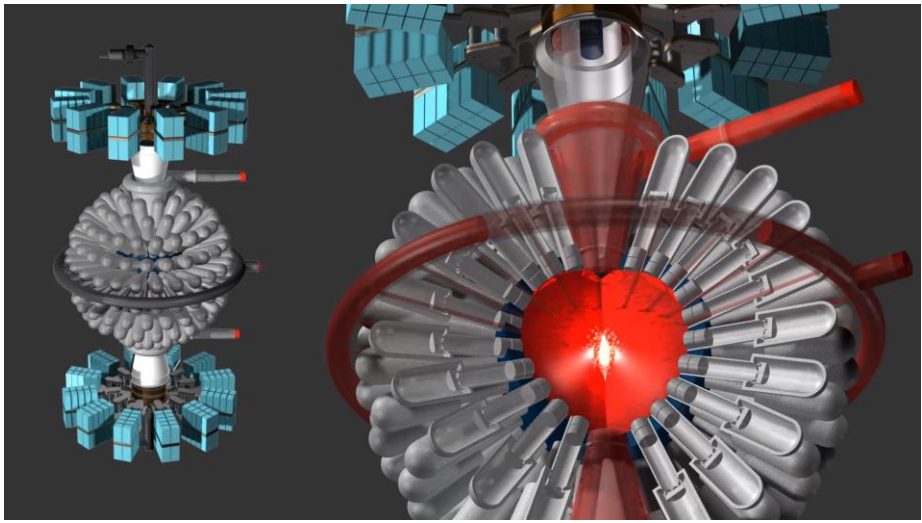
Are we technologically ready? J. Knaster

Typical Activity in Private Sector:
To keep active researches in private sector and develop them to the international or national project level is quite important to realize innovations

Generalfusion

generalfusion

- Founded in 2002, based near Vancouver, Canada
- 70 employees, $100 million in private capital invested
- Magnetized target fusion power plant design would provide a low-cost driver, and eliminate problems of neutron damage
- General Fusion is working to demonstrate the key subsystems and core physics for its technology at full scale



Fusion Energy is New Technology for a New Industry and Business

- **After the success of the ITER project, its positive economic impact will likely surge, and it is expected that stakeholders of the world's fusion research will increase and that new fusion projects will be promoted by private sectors, as well as public sectors**

- **Fusion energy development is passing the turning point, and following the anticipated global crisis towards the end of the 21st century, it is very important to demonstrate its technical feasibility during the decade of 2030 as the prime candidate for energy mix and immediately after to start the construction of Demo-Reactor**

- **It is clear that a sufficient lead time of many years, maybe even decades, is necessary**

World leaders should have a long-range view of this situation

Strong concern of the US withdrawal from the ITER project
My personal opinion

- The history of the fusion research is showing how beautifully the science has matured, and how this maturation has only been made possible with international partnership
- The ITER project is showing that it is becoming a fantastic new tool to show the world how collaborative work contributes to the realization of a new energy source and peace as the ultimate goal
- Our ability to predict and control fusion systems is extraordinary, even as important questions remain
- Though I believe that most of the US fusion community is supporting the ITER, it is necessary to assess correctly the merits and demerits caused by the US withdrawal, which would be a setback not only for fusion, but for all of science for which international partnership is essential
- For me, it looks that there are more demerits;
  - most of other members would remain and continue collaboration
  - US would not participate in the rewards of the ITER success
  - US would lose the opportunity for their scientists, engineer, and other technical staff to participate in this high level international project
- Now all US establishment is necessary to keep supporting the ITER project
- What is now needed is sustained political support, which should be shared by the scientific community

Please take note that the ITER project is more likely "Gemeinschaft" and not "Gesellschaft" especially during the construction phase

Path Forward

Therefore;

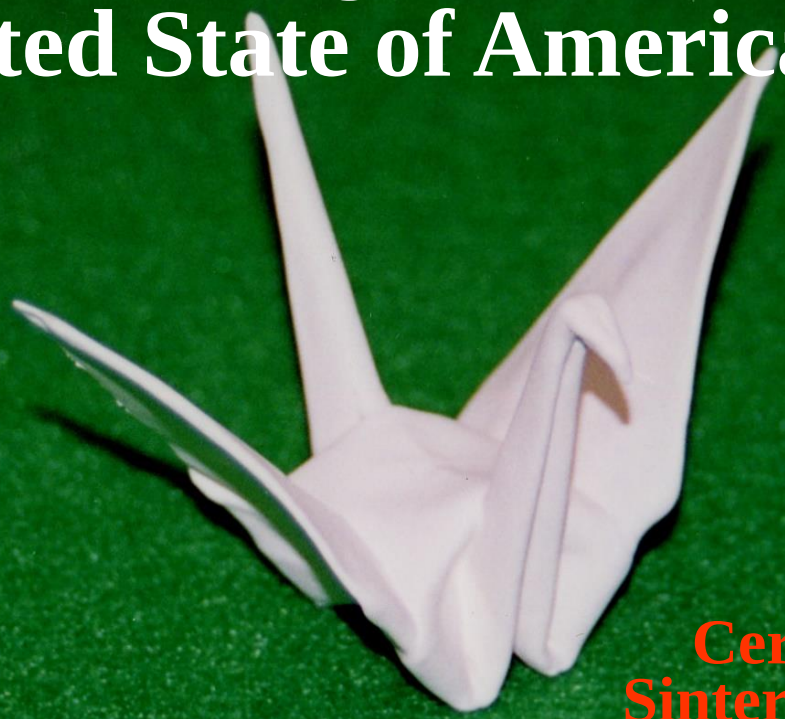
- **The only way is to go forward together. This fact should be understood and shared by all the stakeholders including us here**

- **It needs to be more strongly recognized that in supporting the Fusion Energy Research, especially ITER Project, all the Members have invested a lot of their taxpayers' money**

- **And therefore I would like to reconfirm the importance of fusion research and development, all sharing the responsibility to lead the way to an assured and consolidated success of the project by thoroughly improving its operation and enhancing its efficiency**

- **I have great confidence that fusion energy will attract more and more interest and provide hope for people worldwide. Fusion energy should be one of the most powerful tools to realize zero CO_2 emission to achieve our sustainable world. Fusion research is strongly coupled not only with science, but also with the world economy and environment**

Thank you very much for your attention! I would like to wish the success of fusion research together with United State of America



Ceramic Crane
Sintered with μwave

In our complex world, Peaceful Usage of Nuclear Fusion Energy is keen apart from the world politics!