ITER: A Magnetically-Confined Burning Plasma
Integrating Fusion Science and Technology

R.J. Hawryluk
Deputy Director General
Director of the Department for Administration

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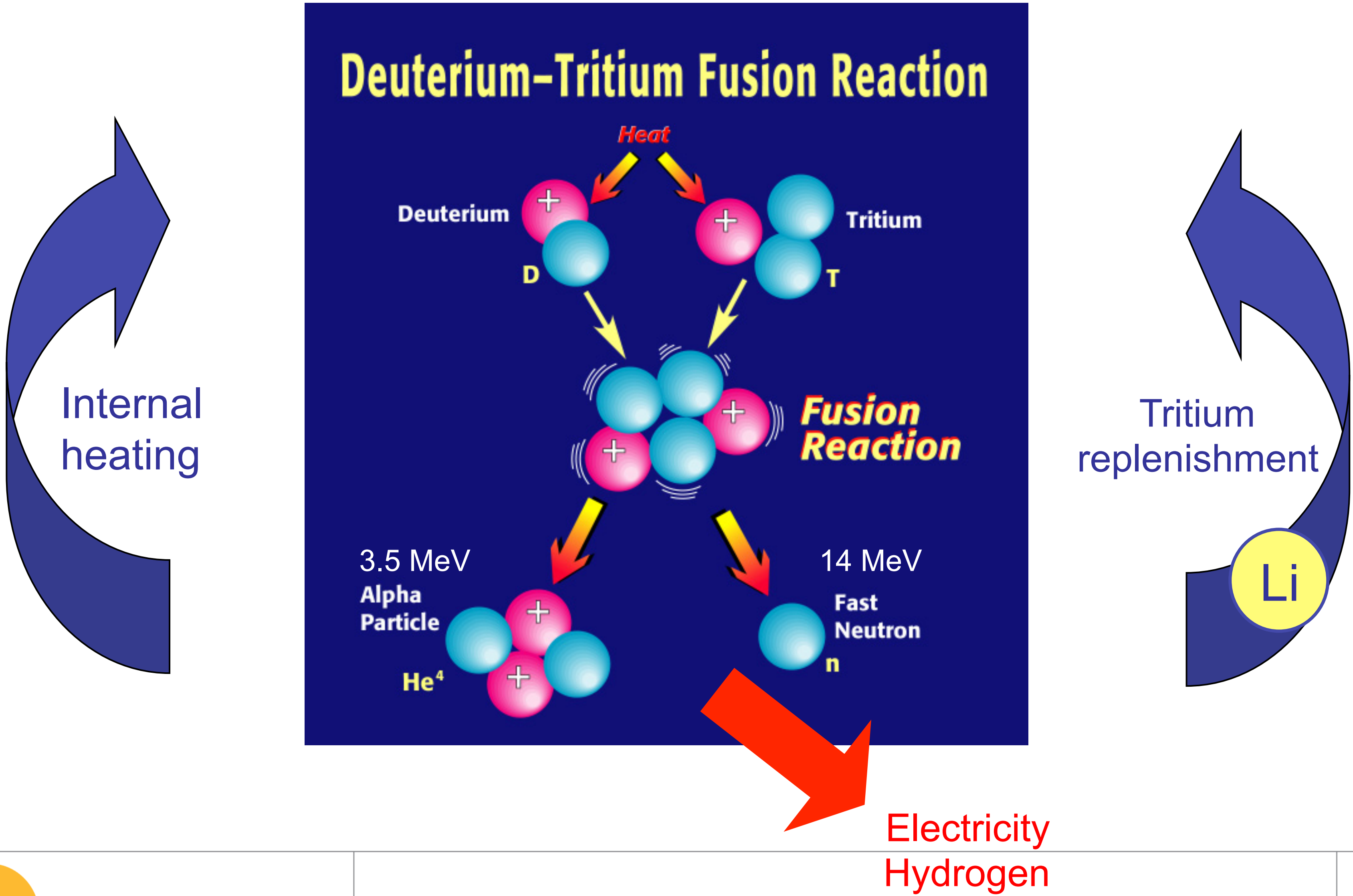
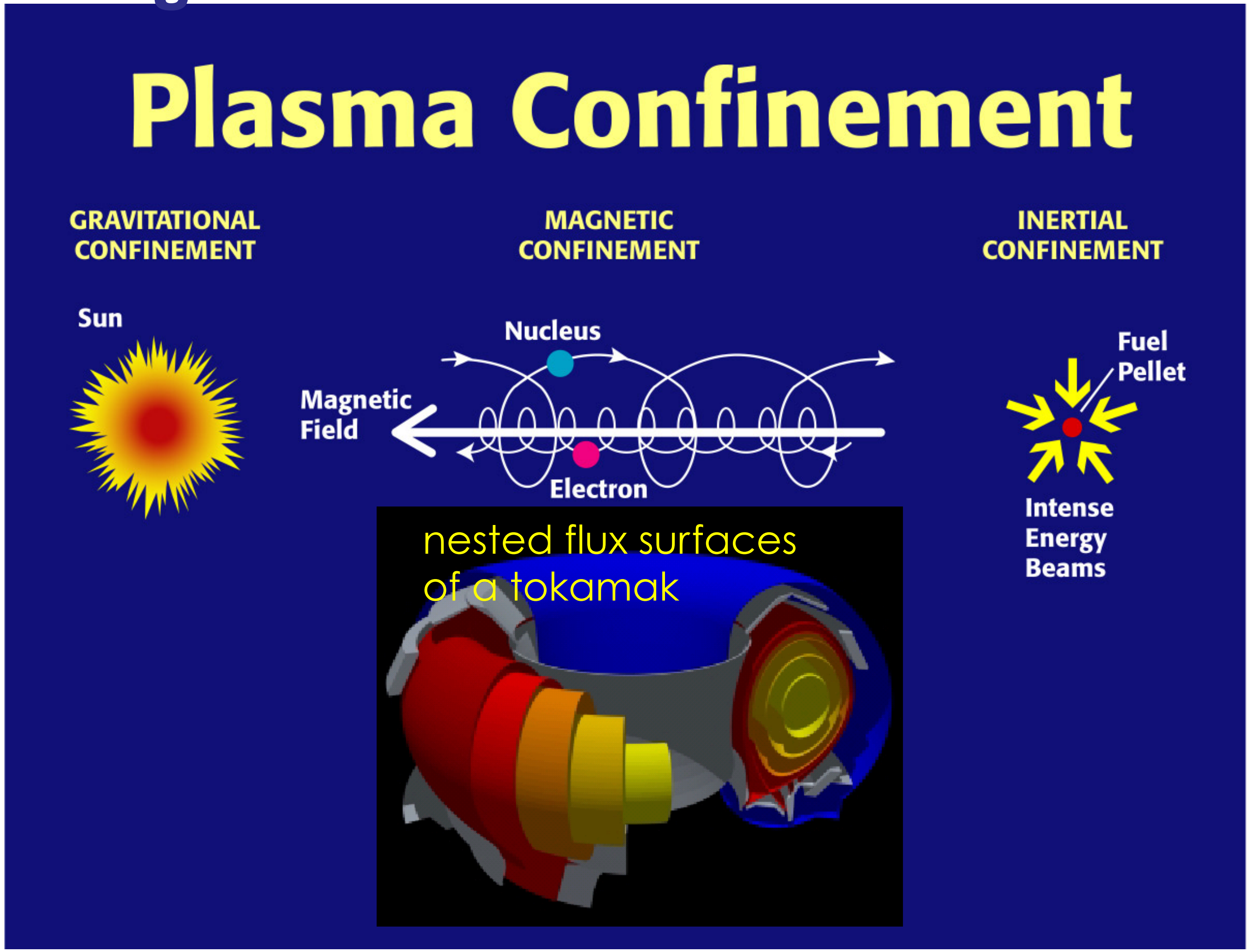
The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

ITER Will Study a Magnetically-Confined Plasma



Two Approaches to Fusion Development: Magnetic and Inertial Confinement



Fusion Performance

$$Gain = Q = \frac{Fusion\ Power}{Input\ Power} \sim n_i T_i \tau_E$$

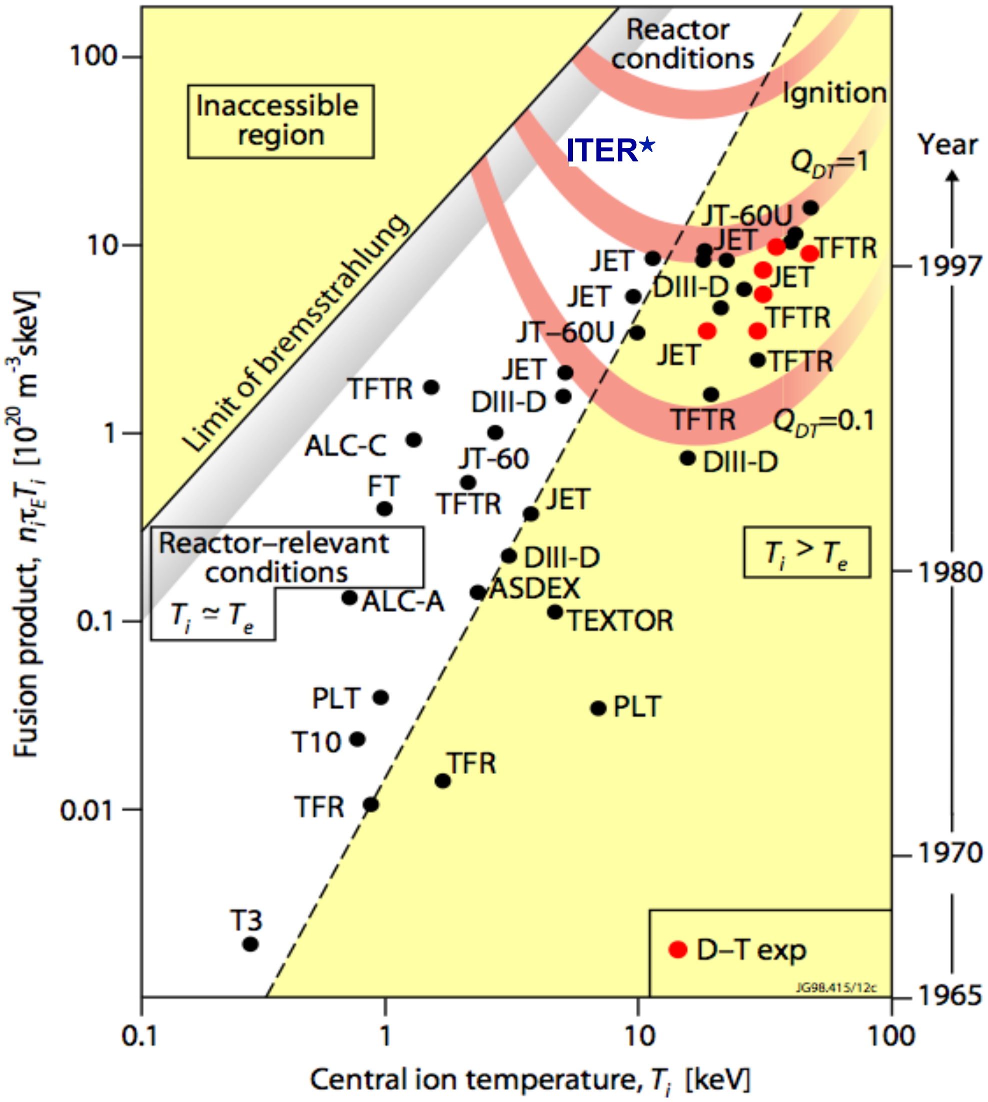
Existing experiments have achieved nTτ ~ 1×10[21] m[-3]skeV and Gain = Q_{DT} ~ 1

JET and TFTR have produced DT fusion powers >10MW for ~1s

ITER is designed to a scale which should yield $Q_{DT} \geq 10$ at a fusion power of 400 – 500 MW for 300 – 500 s

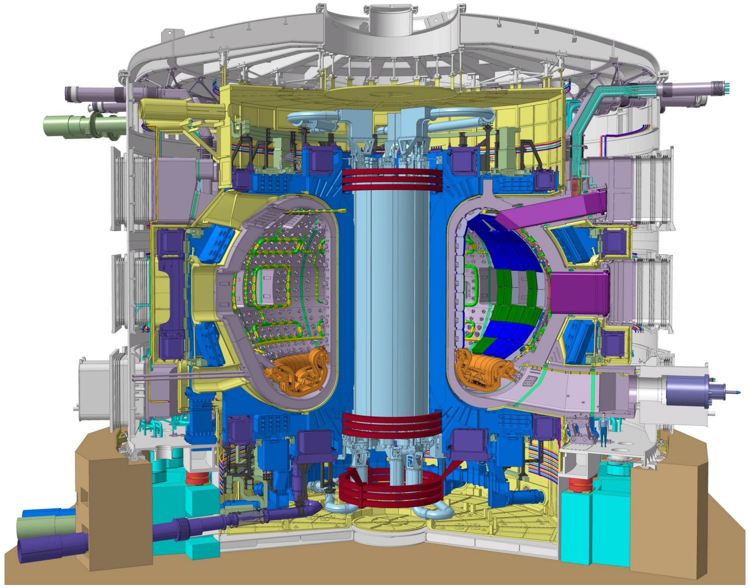
Progress has been determined by

- **Scientific advances**
- **Larger more powerful facilities**



The ITER Agreement was Signed Nov. 21, 2006

China, Europe, India, Japan, Russia, South Korea, U.S.



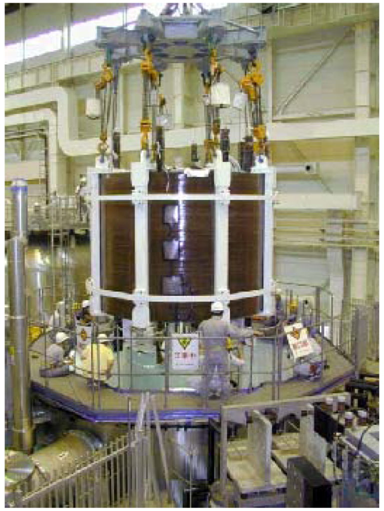
- **Over half the world's population is represented in ITER.**
  - A strong international scientific consensus that magnetic fusion can be an important new non-CO_2-emitting power source.

ITER will Demonstrate the Scientific and Technological Feasibility of Fusion Power

- **ITER is truly a dramatic step. For the first time the fusion fuel will be sustained at high temperature by the fusion reactions themselves.**
  - MFE Today: *10 MW(th) for ~1 second with gain ~1*
  - ITER: *500 MW(th) for >300 seconds with gain >10*
    300 MW(th) for <3000 seconds with gain >5

- **Many of the technologies used in ITER will be the same as those required in a power plant.**

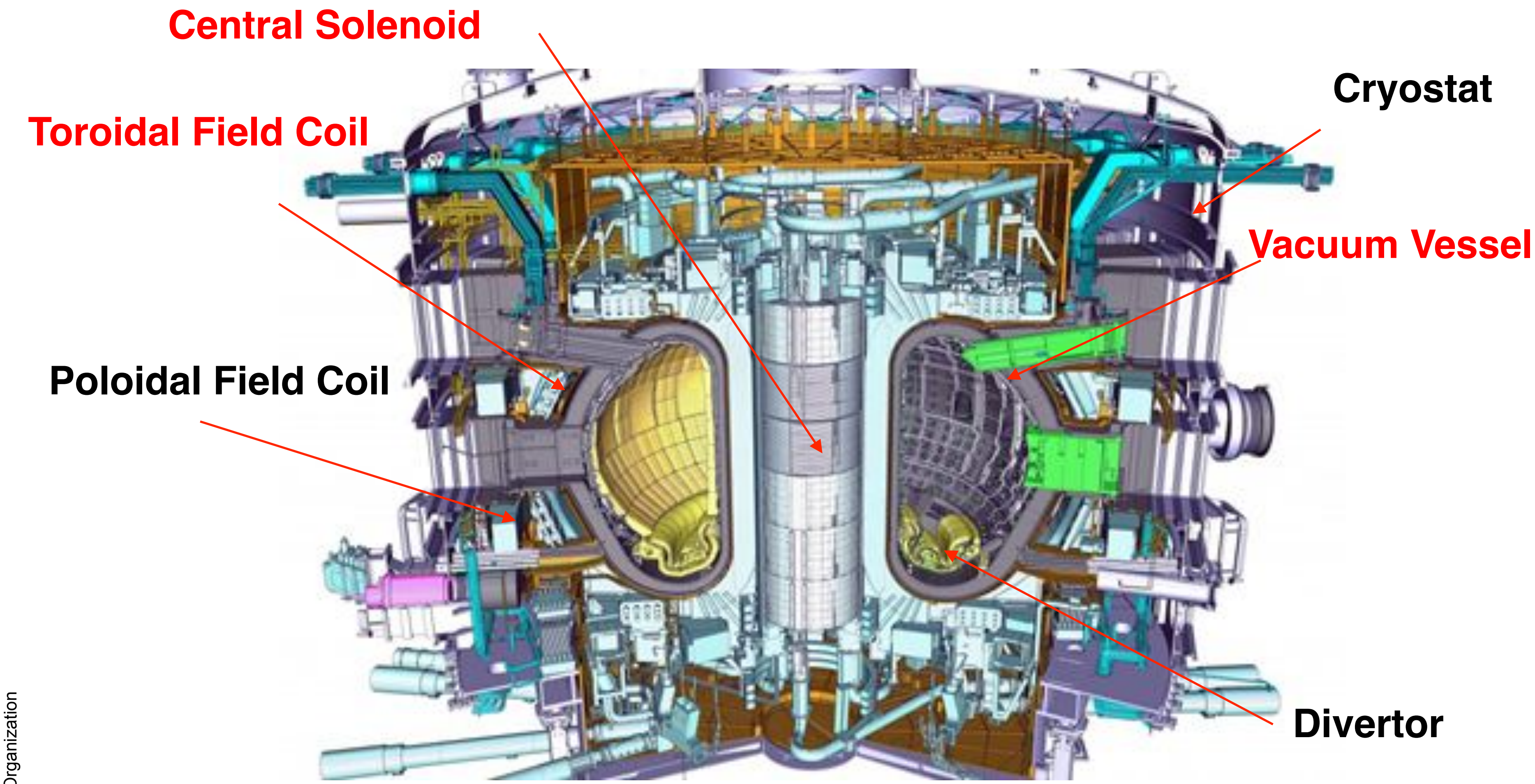
- **Further science and technology development is needed to bridge the gap to commercialization.**



Superconducting model Central Solenoid Coil

Construction of Buildings and Civil Infrastructure by EU is Underway

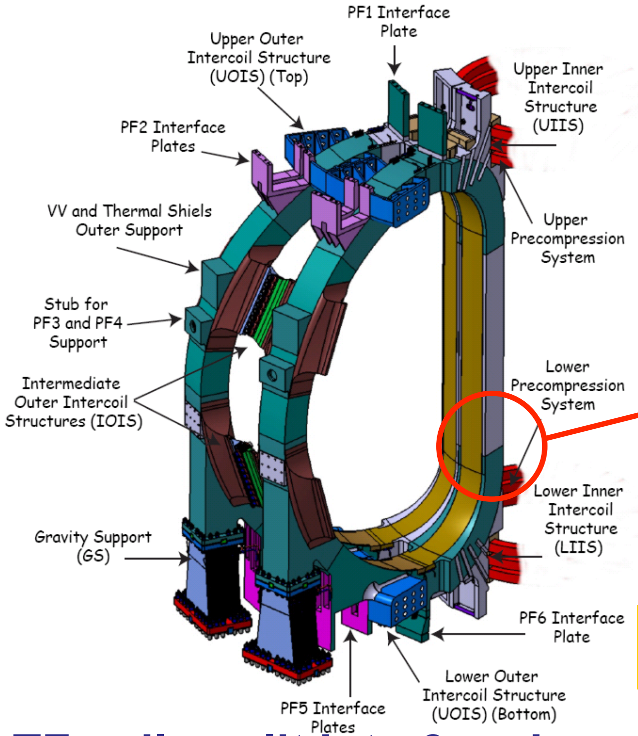
ITER Components are Provided as Contributions from the Members

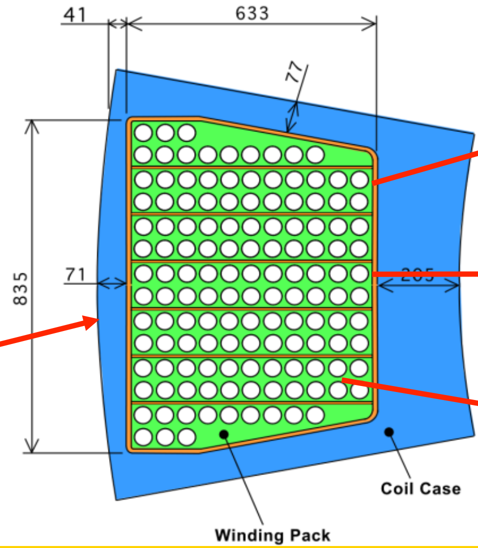


EU

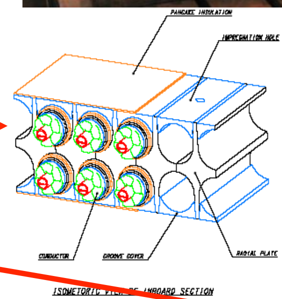
Toroidal Field Coil Status

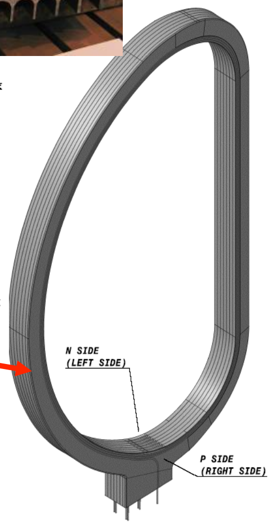
JAPAN





Inner Leg Cross Section





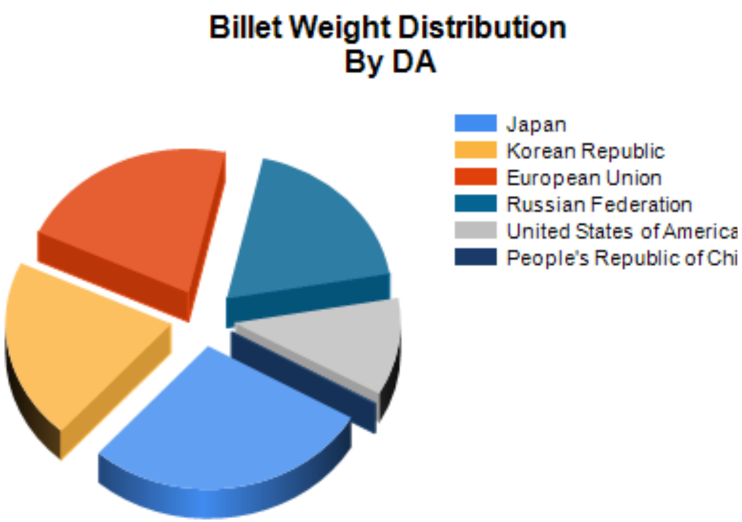
TF Winding Pack

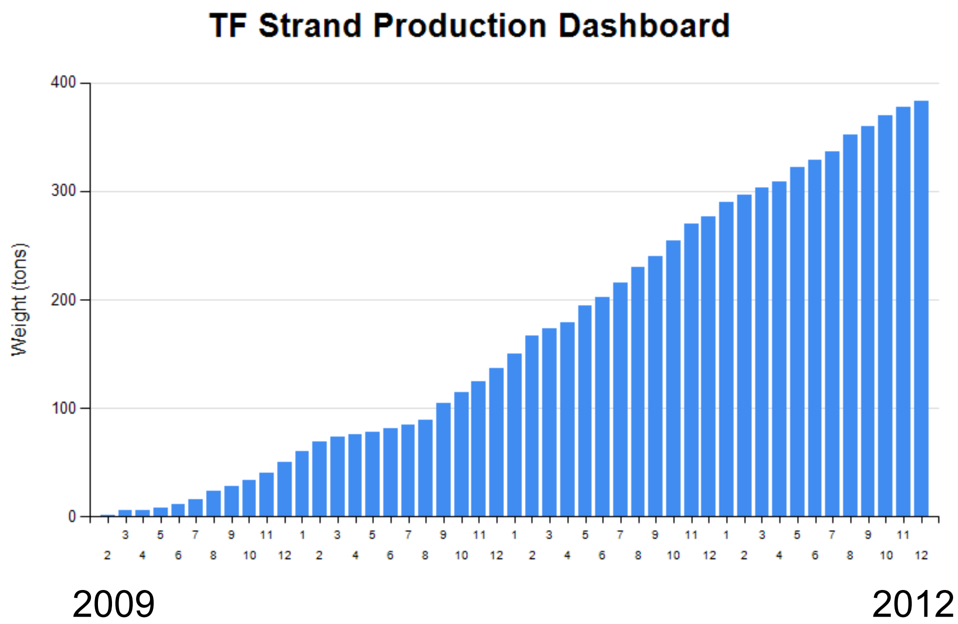
TF coils split into 3 main production areas

- **TF conductors**
  - 450t of Nb_3Sn (Europe, Russia, Japan, Korea, China and US)
- **TF structures**
  - 4500t of high precision stainless steel forgings and plates, assembled by welding in Japan
- **TF windings and coils**
  - 19 coils, 12T peak field, 20kV maximum voltage (Europe and Japan.)

TF Superconducting Strand Procurement is Largest in History

- **Over ~80% of required 450t of Nb_3Sn strand has been produced around the world**
  - Prior to ITER world production was 15 ton/year!



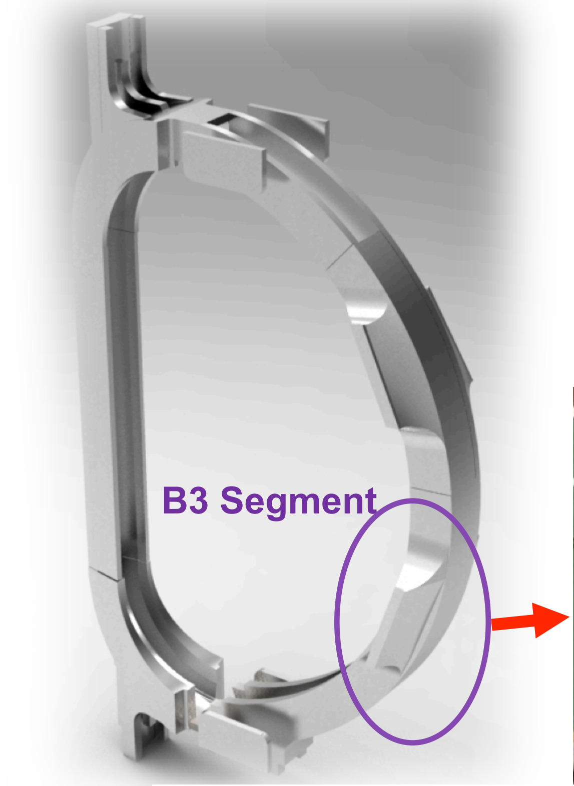


TF Strand Production Summary

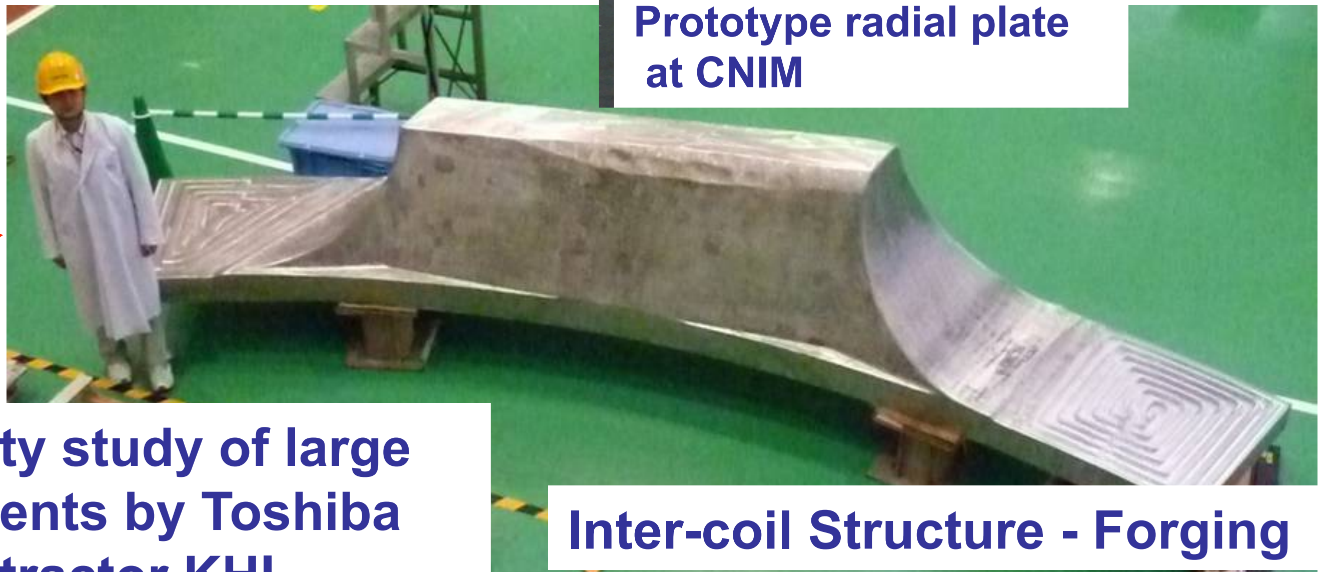
TF Coil Structures Progress

JA

EU



Manufacturability study of large TF coil components by Toshiba and its sub-contractor KHI

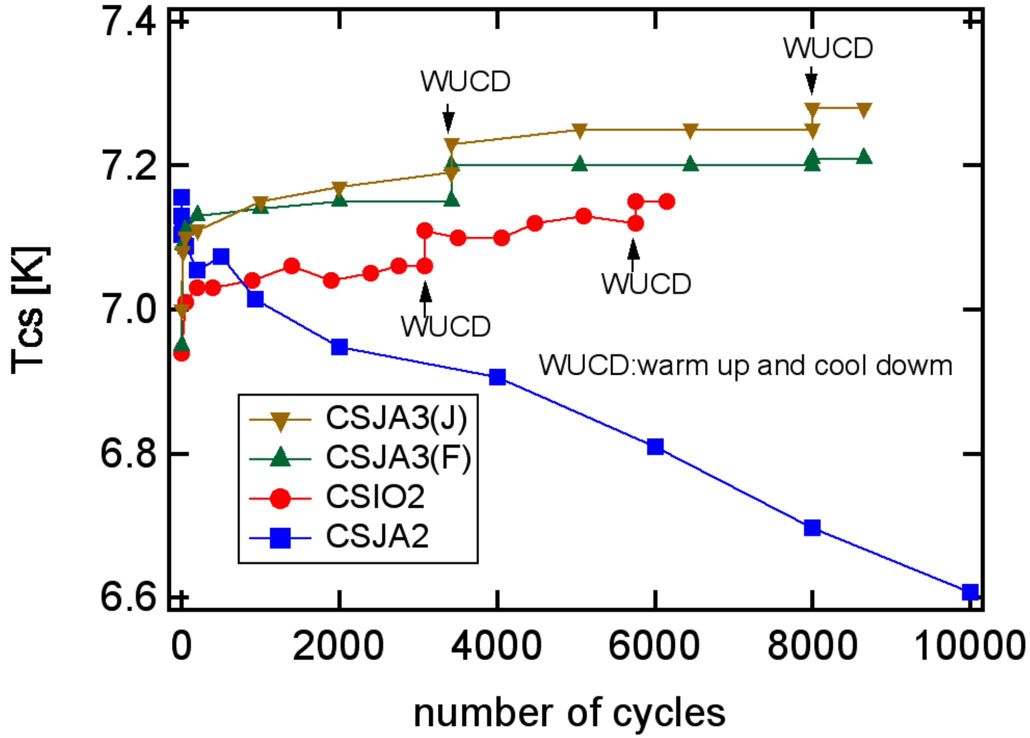


Inter-coil Structure - Forging

Prototype radial plate at CNIM

Pictures courtesy JAEA & Contractors Toshiba & KHI

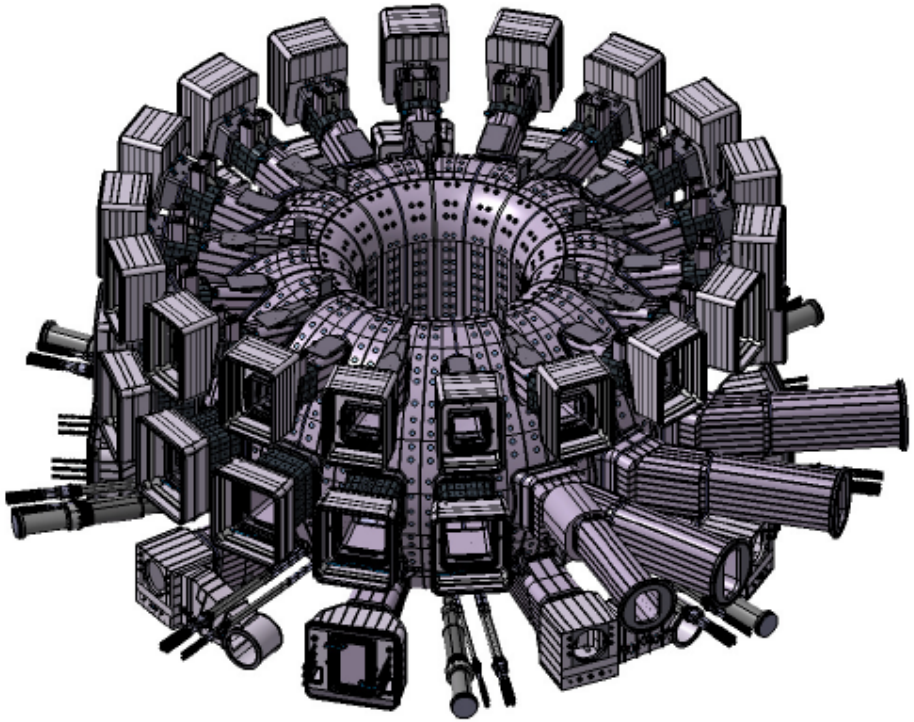
JA Central Solenoid Conductor Meeting US
ITER Specifications Has Been Qualified

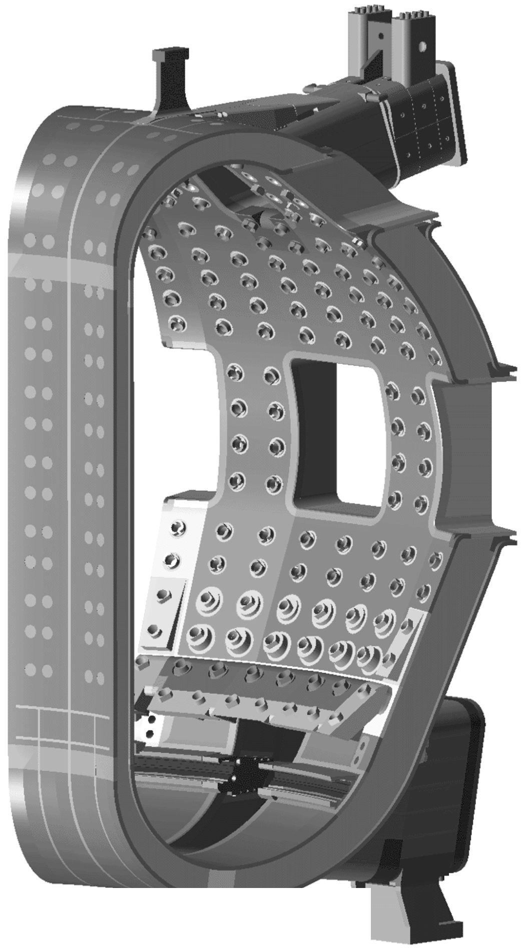


- Three conductors by Furukawa, JASTEC and Oxford Superconducting Technology have been qualified as a CS conductor.
- Japan will provide the conductor and US will fabricate the coil.

Vacuum Vessel Status

EU, KO, IN, RF





- **Vacuum Vessel is double-walled stainless steel**
  - 19.4m outer diameter, 11.3m height, 5300 tonnes
  - provides primary tritium confinement barrier
- **VV sector and port PAs signed (EU, KO, IN, & RF)**
- **EU- VV awarded to AMW (Ansaldo Nucleare S.p.A, Mangiarotti S.p.A and Walter Tosto S.p.A)**
- **KO - VV & port contract awarded to Hyundai Heavy Industries**

KO

Extensive Use of Mock-ups to Verify Manufacturing Design and Fabrication Methods

The size, tight tolerances and large electromagnetic loads on the tokamak components are a challenge,

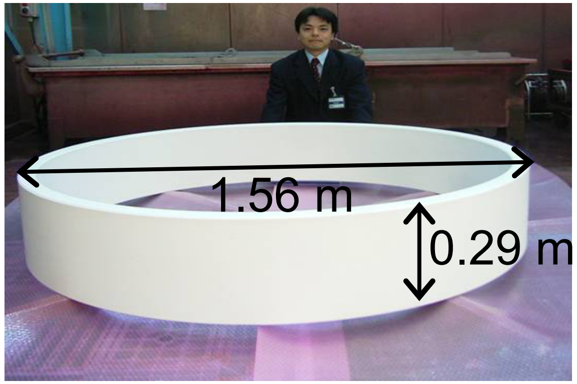
- provides experience in developing the technology for a power plant.

EU, IN, JA

Negative Ion Neutral Beams are Under Development for ITER

		ITER	LHD	JAEA JT60U	JAEA MV TF	IPP RF source
Species		D^-	H^-	D^-	H^-	H^-/D^-
Energy	keV	1000	180	400	937	-
Accelerated current	A	40	30	17	0.33	1.4
Source area	m^2	3.02	0.51	0.78		0.11
Source power	kW	800	180	350		100
Extracted current density	A/m^2	285	250		144	280
Pulse length	s	3600	2	2	2	3600

Figures in red achieve >75% of target value



Substantial extension of existing neutral beam technology

Test facilities are under construction in Europe and India

A full-size mock-up bushing has been manufactured

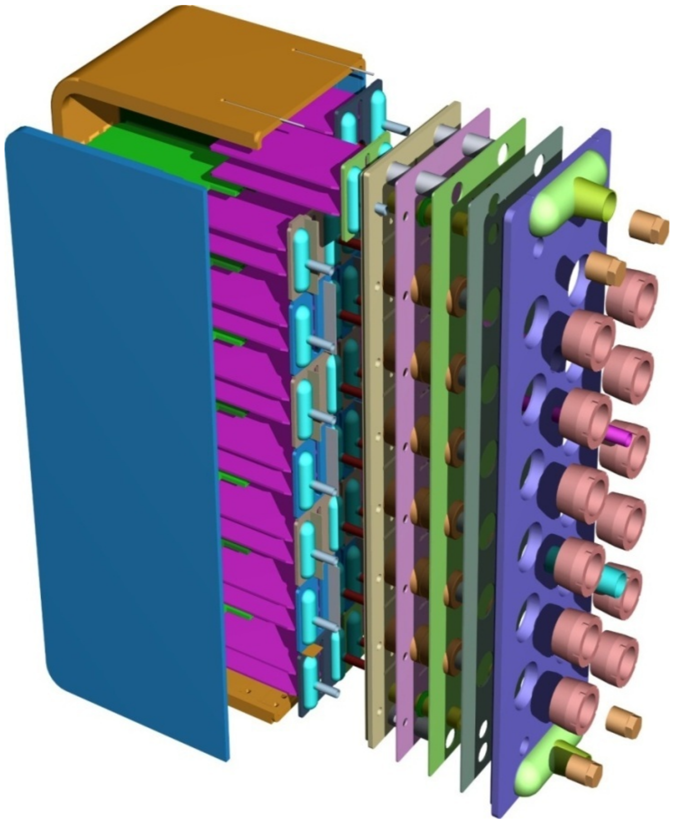
Voltage holding of -240 kV for 1 h has been demonstrated in the single-stage full-size mock-up bushing and 370kV over a two-stage mock-up.

Test Blanket Modules - Tritium Breeding

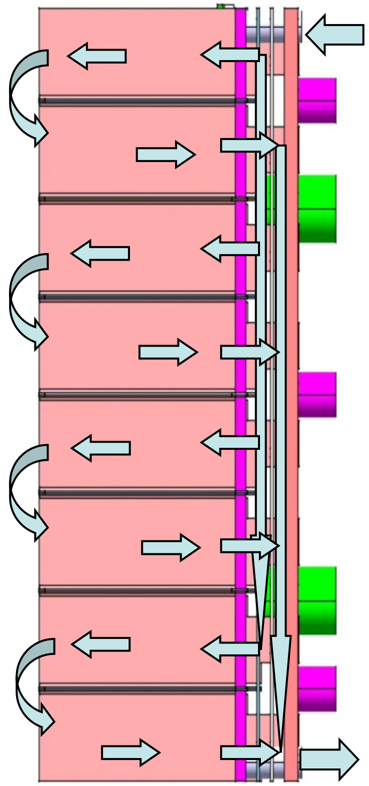
$n + {}^{6}Li \rightarrow T + {}^{4}He + 4.8MeV$
$n + {}^{7}Li \rightarrow T + {}^{4}He + n - 2.47MeV$

- **Three dedicated stations for testing up to six tritium breeding concepts**

He-Cooled Lithium-Lead (HCLL) TBMs



- *Structures:* Eurofer Steel
- *Multiplier / Breeder:* Pb-16Li (^{6}Li 90%)
- *Coolant:* Helium at 8 MPa, 300/500°C



ITER Licensing Process Is Proceeding

- **In December 2010, the ITER safety files were formally accepted by the French Authorities**, which allowed the process of technical evaluation by the Nuclear Safety Regulator (ASN) to be launched as well as the public evaluation of the files organized by the local authorities.

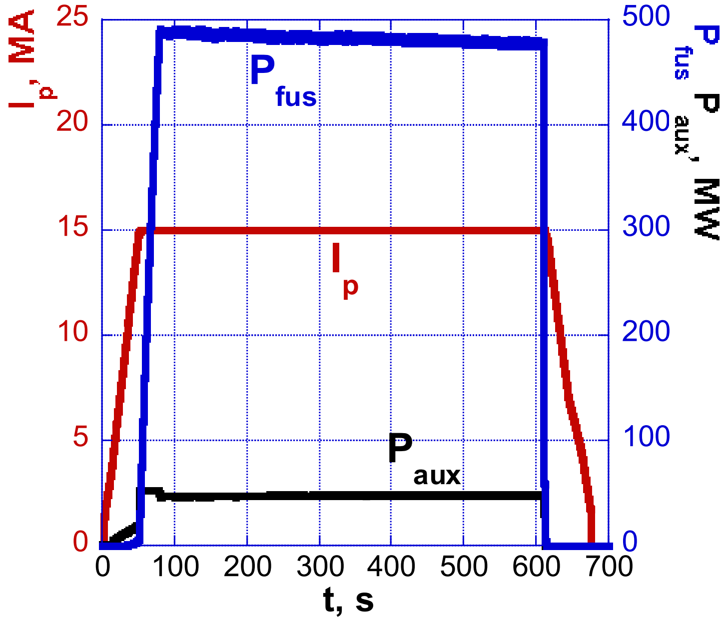
- Public Enquiry was carried out in the period June – August 2011.

  - **A positive recommendation on the ITER Project was received on 19 September from the Inquiry Commission.**

- **The "Groupe Permanent,"** a formal group of independent nuclear safety experts met on 30 November and 7 December 2011

- For the licensing process, a major milestone was achieved when French Prime Minister Jean-Marc Ayrault signed on 9 November 2012 the official decree that **authorizes the IO to create the *Installation nucléaire de base ITER;***

First High Power D-T Experiments Will Generate More Fusion Energy than All Previous MFE Fusion Experiments Combined

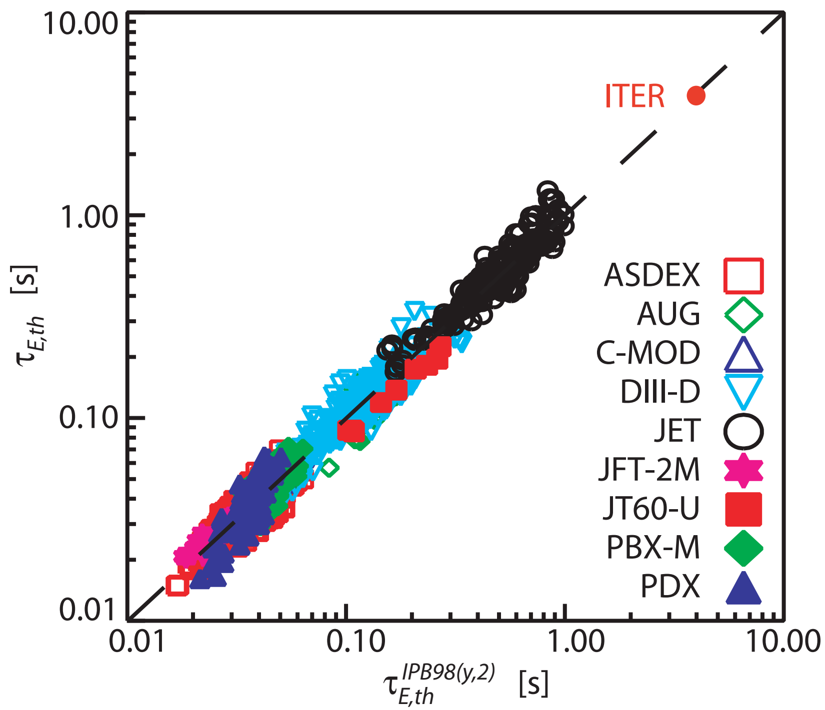


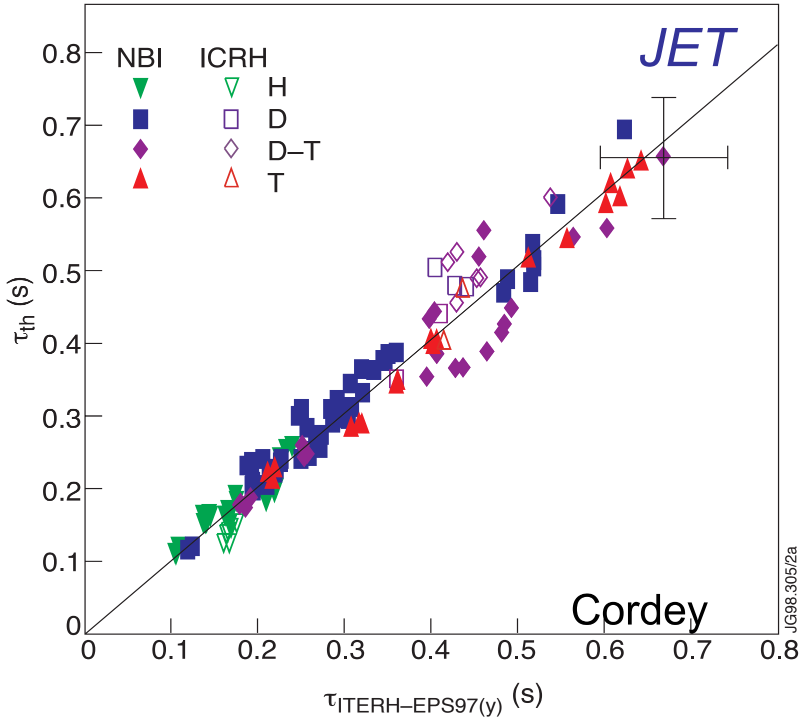
Q=10 scenario
250 GJ

Y. Gribov

- For comparison, JET produced 22 MJ per pulse (0.7 GJ total) and TFTR 7.5 MJ per pulse (1.7 GJ total) during their DT campaigns
- ITER will provide a unique facility to study the physics of magnetically confined burning plasmas

The Energy Confinement Time Required by ITER is a Small Extrapolation from JET D-T Results





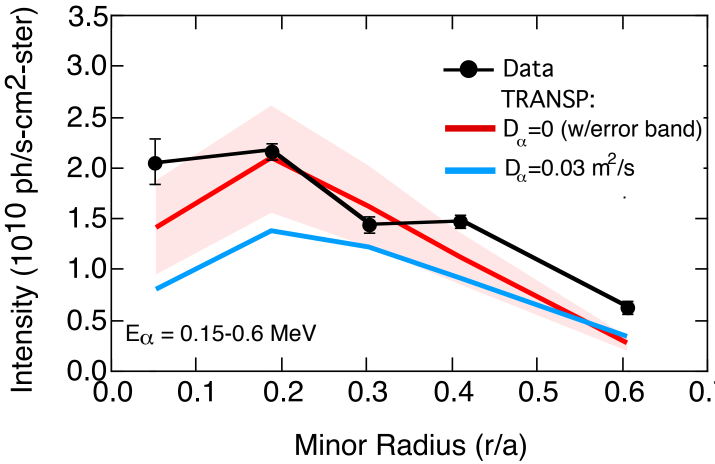
- $\tau_{th} \propto \langle A \rangle^{0.16 \pm 0.06}$

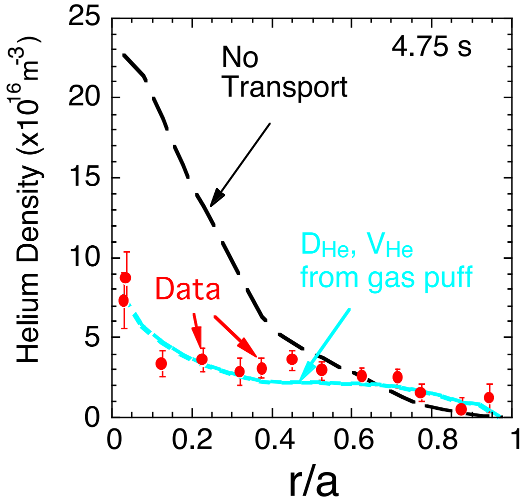
H-mode scaling studies provide a good technical basis for baseline operation of burning plasma experiments.

ITER will enable a definitive test of confinement.

Energetic Alpha-particles Were Well Confined in Normal Shear Discharges

TFTR





Alpha particles were well confined.

$0 \leq D_\alpha \leq 0.03$ m^2/s

R. Fonck, G. McKee, B. Stratton

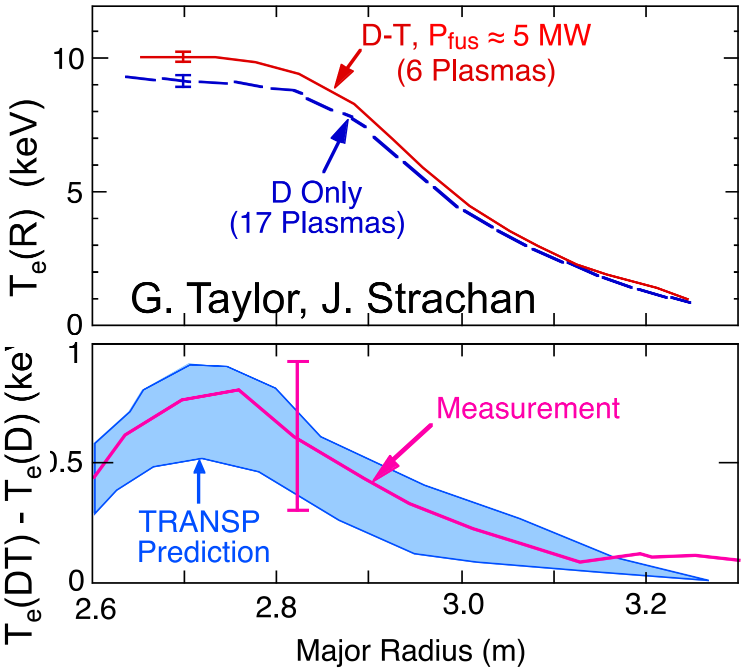
He ash from the slowing down alphas transported from the core to the edge in supershots. ($D_{He}/\chi_D \sim 1$)

E. Synakowski

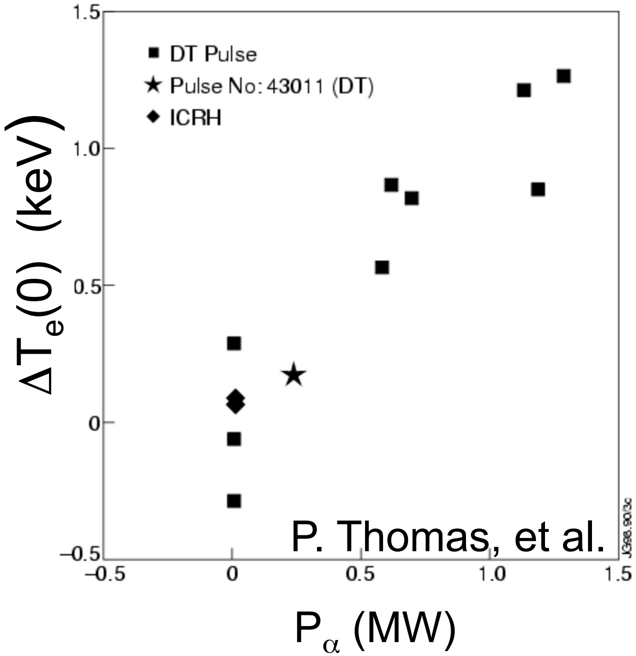
ITER will extend these results especially ash buildup.

Initial Evidence of Alpha-particle Heating on TFTR and JET

TFTR



JET



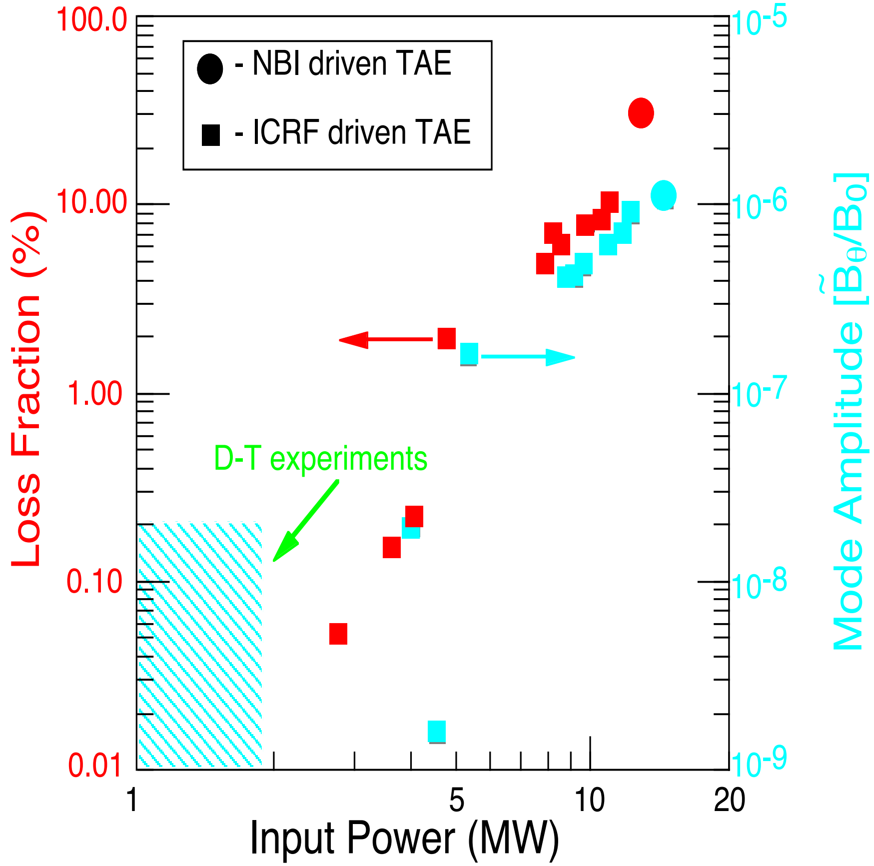
- **Alpha heating ~15% of power through electron channel.**

- **P_{alpha}/P_{heat} ~12%**
  - **30-40% through the electron channel**

- **Comprehensive study of alpha heating requires higher values of P_{alpha}/P_{heat} .**

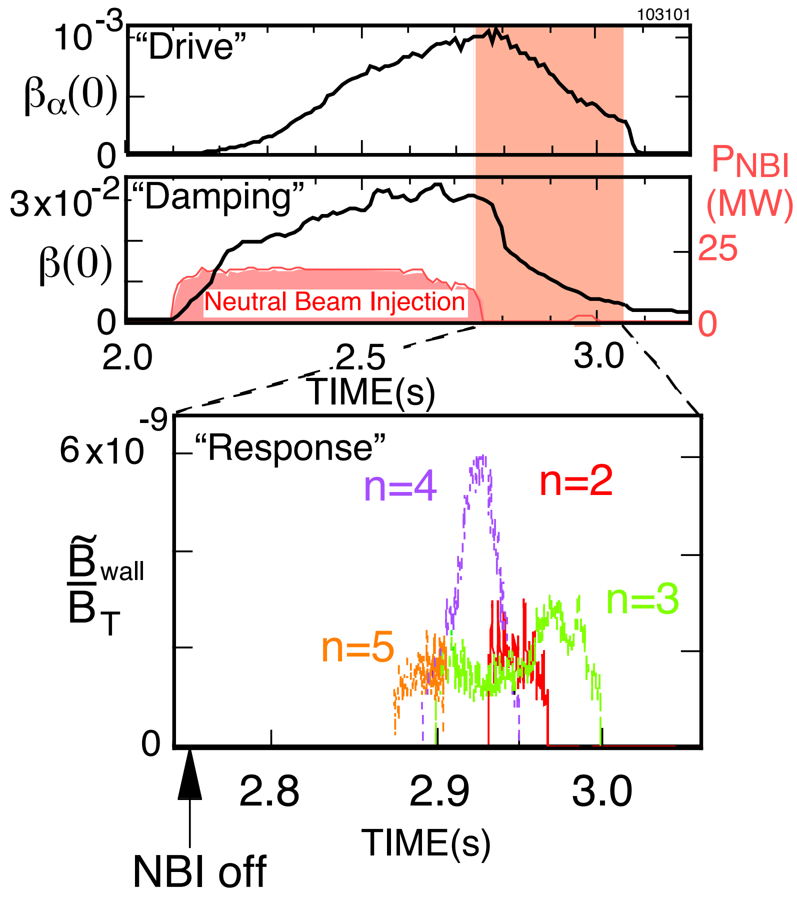
Alpha Particle Driven Instabilities Were Stable in TFTR and JET Normal Shear D-T Discharges

- **As alphas slow down they can interact with Alfvénic instabilities in plasma**
  - $V_{alpha} \sim V_{alfvén}$
- **Some global Alfvén waves (TAE) are *very* weakly damped**
- **Fusion alphas interact with them *more* than the thermal plasma**
- **Alpha particle drives the waves depending upon gradients in alpha distribution at resonance**



TFTR Alpha-particle Physics Studies in Reversed Shear Discharges Resulted in New Discoveries.

- **Alpha-driven TAE (subsequently identified as Cascade Modes) were observed.**
- **Sensitive to the q-profile and damping mechanisms.**
- **ITER will study the role of alpha-driven instabilities in both the high Q_{DT} and steady state operating regimes**
- **PPPL/IFS quasilinear model predicts that alpha particle losses are acceptable in high Q_{DT} operating regimes**
  - Further work required to assess steady state operating regimes.



R. Nazikian, Z. Chang, G. Fu

ITER will Provide a Power Plant Scale Test of the Extraction of Heat from an MFE Fusion Plasma

- **Long pulse, high heat flux operation can result in erosion or local damage.**
  - Nine years of JET operation has a comparable ion fluence to the divertor as~3 high power DT shots on ITER.
  - Where will the sputtered material migrate to?
  - Development of high recycling divertor, Edge Localized Modes and Disruption Mitigation are critical issues.
- **Dust has not been an issue in current experiments but there will be safety restrictions on ITER**
- **Tritium retention in graphite based on JET and TFTR experiments would be a serious concern.**
  - TFTR tiles 16% retention
  - JET 12% retention
- **Results from JET with tungsten divertor for reduced tritium retention are very encouraging.**

MFE has Entered the Fusion Plasma Regime and ITER will Test Performance at Power Plant Scale

- **MFE has studied DT fusion plasmas with a Gain ~ 1 and fusion energy of 22 MJ per pulse**

- **Detailed results from a broad international program have provided a solid basis for predicting ITER fusion performance**

- **An international R&D Program has extended technology to provide a strong scientific and technology basis for constructing ITER**

- **ITER and the associated International Magnetic Fusion Program are on track to:**
  - Produce fusion power of 500 MW at a Gain of 10 for 300-500s at the physical size of a power plant
  - Demonstrate the technological feasibility of fusion power

- ***Full potential and consequences of alpha heating will be explored on ITER!***