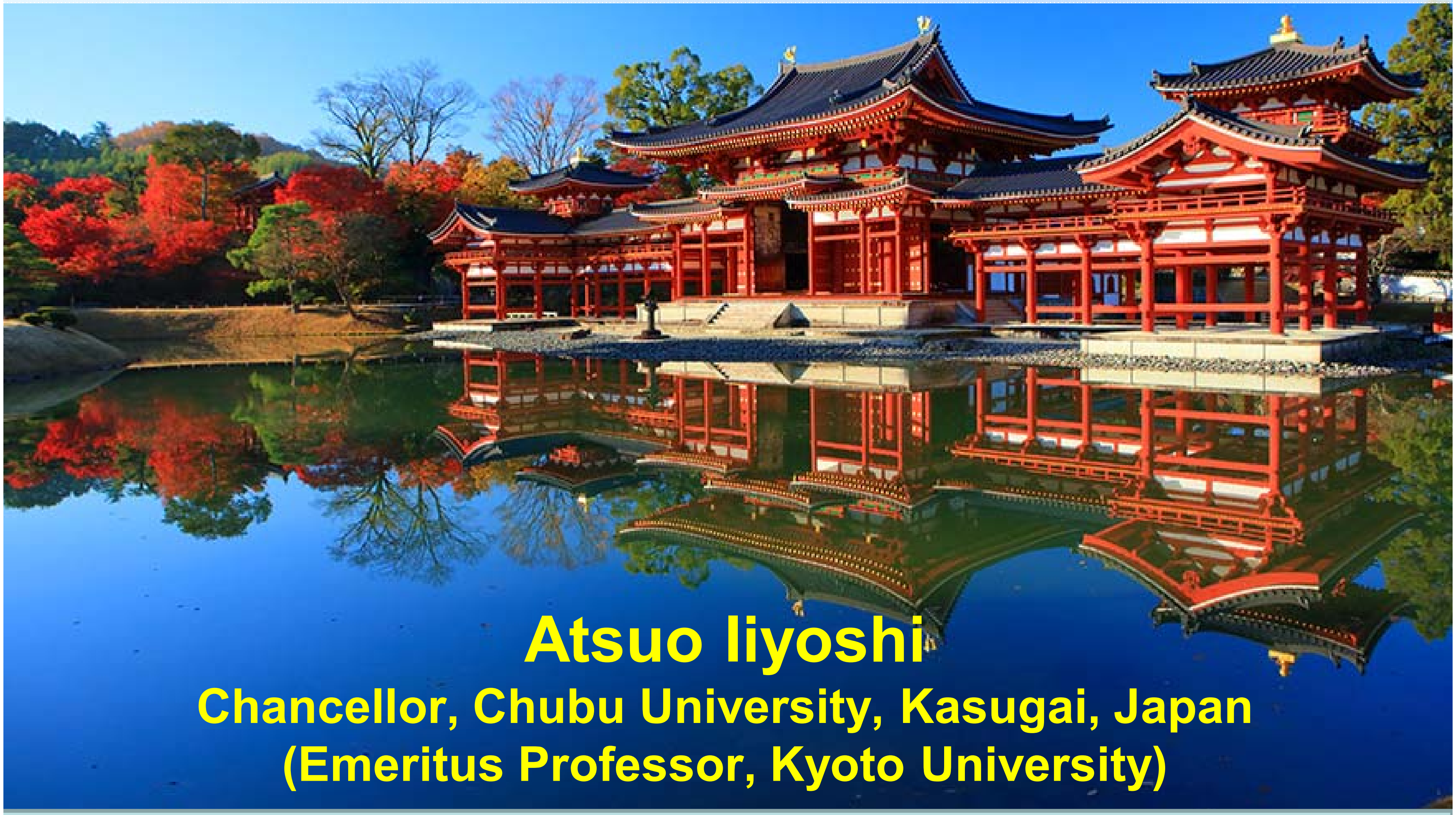
Fusion for Sustainable World Development



Atsuo Iiyoshi

Chancellor, Chubu University, Kasugai, Japan

(Emeritus Professor, Kyoto University)

Byodoin Hoo-do, Uji, Kyoto

The temple close to the Uji-campus of Kyoto University

PHOENIX: A legendary bird believed to burn itself, to revive as a new bird.

Outline

1. Pioneering fusion research at Kyoto Univ.

2. IAEA-FEC held in Japan : 1974 Tokyo, 1986 Kyoto and 1998 Yokohama.

3. Comments on the world fusion research, including ITER.

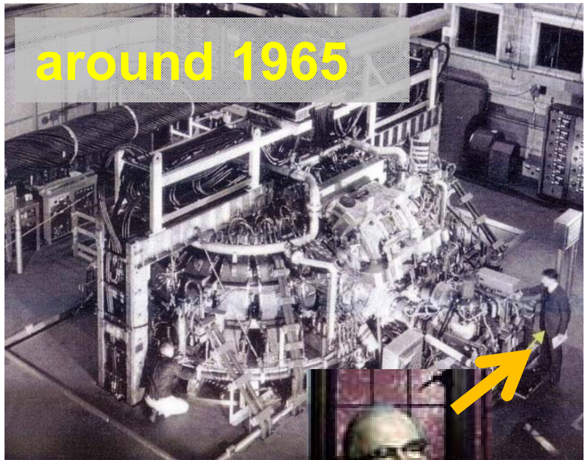
4. Outstanding technical issues for fusion energy development

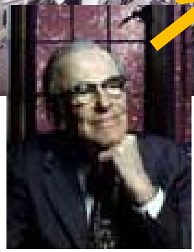
5. Fusion research contribution to sustainable world development

6. Conclusion

Pioneering fusion research at Kyoto Univ.

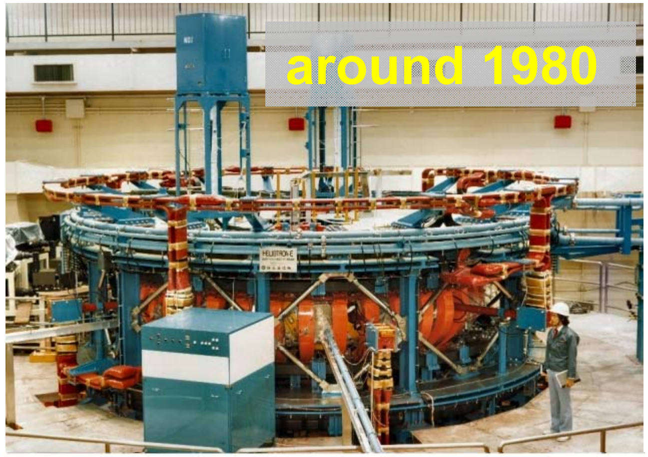
C-Stellarator (Princeton)

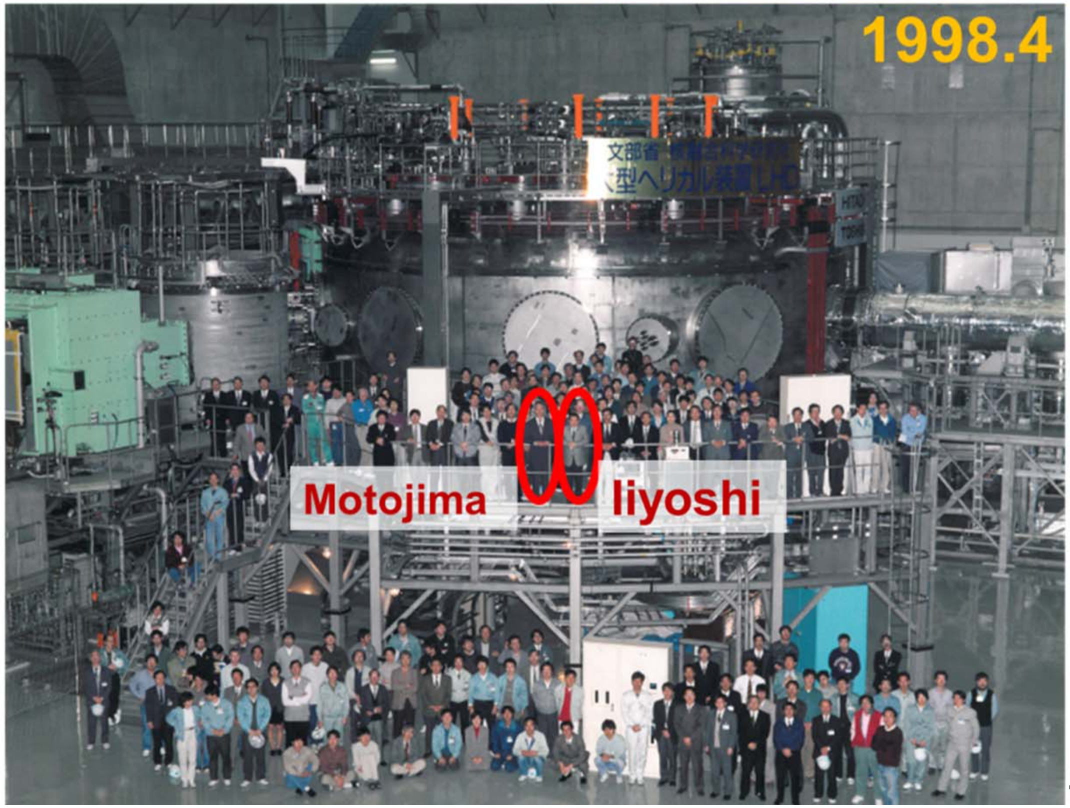




L.Spitzer

Heliotron E (Kyoto Univ.)

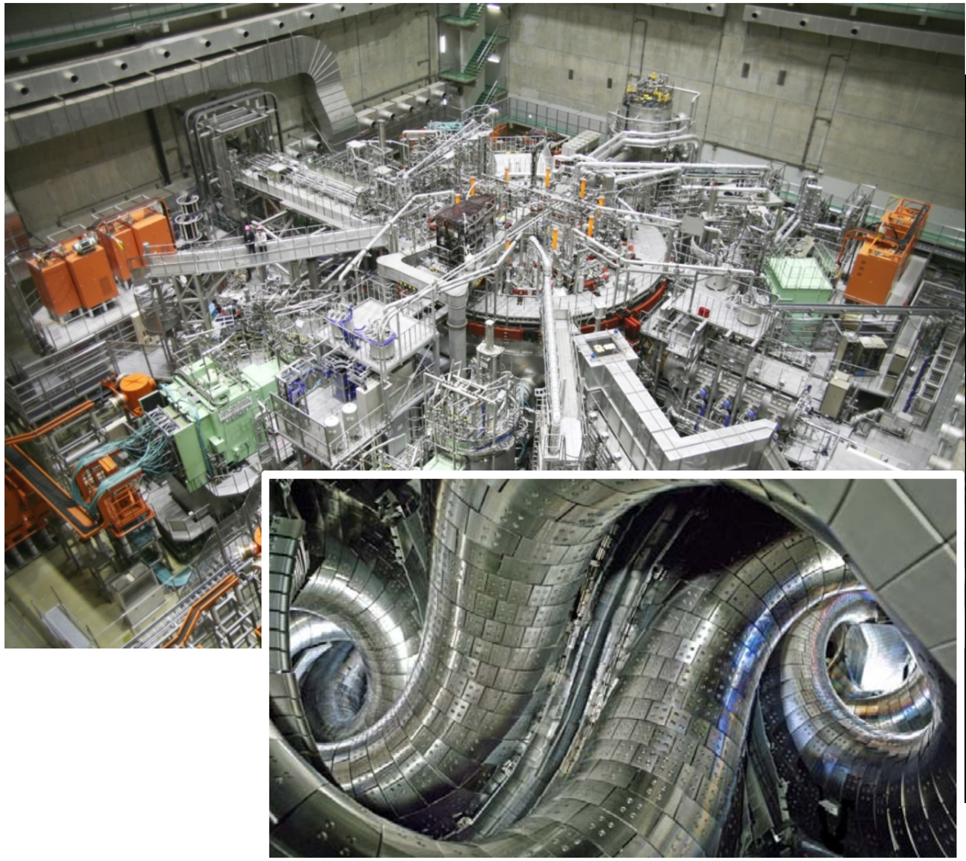




The Large Helical Device (LHD) at NIFS, Toki, Japan

Machine construction and the first plasma production went on time.

Progress in Large Helical Device (LHD) as a steady-state device



- Steady increase in plasma temperature.
- High plasma densities of the order of 10^{21} m^{-3} achieved.
- Steady-state plasma confinement, reaching a total injected energy of 3.4 GJ for a 48 min-long discharge.
- Deuterium experiments will start in March, 2017.

Looking back on the IAEA-FEC in Yokohama, 1998

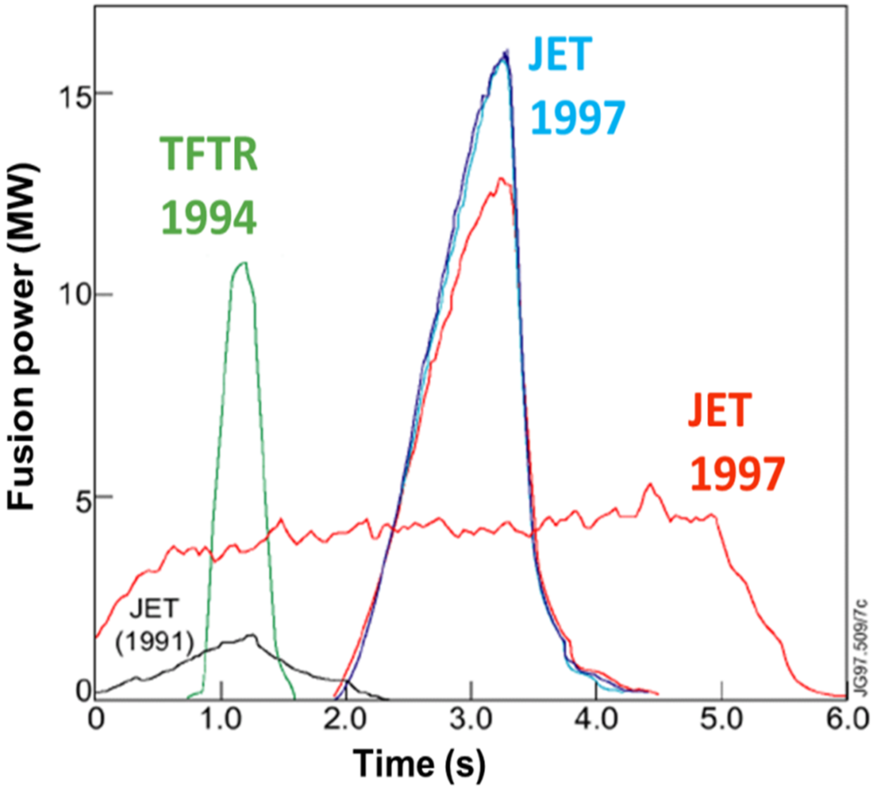
- IAEA-FEC held right after the D-T burning experiments in TFTR and JET.

- At the same time, ITER-EDA approaching a critical stage
  - ✓ Design report concluded on July 1998, based on discussion over the past 6-year output.
  - ✓ 3-yr extension of EDA for the cost reduction to be reported in 2001.

- Also, helical systems research entering a new era of large-device experiments, producing the first plasma in LHD

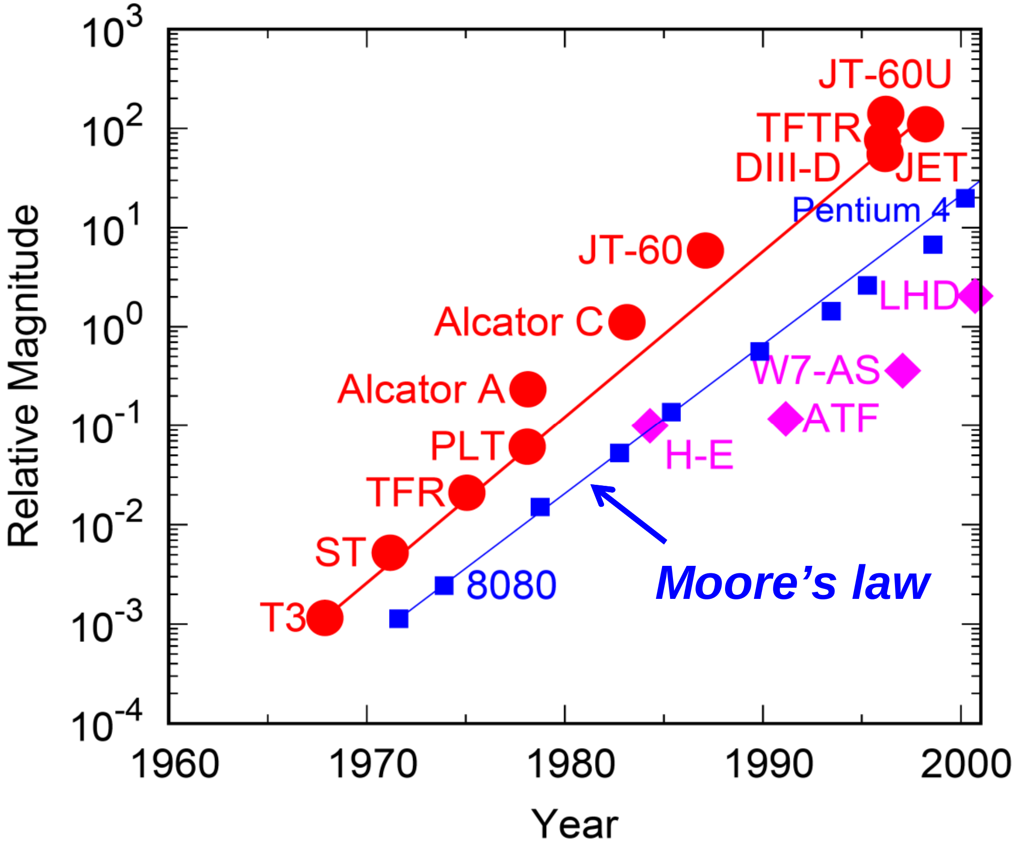
Great achievements

Fusion energy on the Earth: 4-decades after H. Bhaba's statement in Geneva, 1955



J.Jaquinot et al., PPCF 41 (1999) A13

Fusion triple product had grown as fast as *Moore's law*



Construction of ITER in progress

"From ITER Communication"

Official statement for the First Plasma is in December, 2025

A two-year effort by the ITER Organization and the seven Domestic Agencies came to conclusion on 16 June, as the ITER Council officially announced its endorsement of the Resource-Loaded Integrated Schedule for the ITER Project, which identifies the date of the First Plasma production as in December 2025.

- D-T burning in ITER may be further in the future
- 4-decades after D-T experiments in JET and TFTR

Impact of the delay and increased cost in ITER

The delay in ITER project schedule and the increase in construction cost need to be recognized very seriously.

The fusion community needs to make more efforts together to resolve outstanding technical issues, intended to

- Speed up the ITER construction and experimental schedule
- Obtain a fundamental understanding for the D-T burning experiments in ITER
- Appeal to gain more public support for fusion.

In return to the large investment, the development of fusion energy needs to be understood by public as one of the few pathways to enable sustainable world development.

Outstanding technical issues with magnetic fusion

There are still outstanding technical issues including:

- Disruption (tokamaks)
- Edge Localized Mode (ELM) (tokamaks)
- Confinement physics
- Divertor, power and particle handling
- Impurity control
- Materials development (IFMIF, fusion neutron test facility)
- Test blanket module design and development
- Decommissioning
- ………..

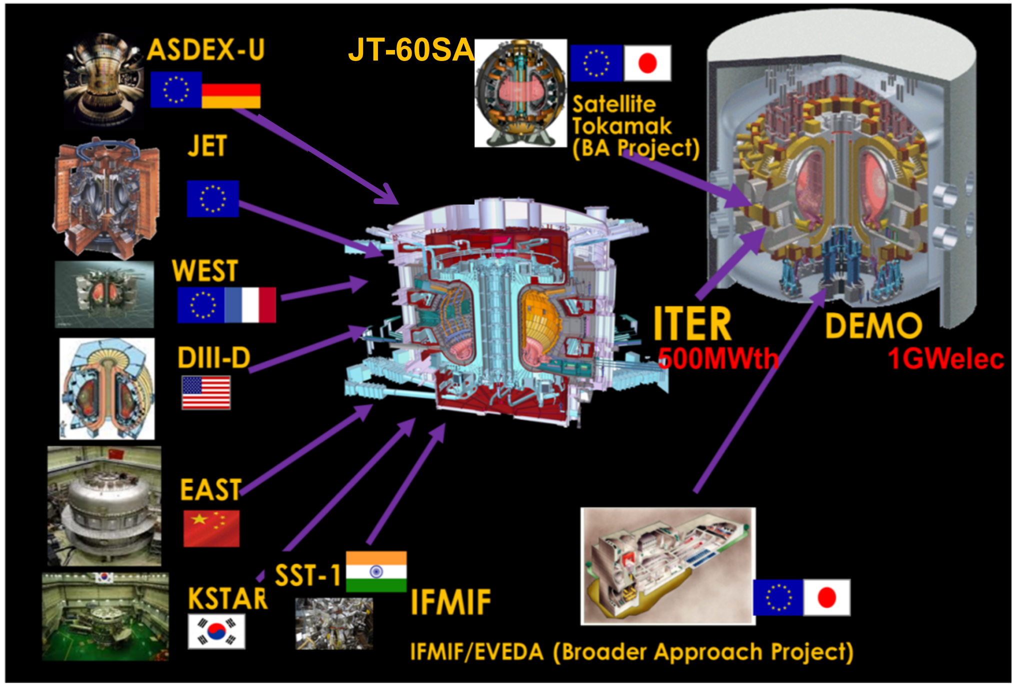
Resolutions of these issues are crucial for the success of ITER.

Recent highlights on tokamak research

A great deal of effort has already been made to resolve outstanding technical issues, more specifically:

- ELM control by the use of a non-symmetric perturbation magnetic field in DIII-D and many other tokamaks
- Tungsten wall experiments in JET and ASDEX-U, based on the prediction that tungsten will be used as the wall material in ITER and DEMO
- WEST and JT-60SA will soon be coming on line
- EAST and KSTAR taking a leading role in the steady state plasma control

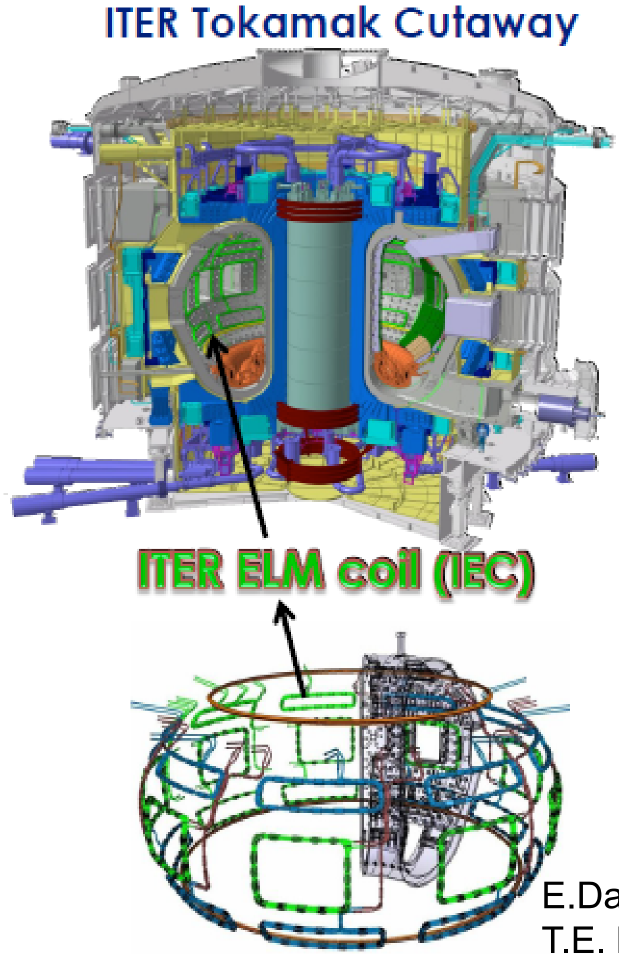
Growing activities in Asia

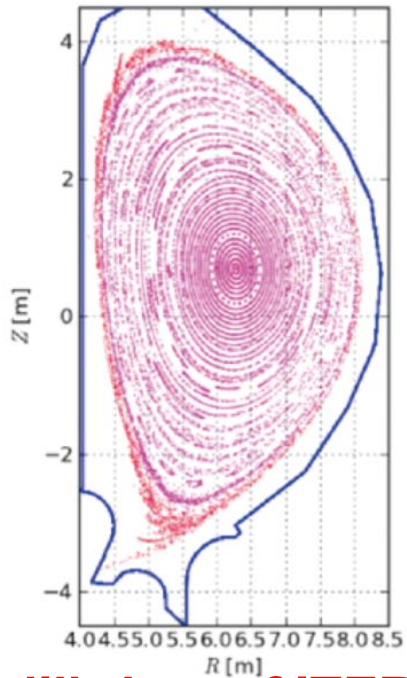


Research synthesis is important

A good example of research synthesis can be found between tokamaks and helical systems

ELM control coil: Resonant magnetic perturbation (RMP) onto an axisymmetric tokamak magnetic field

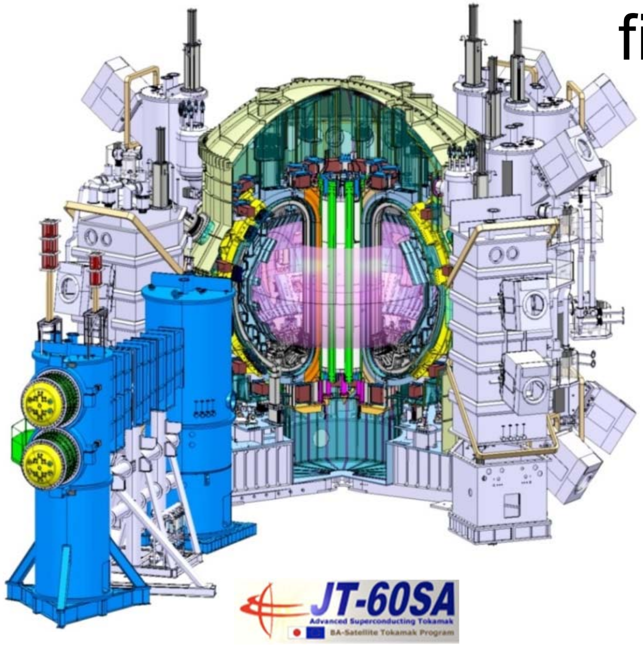




3D equilibrium of ITER plasma
(by HINT2 code, NIFS)

E.Daly et al., Fusion Sci. Tech. 64 (2013) 168.
T.E. Evans et al., Nucl. Fusion 53 (2013) 093029.

JT-60SA is expected to resolve outstanding issues for ITER

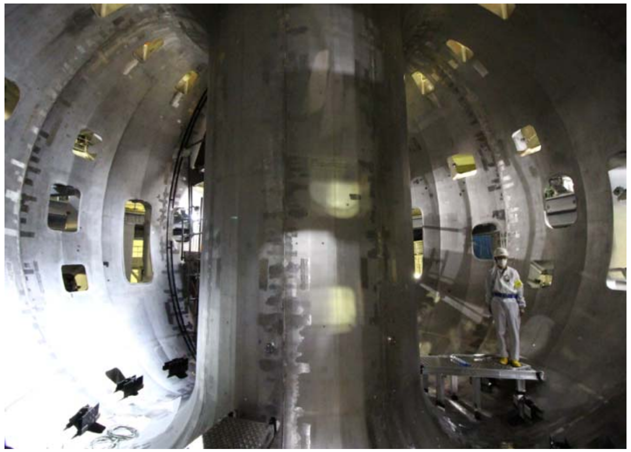


JT-60SA is coming up on schedule for the first plasma production in 2019, so as to:

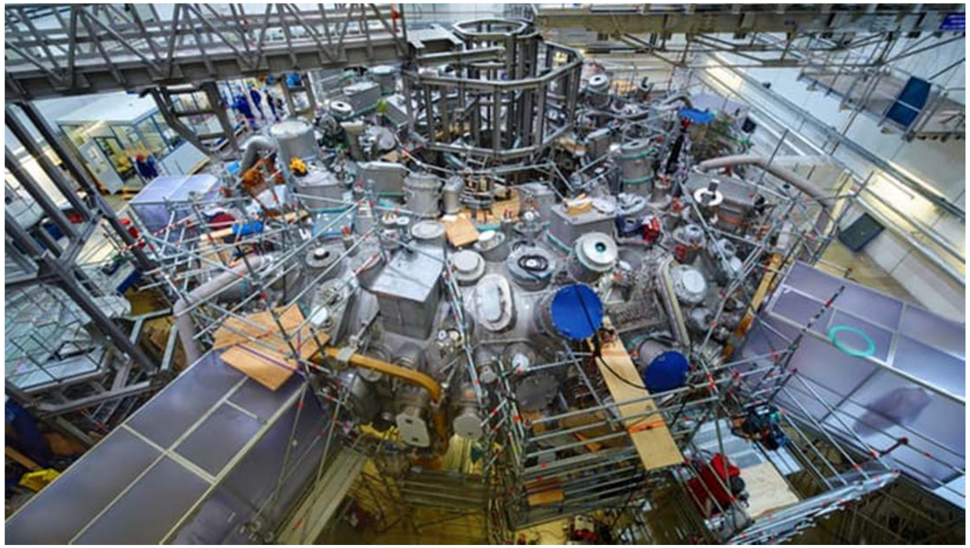
1. Support the ITER project, producing break-even-equivalent high-temperature deuterium plasmas.
2. Complement ITER with long pulse sustainment ~100s of high-pressure steady state plasmas, necessary for DEMO.
3. Train next generation scientists to play leading roles in ITER and beyond.

The first TF Coil completed

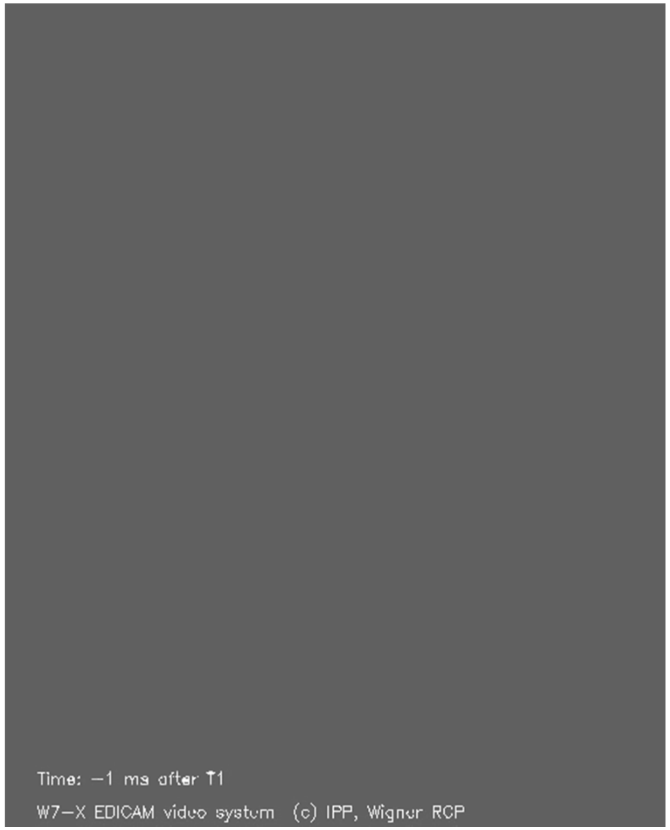
Inside the Vacuum Vessel



The first plasma in Wendelstein 7-X



German Chancellor, Angela Merkel, pushed the button for the first hydrogen plasma on February 3, 2016.



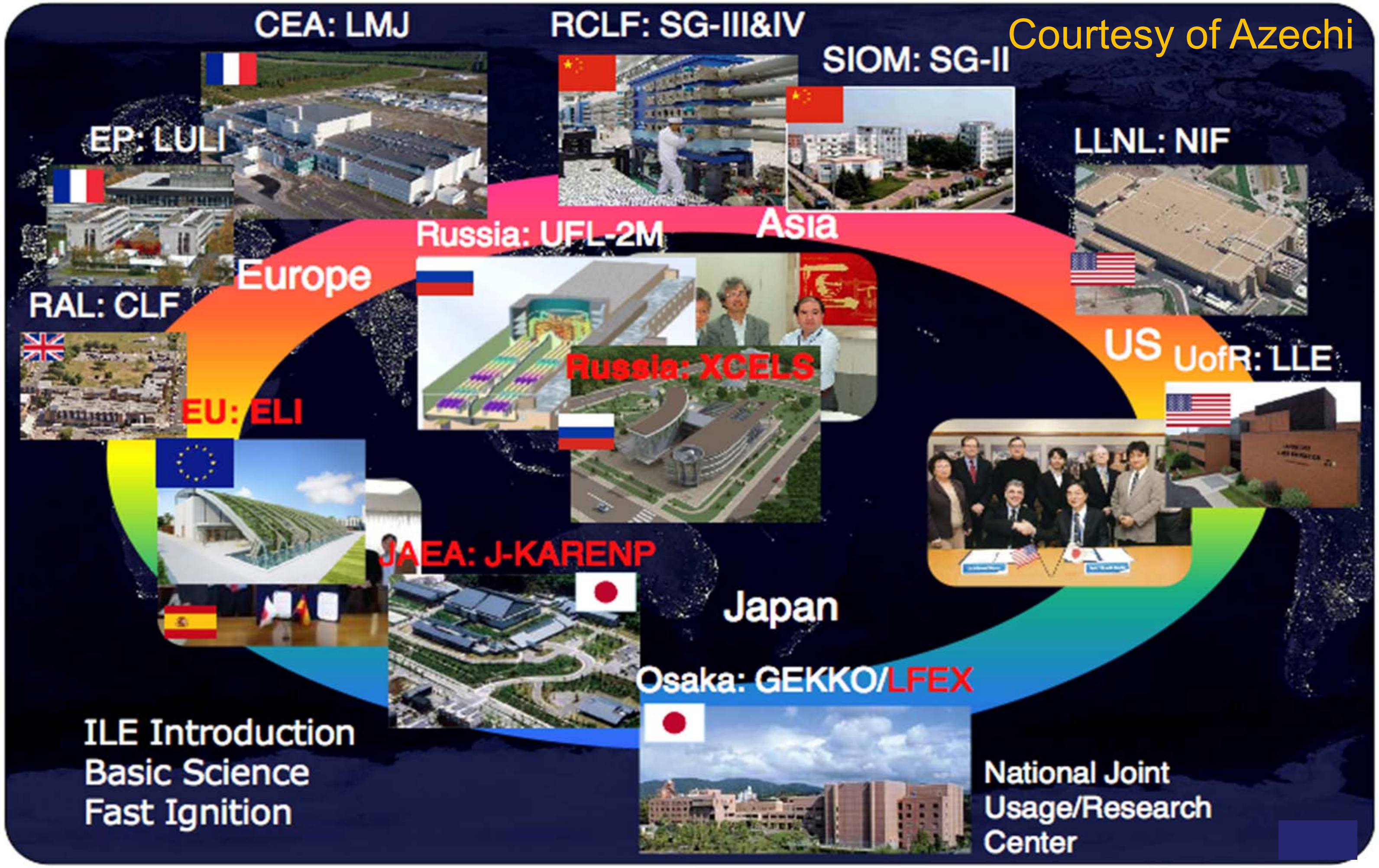
This movie: ~700 ms

©IPP-Greifswald

Nested magnetic surfaces confirmed, and high-*T*e plasmas produced in its first campaign.

World Centers for High Power Laser Research

- With the operation of NIF at LLNL, a large amount of laser energy input for pellet implosions has been achieved towards D-T ignition.
- A great deal of progress on the understanding of implosion physics has been achieved, demonstrating improved efficiencies of D-T burn.



Contribution by fusion research to sustainable world development

- Application of fusion neutrons:

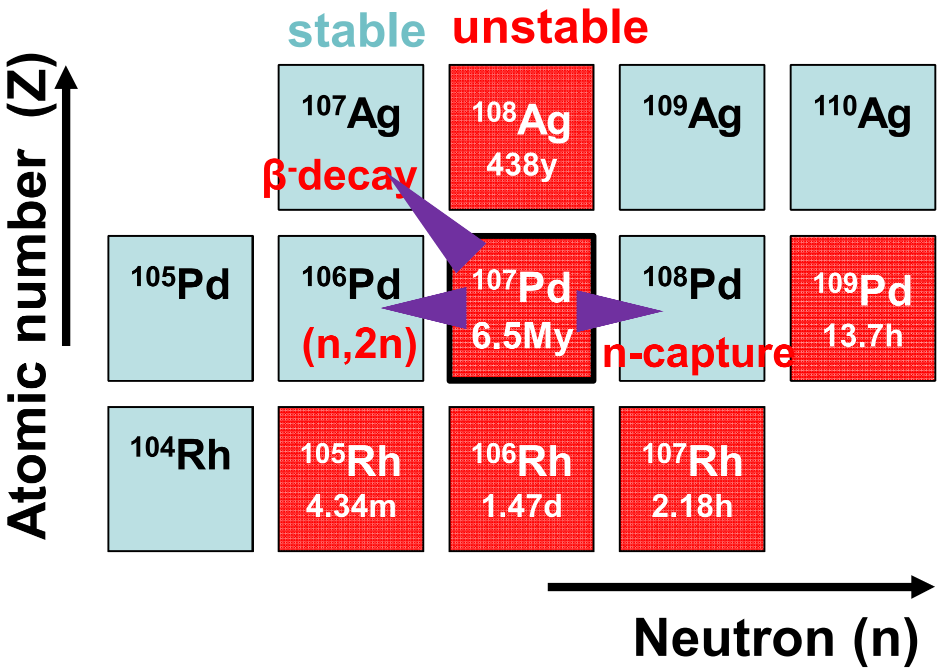
  transmutation of long-lived fission products (LLFP)

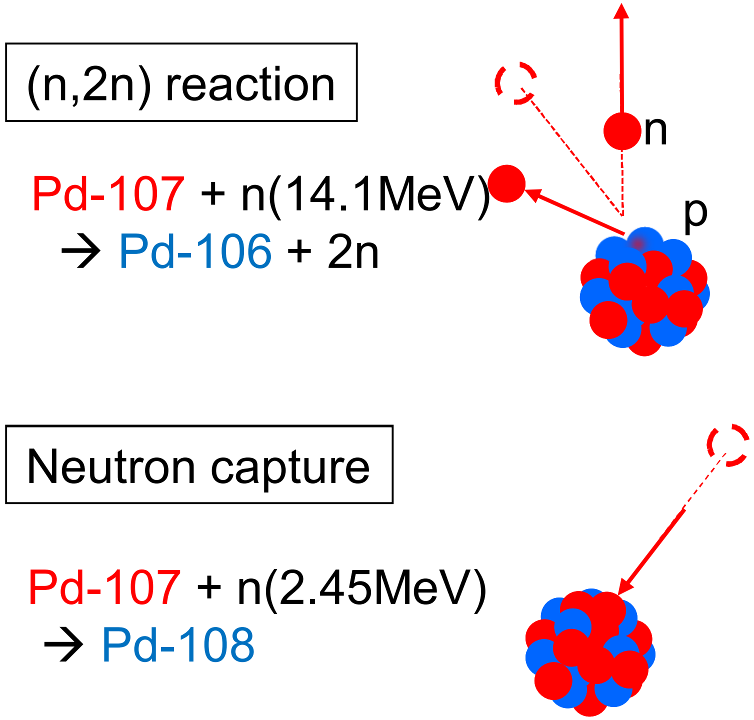
- Application of high-temperature superconducting magnet technologies

Fusion neutrons for the transmutation of LLFPs (long-lived fission products)

CHUBU UNIVERSITY ImPACT report 2015-PM08-05-01
M. Sato et al.,

Mono energy fusion neutron is better for transmutation





A LLFP: Pd-107 with a half life time (β decay) of 6.5 M years can be:

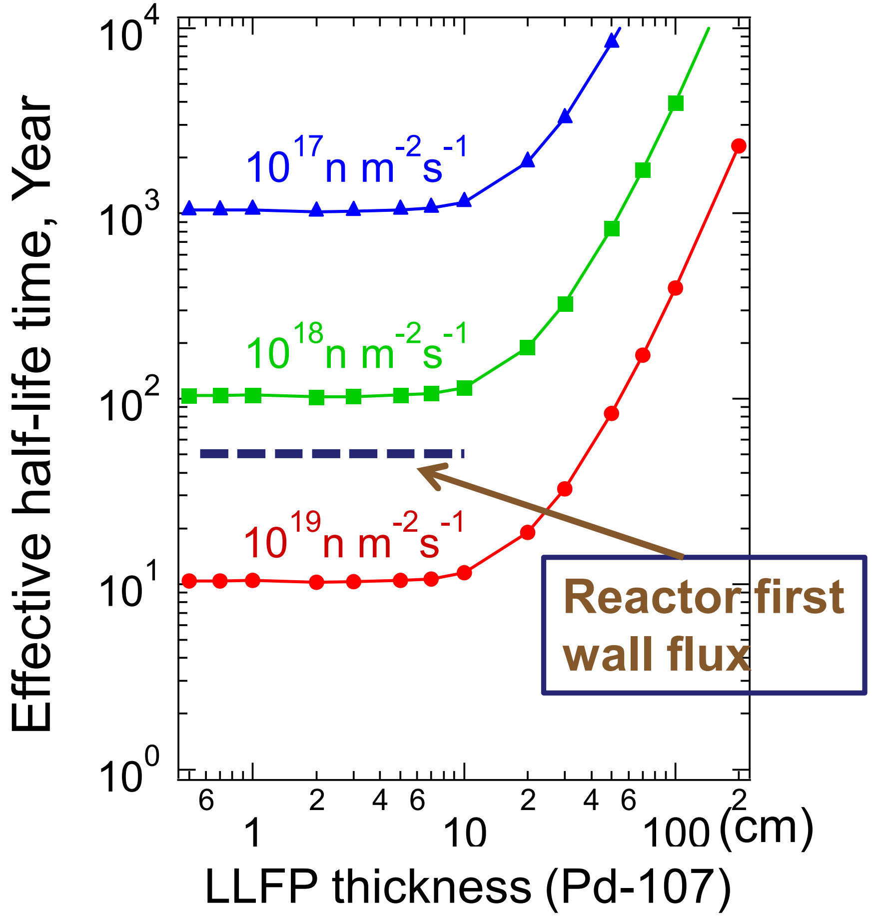
- transmuted into stable Pd-106 by D-T neutrons (14.1 MeV)
- transmuted into stable Pd-108 by D-D neutrons (2.45MeV)

Control over nuclear reactions is possible by the choice of neutron energy.

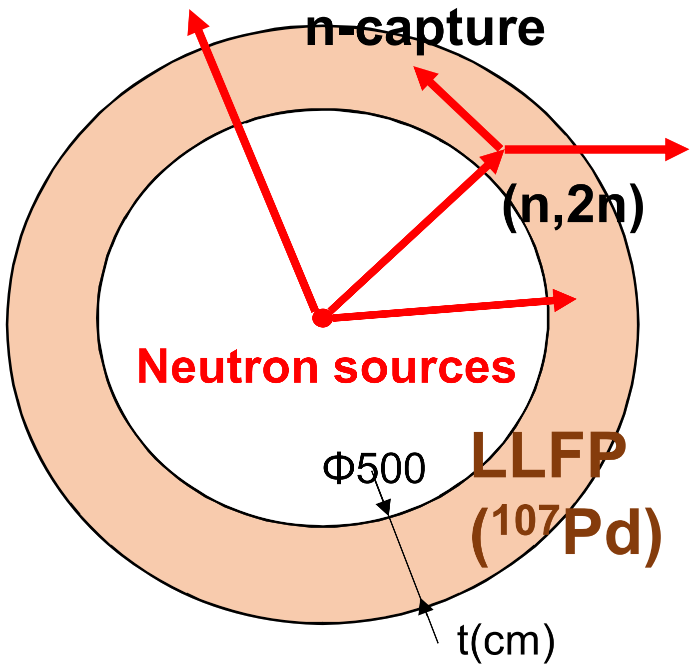
Fusion neutrons for the transmutation of LLFPs (long-lived fission products)

CHUBU UNIVERSITY ImPACT report 2015-PM08-05-01
M. Sato et al.,

Required neutron fluxes to shorten the LLFP life time



PHITS (Monte Carlo code) is applied to a shell geometry of LLFP(^{107}Pd) containing 14.1 MeV neutron sources



D-T neutrons of ~10^{19} n/m^{2}sec can decrease the half-life time of a LLFP to around 10 years

Fusion neutrons for the transmutation of LLFPs (long-lived fission products)

CHUBU UNIVERSITY ImPACT report 2015-PM08-05-01
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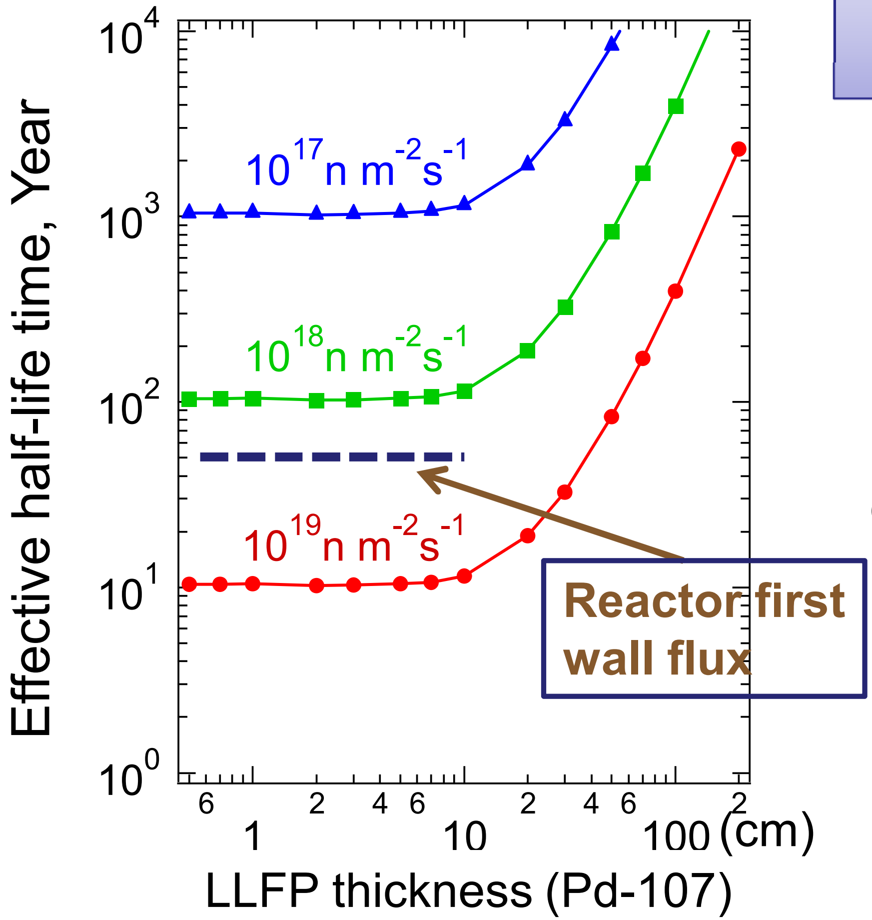
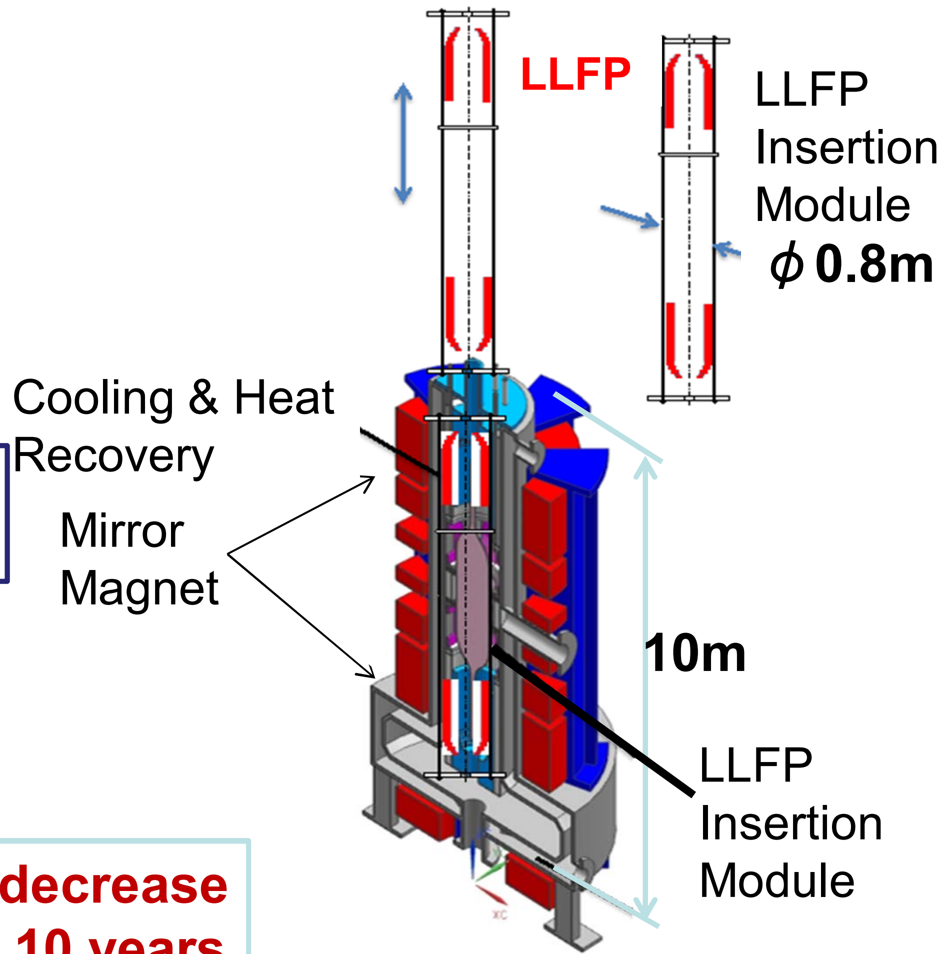
Required neutron fluxes to shorten the LLFP life time



A schematic view of the proposed LLFP transmutation system by the use of fusion neutrons



D-T neutrons of ~10^{19} n/m^{2}sec can decrease the half-life time of a LLFP to around 10 years

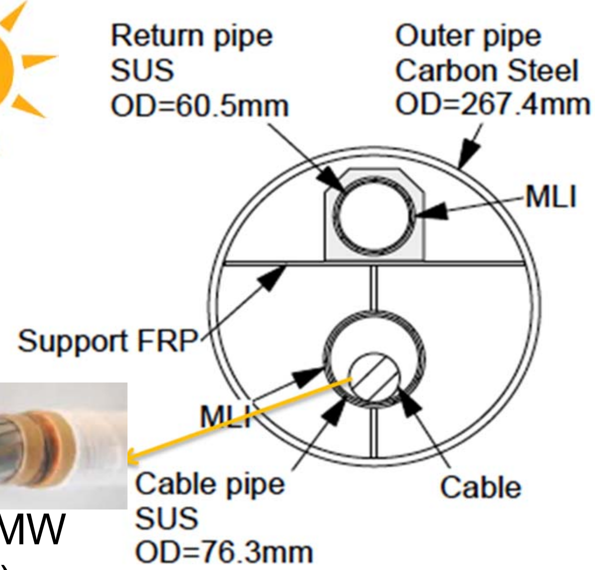
DC Superconducting Power Transmission

Ishikari, Hokkaido

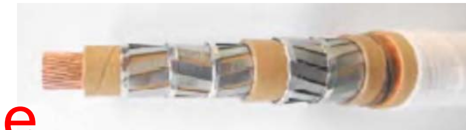
CHUBU UNIVERSITY S. Yamaguchi et al.,

500-meter SC cable

PV panels



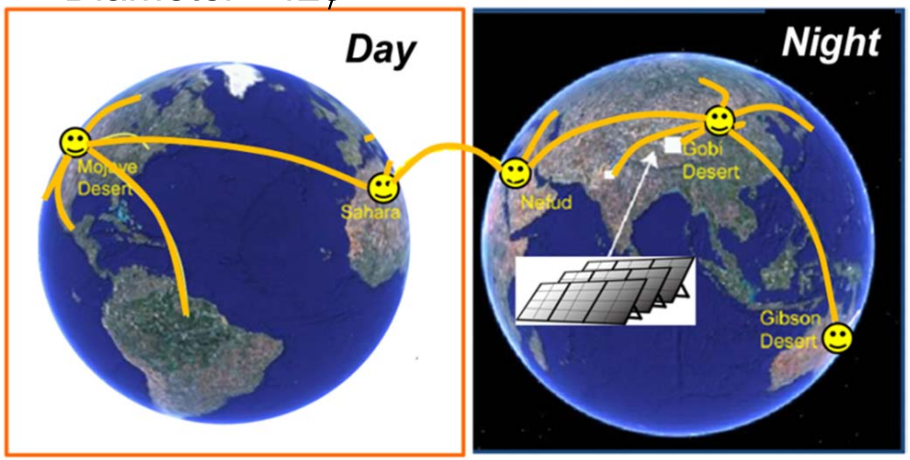
Bi2223 HTS cable@77K



Power Loss of SC cable
~ 1/10 of Copper cable

Power = 100MW
(±10kV, 5kA)
Diameter =42ϕ

SAKURA Internet Data Center



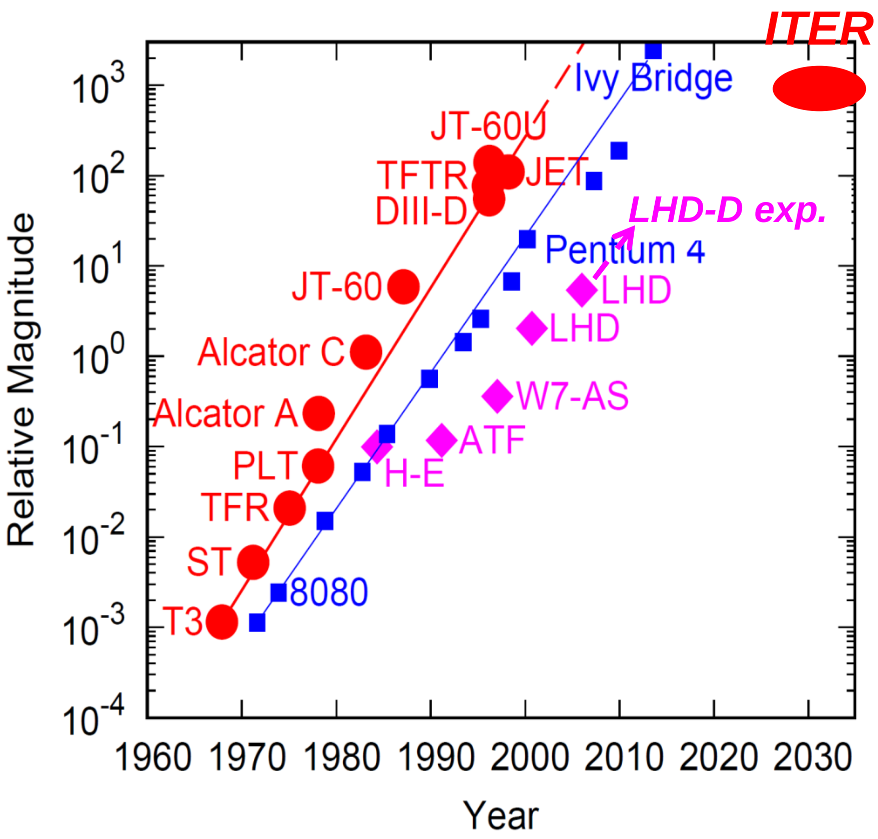
"Energy Super Highway"

Conclusions

- Fusion research has reached a level of technical maturity to build ITER, which, however, does not mean everything is finished successfully. There are still outstanding technical issues.

- Worldwide competitive and collaborative network research is becoming more important for the success of fusion research

- Research synthesis is important to produce new ideas to resolve outstanding technical issues



Conclusions (contd.)

- I would like to encourage next-generation researchers here and all over the world to challenge all the existing technical difficulties.
- In return to the large investment, the contribution to sustainable world development by fusion research is important.
- I sincerely hope that this IAEA Fusion Energy Conference here in Kyoto is landmarked to provide us with an opportunity to bring about new ideas for revitalizing fusion research.

Thank you very much for your attention.