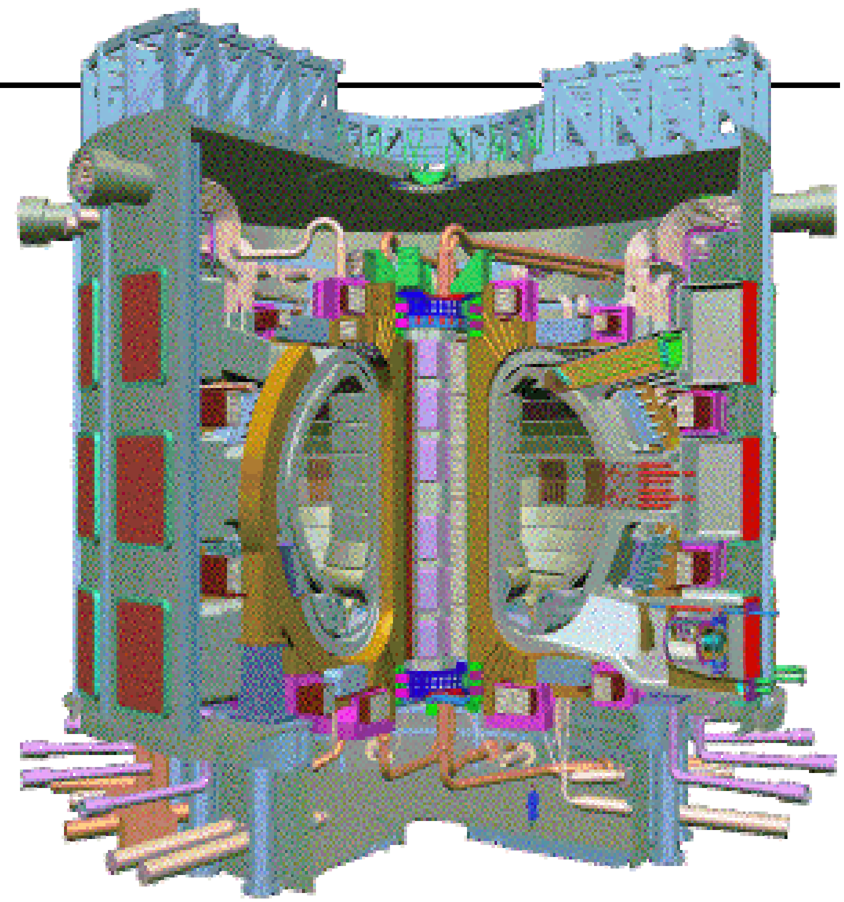
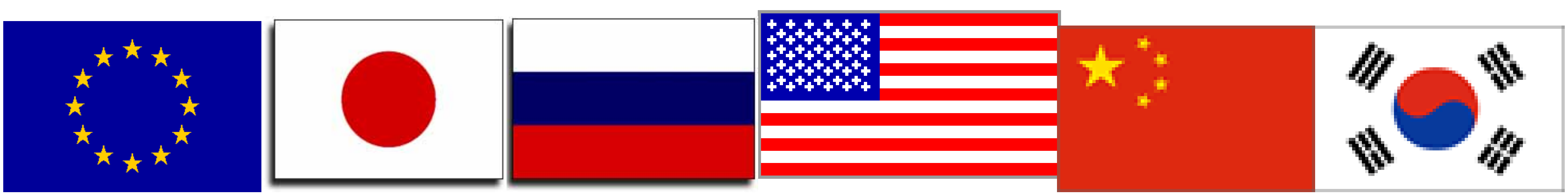
ITER

An experiment in science, technology, and international collaborations



Ned Sauthoff
U.S. ITER Planning Officer

Lawrence Berkeley National Laboratory
April 7, 2004



DOE/SC Facilities Plan

"ITER is an international collaboration to build the first fusion science experiment capable of producing a self-sustaining fusion reaction, called a 'burning plasma.'

It is the next essential and critical step on the path toward demonstrating the scientific and technological feasibility of fusion energy."

Roadmap

Very brief overview of toroidal magnetic confinement, burning plasmas, and ITER

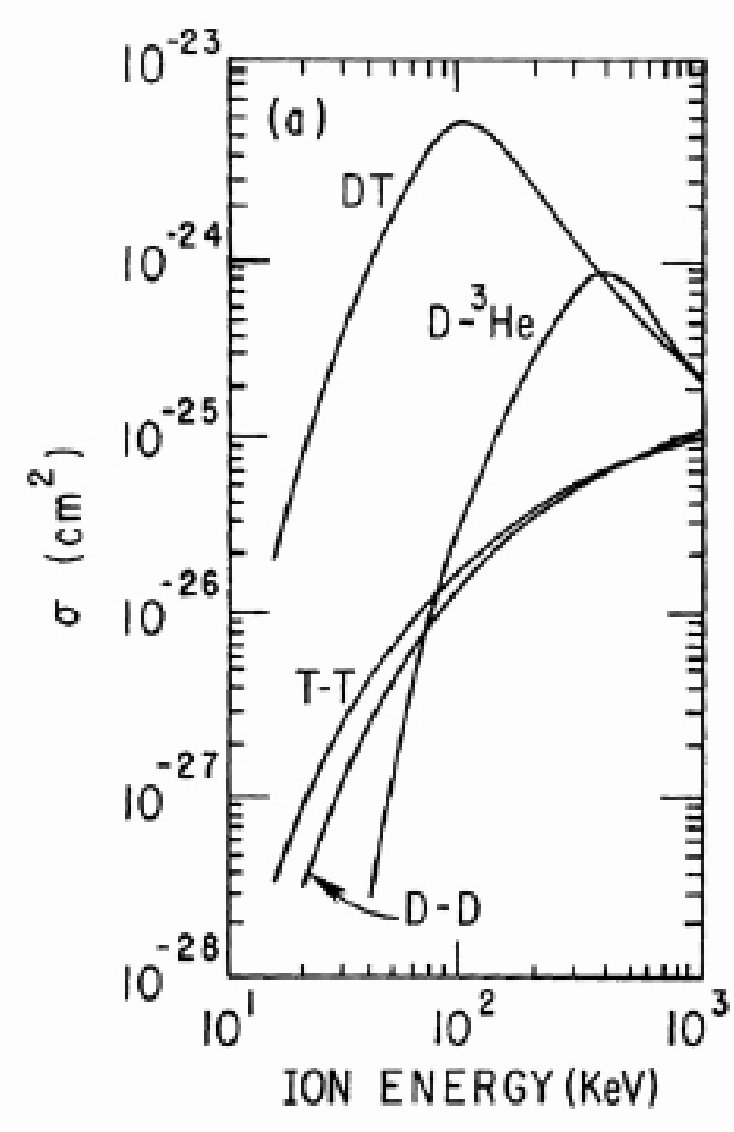
ITER as an experiment in … Science

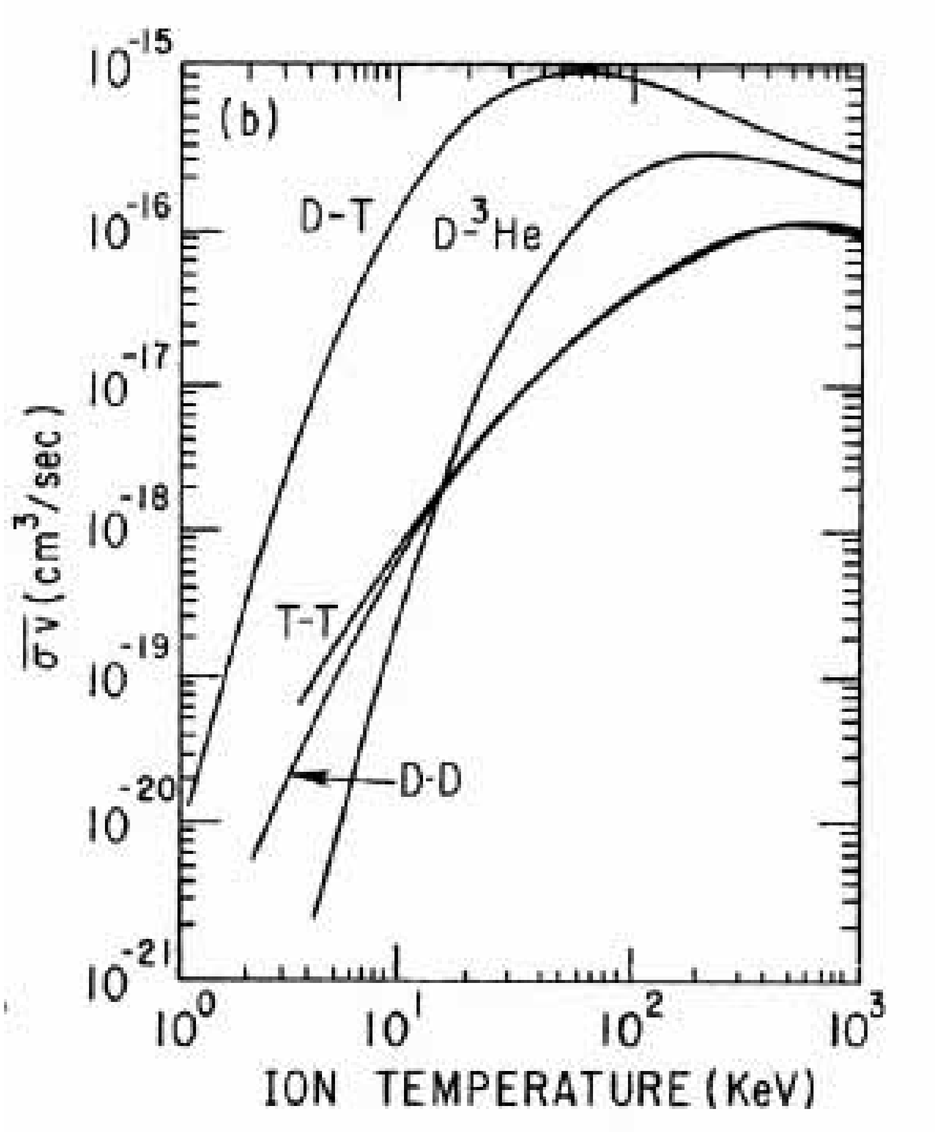
ITER as an experiment in … Technology

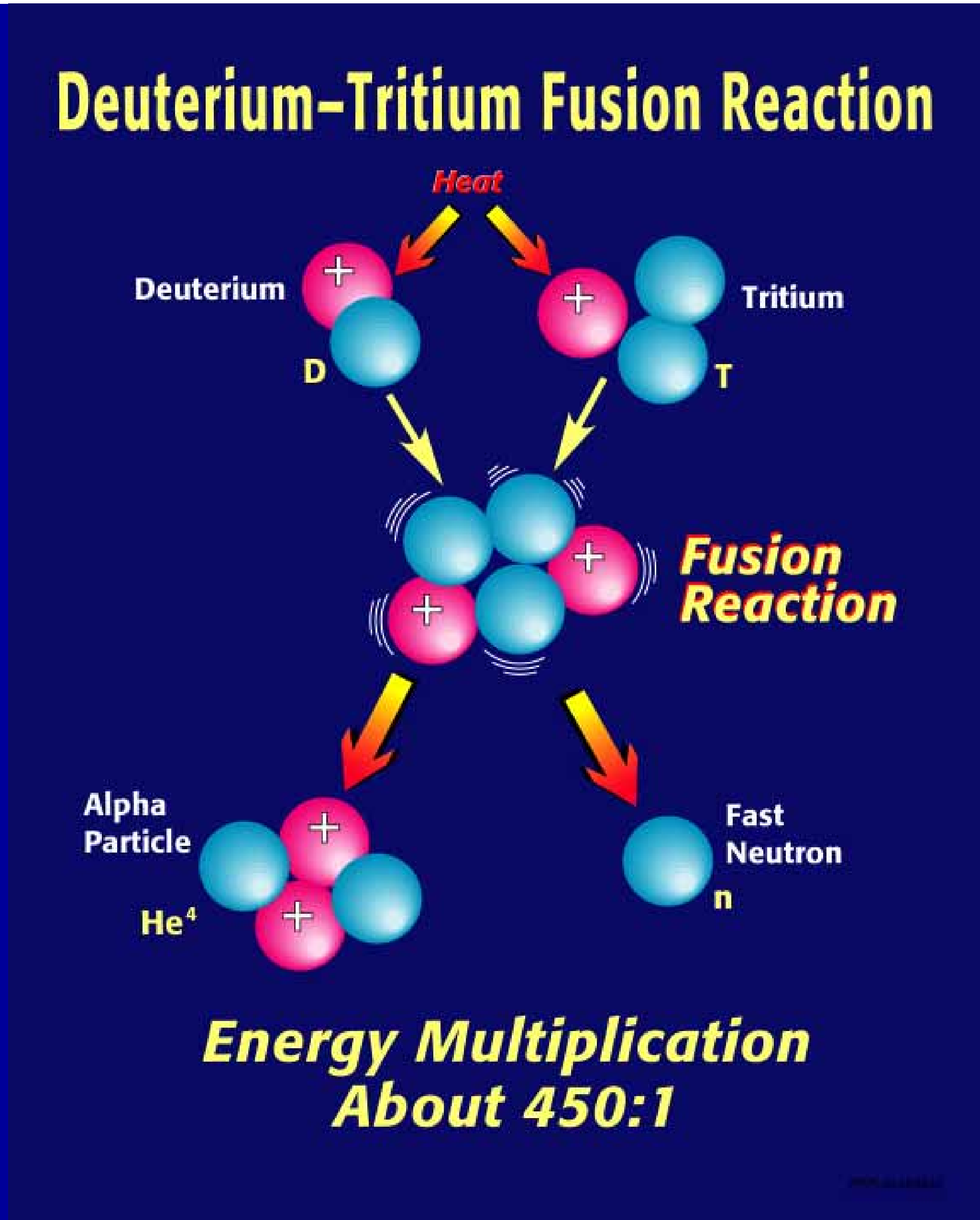
ITER as an experiment in … International Collaboration

A look to the future

Relevant Fusion Reactions for Burning Laboratory Plasmas



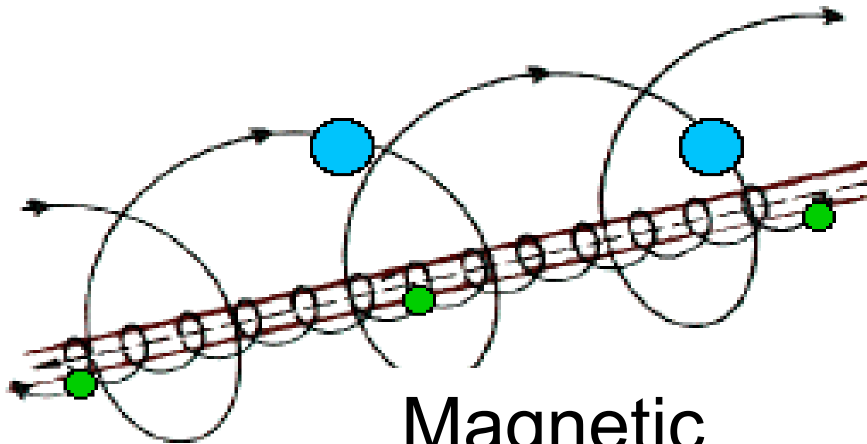




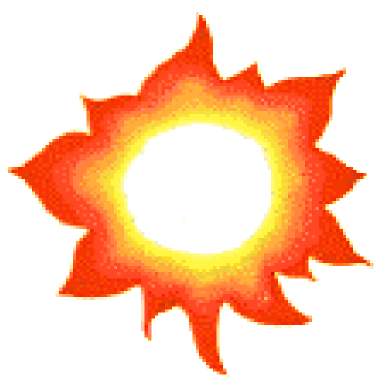
$D^{+} + T^{+} \rightarrow {}^{4}He^{++}$ (3.5 MeV) + n^{0} (14.1 MeV)

Three Different Approaches

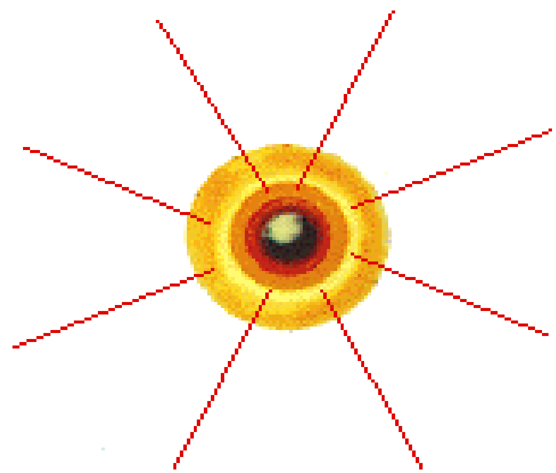
$\boldsymbol{F} = q\,\boldsymbol{E} + (q/c)\,\boldsymbol{V} \times \boldsymbol{B}$



Magnetic



Gravitational



Inertial

Other approaches: Muon catalyzed fusion

Fusion Power Metric

- **Fusion power density**

$$p_{fus} = E_{fus} n_d n_t \left\langle \sigma_{fus} v \right\rangle \sim n^2 T^2$$

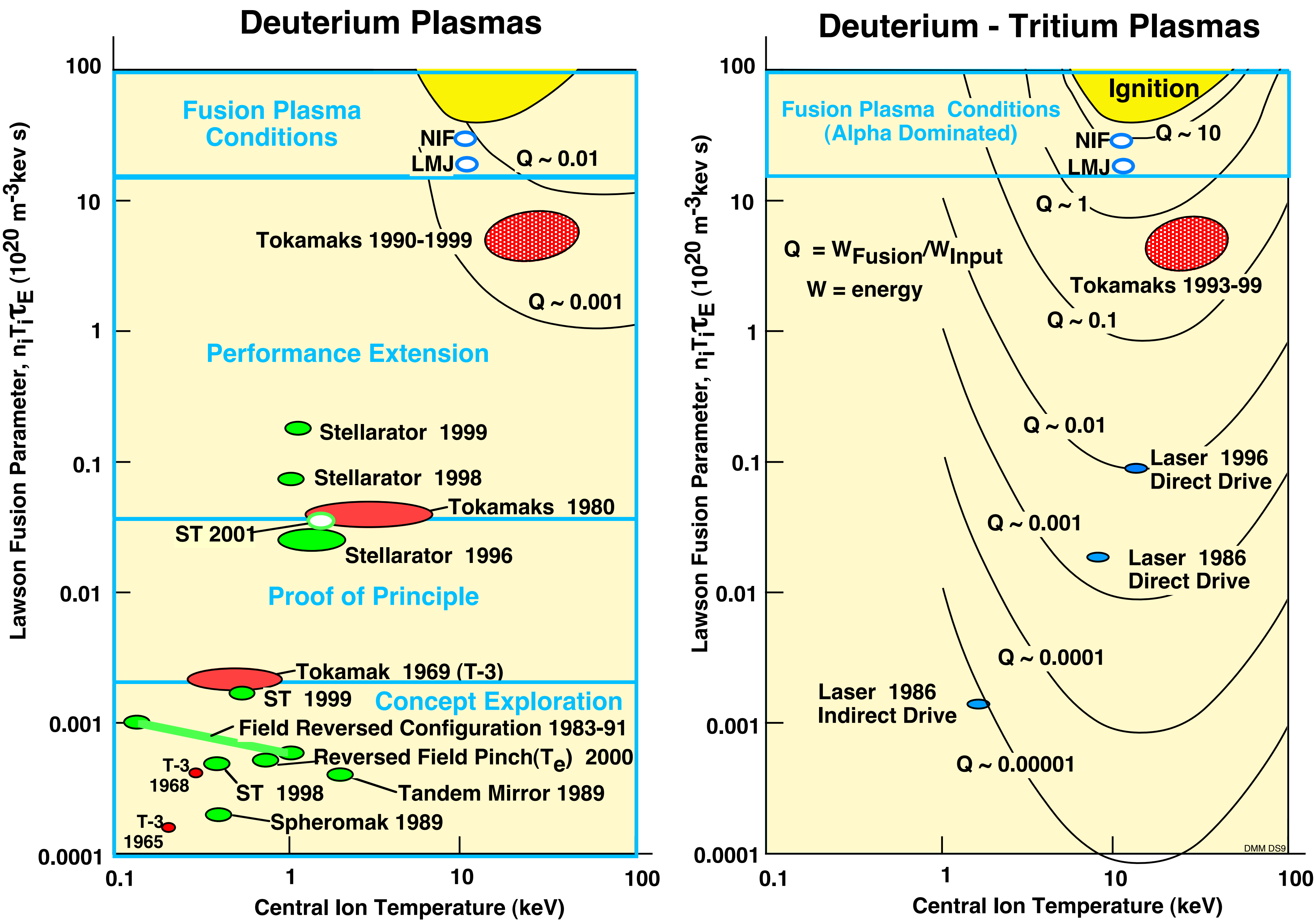
- **Heat loss**

$$P_{loss} \cong \frac{3nT}{\tau_E}$$

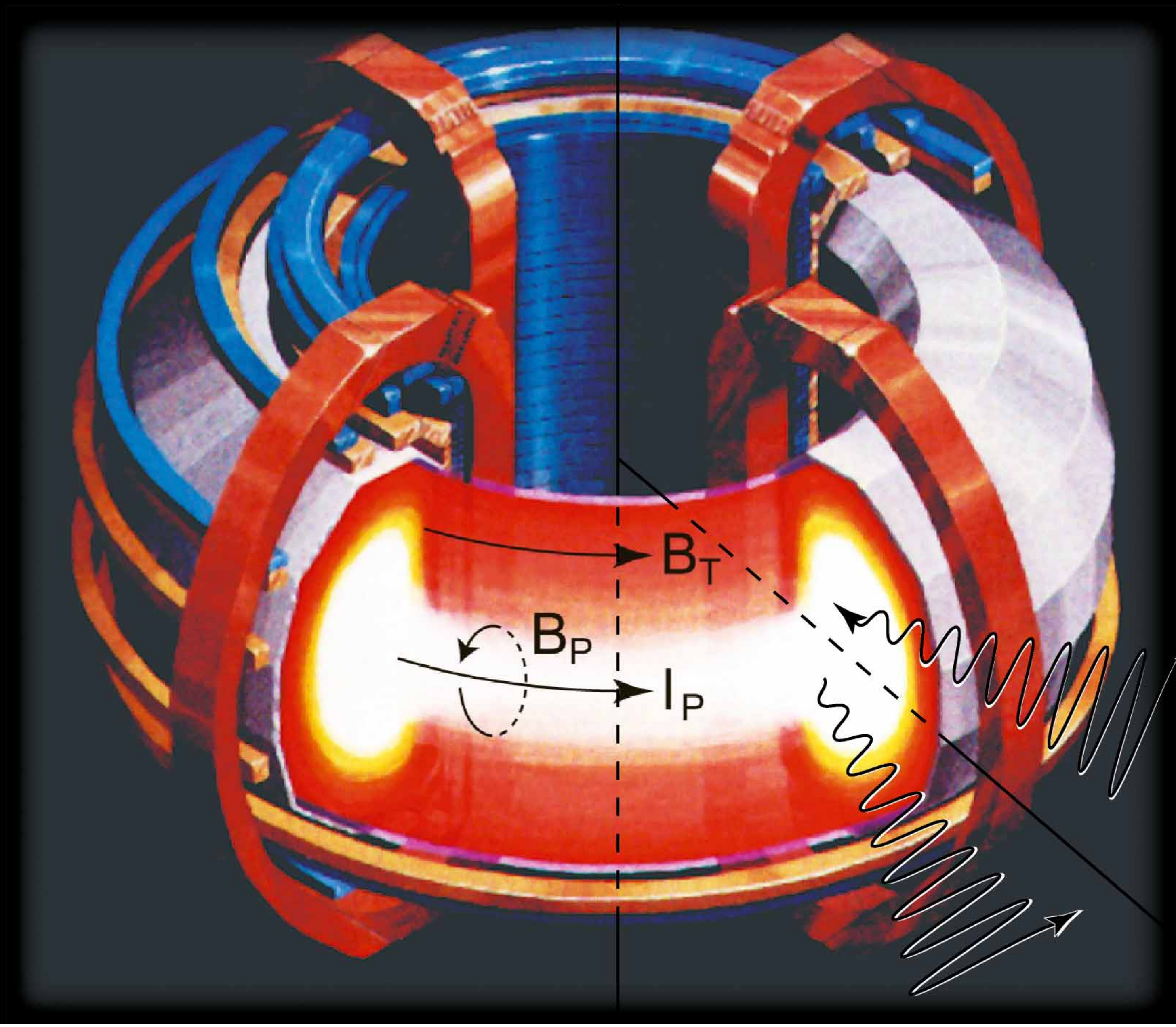
- **Fusion gain is determined by**

$$\frac{P_{fus}}{P_{loss}} \propto nT\tau_E$$

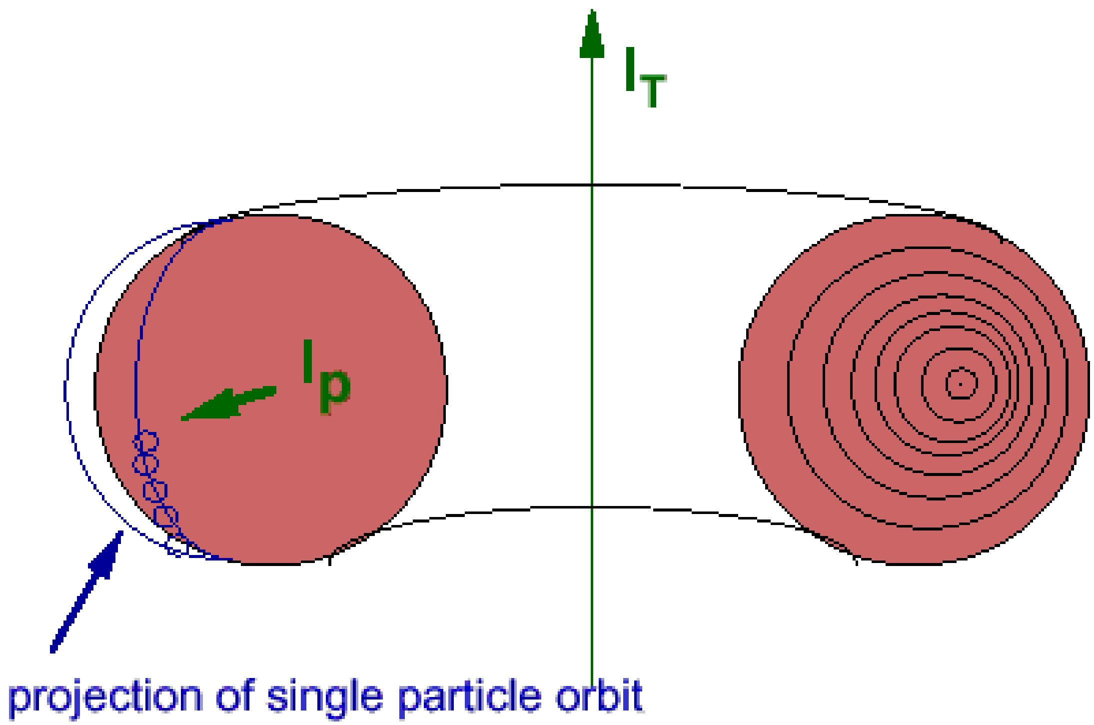
The Tokamak is Ready to Explore the Science of Fusion Plasmas



Toroidal plasmas and the tokamak configuration

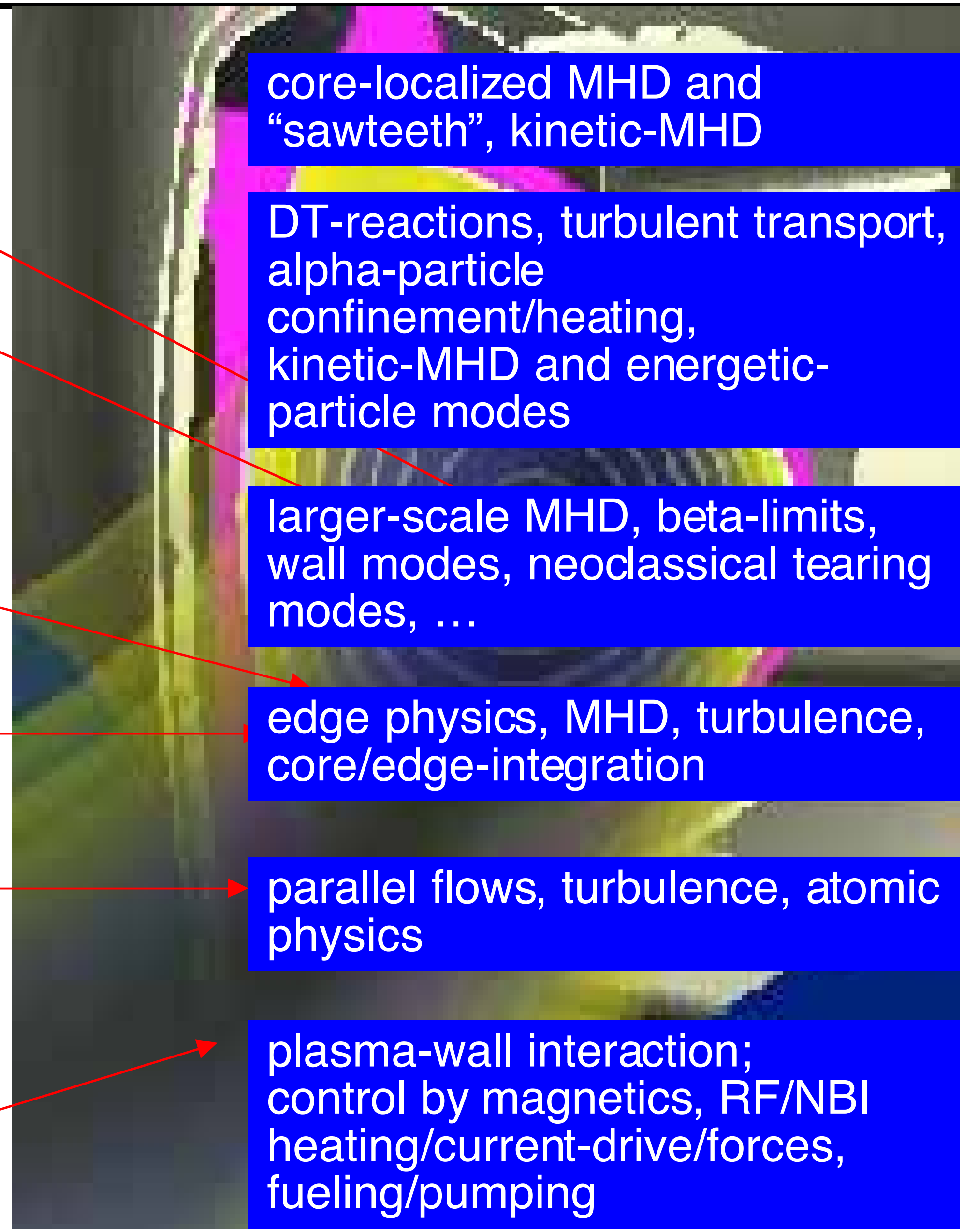


Toroidal plasma confinement 0verview



- **Ignorable equilibrium coordinate produces a conserved quantity**
- **Symmetry-breaking effects:**
  - collisions
  - non-axisymmetric instabilities

Elements of an Integrated Tokamak Plasma



Sawtooth/fishbone region: core-localized MHD and "sawteeth", kinetic-MHD

Core confinement region: DT-reactions, turbulent transport, alpha-particle confinement/heating, kinetic-MHD and energetic-particle modes

Magnetic island region: larger-scale MHD, beta-limits, wall modes, neoclassical tearing modes, …

Pedestal region: edge physics, MHD, turbulence, core/edge-integration

Scrape-off layer: parallel flows, turbulence, atomic physics

Wall/Conductors/Actuators: plasma-wall interaction; control by magnetics, RF/NBI heating/current-drive/forces, fueling/pumping

ITER's systems

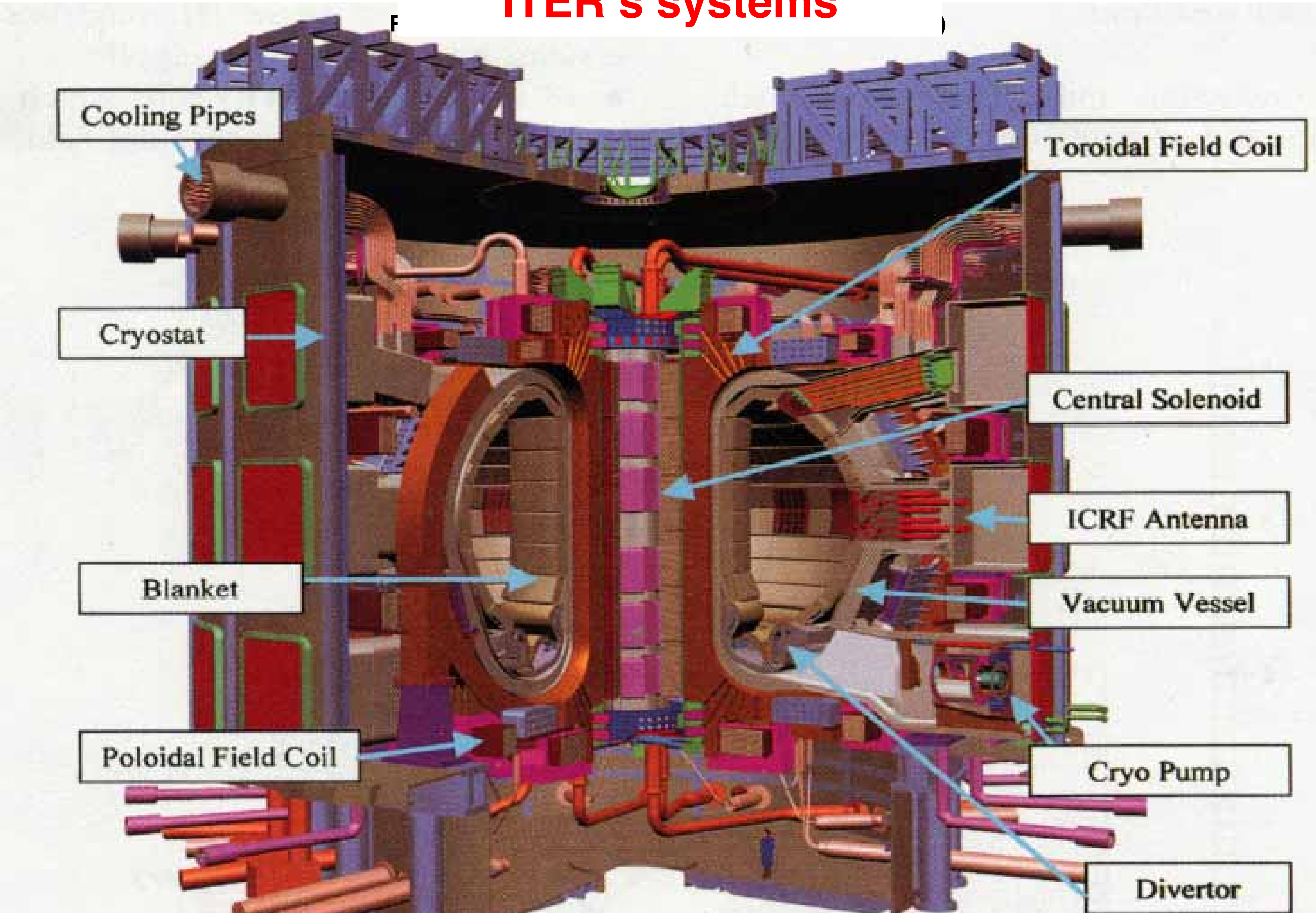


Fig. 1 Cutaway of ITER

The nature of ITER

- **ITER is a collection of activities aimed at demonstrating the scientific and technological feasibility of fusion energy.**
  - Physics R&D aimed at producing a basis
    - for facility-design and
    - for research operations
  - Technology R&D
  - Design, fabrication, assembly, test, commissioning
  - Operations
  - Decommissioning
- **In the context of "partners", with no partner dominant**

ITER's Current Objectives

- **Programmatic**
  - Demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes.

- **Physics:**
  - Produce and study a plasma dominated by α-particle heating
  - Q~10: $P_{fusion} \sim 10 \times P_{external}$ ($P_{alpha} \sim 2 \times P_{external}$) for ≥ 300s
  - Q~5: aiming at $P_{fusion} \sim 5 \times P_{external}$ ($P_{alpha} \sim P_{external}$) for steady-state
  - retain the possibility of exploring "controlled ignition" (Q ≥ 30)

- **Technology:**
  - demonstrate integrated operation of technologies for a fusion power plant, except for material and component developments
  - average neutron wall load ≥ 0.5 MW/m^2 and average lifetime fluence of ≥ 0.3 MW $years/m^2$
  - test concepts for a tritium breeding module

The US ITER Time Line (1 of 2)

1988-1990 Europe, Japan, USSR and US conduct Conceptual Design Activity

- Engineering Design Activity (EDA) begins
  with 3 co-centers (EU, Japan, US);
  International Tokamak Physics Activity (ITPA) commences

ITER Design and Technology have been developed

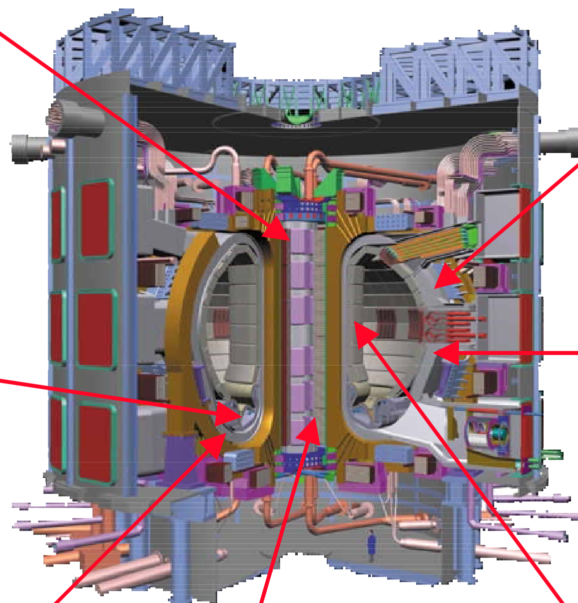
Completed R&D Activities by July 2001.

CENTRAL SOLENOID MODEL COIL

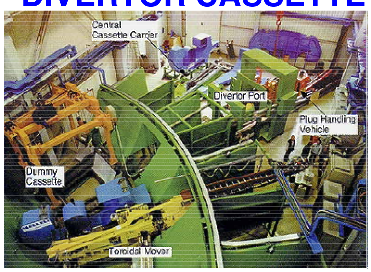
Radius 3.5 m
Height 2.8m
B_{max}=13 T
W = 640 MJ
0.6 T/sec

VACUUM VESSEL SECTOR

Double-Wall, Tolerance Å 5 mm



REMOTE MAINTENANCE OF DIVERTOR CASSETTE

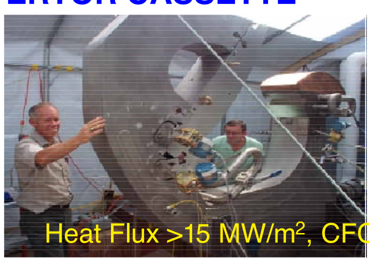


Attachment Tolerance Å 2 mm

BLANKET MODULE

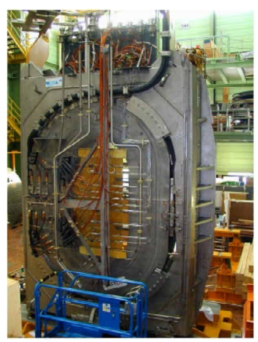
HIP Joining Tech
Size : 1.6 m x 0.93 m x 0.35 m

DIVERTOR CASSETTE



Heat Flux >15 MW/m^2, CFC/W

TOROIDAL FIELD MODEL COIL



Height 4 m
Width 3 m
B_{max}=7.8 T
I_{max} = 80kA

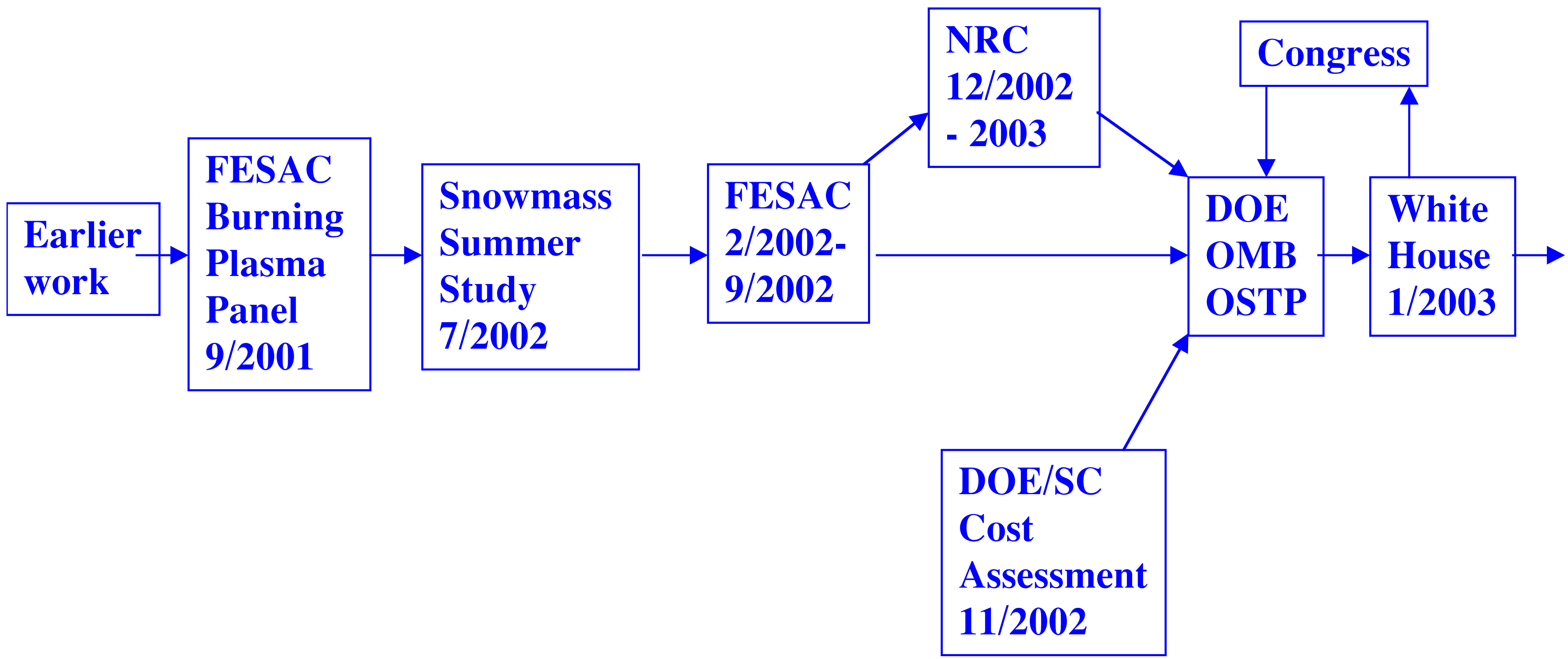
REMOTE MAINTENANCE OF BLANKET

4 t Blanket Sector
Attachment Tolerance Å 0.25 mm

The US ITER Time Line (1 of 2)

1988-1990	Europe, Japan, USSR and US conduct Conceptual Design Activity
•	Engineering Design Activity (EDA) begins with 3 co-centers (EU, Japan, US); International Tokamak Physics Activity (ITPA) commences
1996-8	US concerns mount; international concerns lead to re-scoping; US withdraws from ITER and the ITPA in 1998
•	EDA Extension starts with EU, JA and RF pursuing lower-cost, more advanced design
•	US resumes participation in ITPA
2001-present	ITER Transitional Arrangements, …
2003	4 sites proposed (France, Spain, Japan, Canada)
2003	US, China and Korea join ITER Negotiations

The path to the US decision on Burning Plasmas and participation in ITER negotiations



US decision on joining ITER Negotiations

“Now is the time to expand our scope and embrace international efforts to realize the promise of fusion energy.

Now it is time to take the next step on the way to having fusion deliver electricity to the grid.

The President has decided to take that step.

Therefore, I am pleased to announce today, that President Bush has decided that the United States will join the international negotiations on ITER.”

(Energy Secretary Abraham, Jan 30, 2003)

Roadmap

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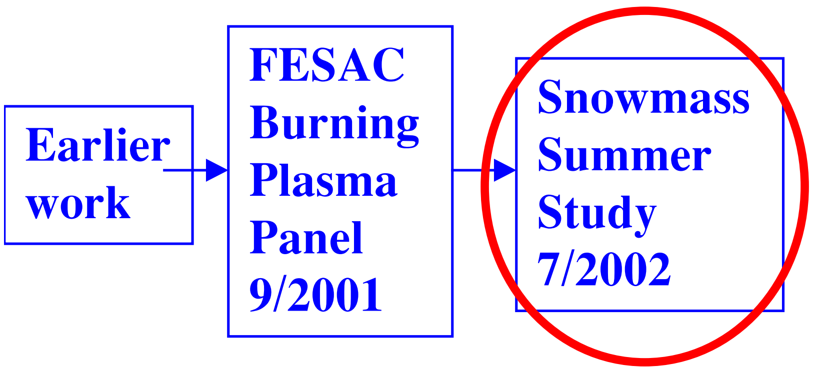
The path to the US decision on Burning Plasmas and participation in ITER negotiations



Snowmass identified issues and assessed burning plasma experiments

	Normal conductor Tokamak FIRE IGNITOR	Superconducting Tokamak ITER	BP contributions to ICCs
Physics	Argue for scientific and technological benefits of approaches		Assess benefits of a tokamak BPX to ICC path
Technology	Identify key scientific, technological, and path issues Determine assessment criteria Perform uniform assessments of approaches		
Experimental Approach and Objectives			

Major MFE Conclusions of Snowmass

- Why a burning plasma

2. Burning plasma options

3. Assessment of contributions of the options

4. Assessment of the feasibility of the options

5. Assessment of fusion development paths

6. Relation to the national program

Conclusion #1 - Why a burning plasma

- The study of burning plasmas, in which self-heating from fusion reactions dominates plasma behavior, is at the frontier of magnetic fusion energy science.
- The next major step in magnetic fusion research should be a burning plasma program, which is essential to the science focus and energy goal of fusion research.

Conclusion #1 - Supporting Material

- **a crucial and missing element in the fusion energy sciences program**

- **The tokamak is now at the stage of scientific maturity that we are ready to undertake the essential step of burning plasma research.**

- **Burning plasmas afford unique opportunities to explore, for the first time in the laboratory, high-temperature-plasma behavior in the regime of strong self-heating.**

- **Recent physics advances in tokamak research, aimed at steady-state and high performance, demonstrate the potential to significantly increase the economic attractiveness of the tokamak.**
  - Therefore, Advanced Tokamak (AT) research capability is highly desirable in any burning plasma experiment option.

- **Physics and technology learned in a tokamak-based burning plasma would be transferable to other configurations.**

Key aspects of a Burning Plasma

- **Dynamical properties are governed by a complex set of interactions among the physical phenomena**

  – Self-heating:
  alpha particles, produced by fusion, are the principal means of heating and sustainment.
    - Spatial profiles are largely self-organized
    - Reduced extent of external control makes achievement of steady-state high performance more challenging

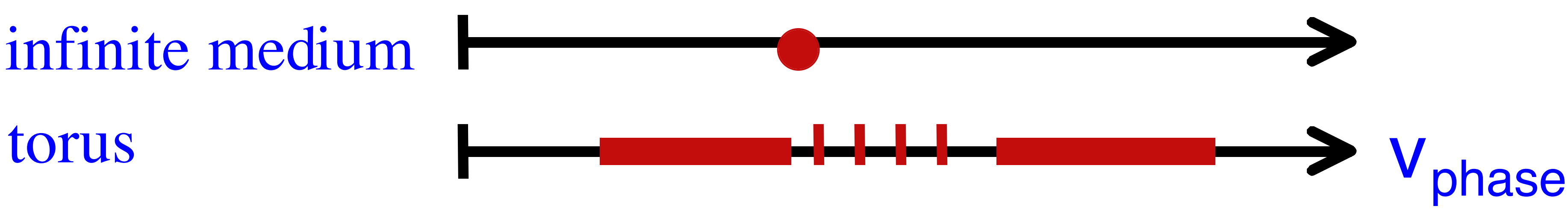
  – Energetic articles:
  super-Alfvénic alphas can excite modes which can redistribute the energetic particles

  – Size-scaling:
  interactions between physical phenomena are scale-dependent
  (turbulence scale relative to system-size, core/edge/wall interface, error-field sensitivity, …)

Effects of fusion-reactions

- **Fast-alphas**
  - heat the plasma (mostly electrons) while slowing-down
    - Changes equilibrium, enables greater self-organization
  - deposit Helium in the core, following slowing-down (ash build-up)
  - can drive Alfvén modes, leading to accelerated loss of fast-alphas

Phase velocity spectrum



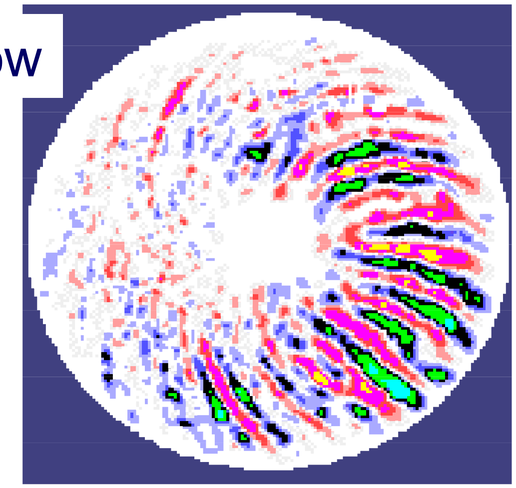
waves driven by wave-particle resonance

$$V_{\substack{Alfven\\wave}} = V_{\substack{alpha\\particle}}$$

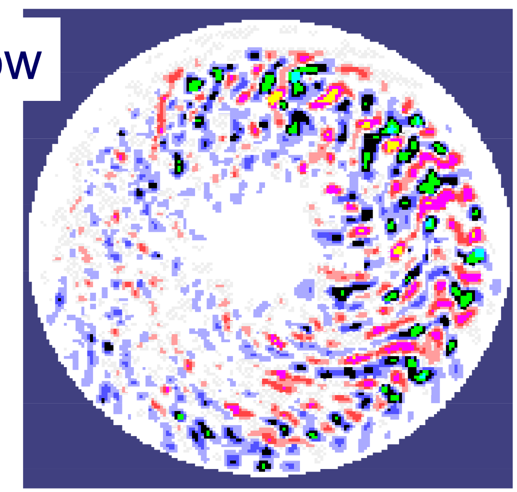
Turbulence simulations are exploring transition from structures that are extrinsic to those that are intrinsic

Gyrokinetic Simulation: Z. Lin

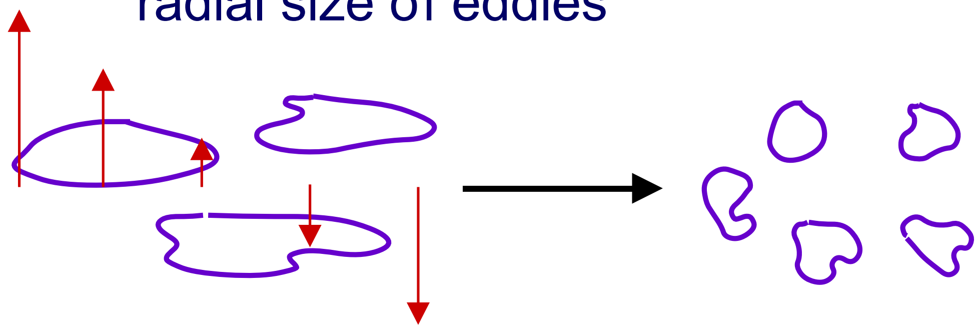
No flow



With flow



• Sheared ExB flow reduces radial size of eddies



• Breakup of long finger structures suppresses transport

• Techniques are being developed for the direct control of the turbulence

Gyrokinetic Simulations of Plasma Microinstabilities

simulation by

Zhihong Lin et al.

Science 281, 1835 (1998)

Conclusion #3

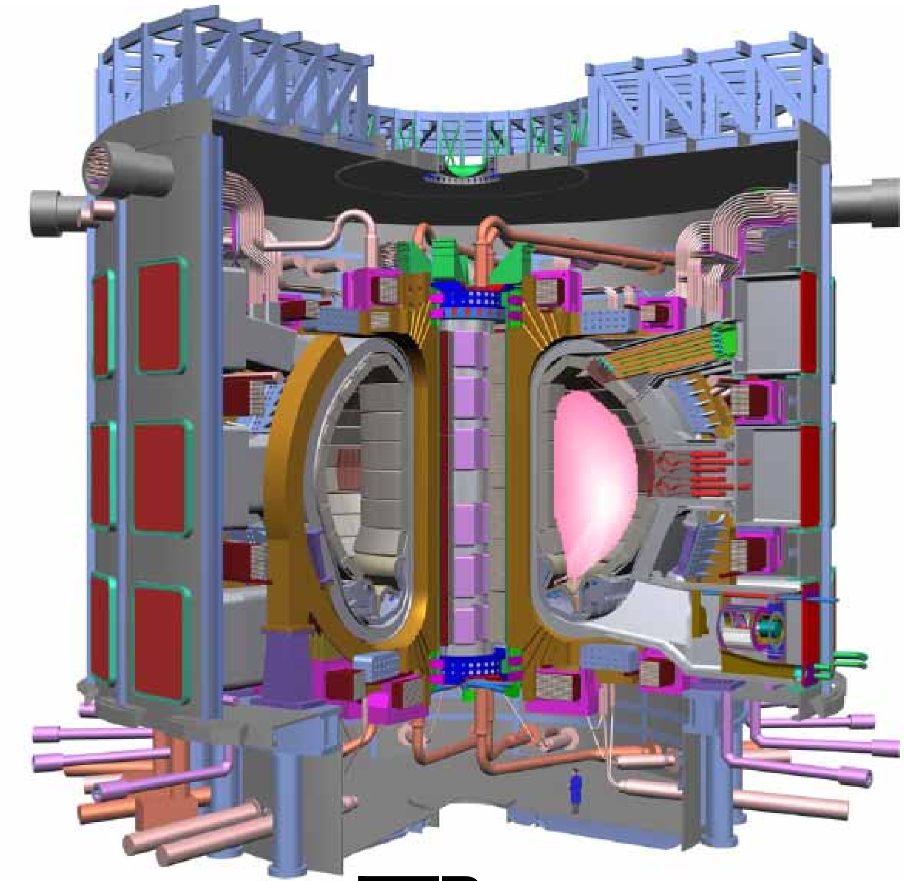
- **IGNITOR, FIRE, and ITER would enable studies of the physics of burning plasma, advance fusion technology, and contribute to the development of fusion energy. The contributions of the three approaches would differ considerably.**

  – IGNITOR offers an opportunity for the early study of burning plasmas aiming at ignition for about one current redistribution period.

  – FIRE offers an opportunity for the study of burning plasma physics in conventional and advanced tokamak configurations under quasi-stationary conditions (several current redistribution time periods) and would contribute to plasma technology.

  – ITER offers an opportunity for the study of burning plasma physics in conventional and advanced tokamak configurations for long durations (many current redistribution time periods) with steady state as the ultimate goal, and would contribute to the development and integration of plasma and fusion technology.

Experimental Approaches to Burning Plasmas

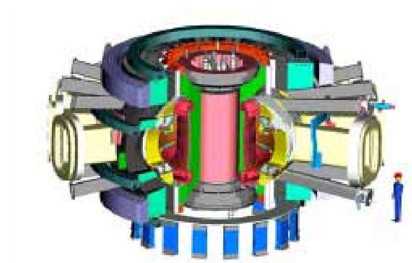


ITER

International Thermonuclear Experimental Reactor

Integrates burning and steady state

International partnership (~ $5B)



FIRE

Fusion Ignition Research Experiment

Burning, but integration later

US-based (~ $1B)

Conclusion #3 - Common Benefits of Burning Plasma Approaches

- **PHYSICS**
  - 1. Strongly-coupled physics issues of equilibrium, stability, transport, wave-particle interactions, fast ion physics, and boundary physics in the regime of dominant self-heating.
- **TECHNOLOGY**
  - 2. Plasma support technologies (heating, fuel delivery, exhaust, plasma-facing components, and magnets) will benefit most because parameters and plasma conditions will be close to those required for power production.
  - 3. Nuclear technologies (remote handling, vacuum vessel, blankets, safety and materials) will advance as a result of the experience of operating in a nuclear environment. The level of benefit will depend on tritium inventory, pulse length, duty factor, and lifetime fluence.

Representative ITER Scenarios examined at Snowmass

Parameter	400 MW	500 MW
R/a (m/m)	6.2/2.0	6.2/2.0
Volume (m^3)	831	831
Surface (m^2)	683	683
Sep. length (m)	18.2	18.2
$S_{cross\text{-}sect}$ (m^2)	21.9	21.9
B_T (T)	5.3	5.3
I_p (MA)	15.0	15.0
κ_x/δ_x	1.85/0.48	1.85/0.48
κ_{95}/δ_{95}	1.70/0.33	1.70/0.33
$\imath_i(3)$	0.84	0.84
V_{loop} (mV)	75	75
q_{95}	3	3
β_N	1.8	2.0
$\langle n_e \rangle$ (10^{19} m^3)	10.1	11.3
$\langle n_e \rangle / n_G$	0.85	0.94
$\langle T_e \rangle$ (keV)	8.8	8.9
$\langle T_i \rangle$ (keV)	8.0	8.1
β_T (%)	2.5	2.8
β_p	0.65	0.72

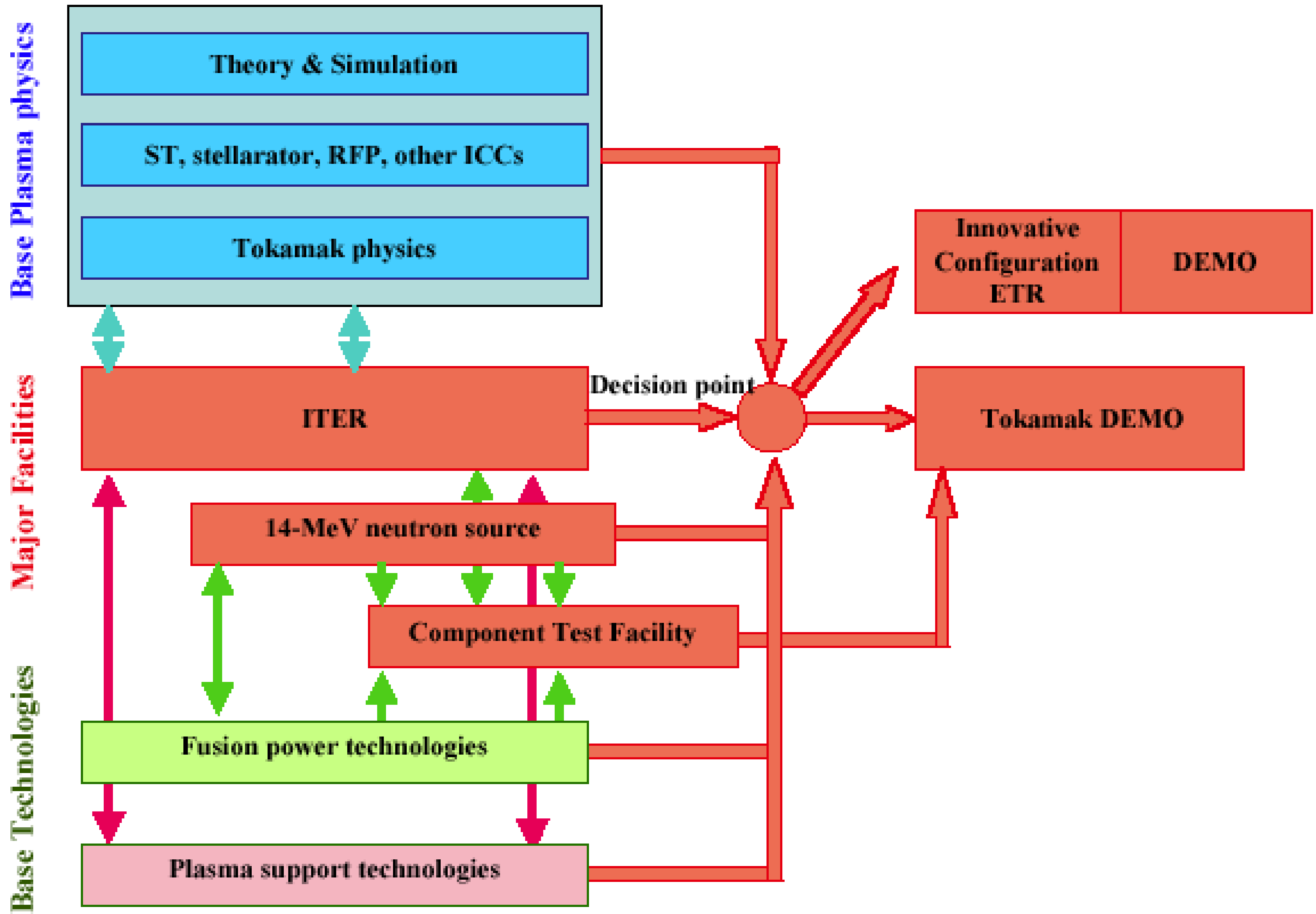
Parameter	400 MW	500 MW
$P_{RF}+P_{NB}$ (MW)	7+33	17+33
P_{OH} (MW)	1	1
P_{TOT} (MW)	121	151
P_{BRM} (MW)	21	26
P_{SYN} (MW)	8	8
P_{LINE} (MW)	18	27
P_{RAD} (MW)	47	61
P_{FUS} (MW)	400	500
$P_{LOSS}/P_{L\text{-}H}$	87/48	104/51
Q	10	10
τ_E (s)	3.7	3.4
W_h (MJ)	320	353
W_{fast} (MJ)	32	34
$H_{H98\,(y,2)}$	1.0	1.0
τ_{He}^{*}/τ_E	5	5
$Z_{eff,ave}$	1.66	1.72
$f_{He,,axis\,/\,ave}$ (%)	4.3/3.2	4.4/3.2
$f_{Be,axis}$ (%)	2.0	2.0
$f_{Ar,axis}$ (%)	0.12	0.14

Conclusion #3 - Key Benefits of ITER

- **PHYSICS**
  1. Capability to address the science of self-heated plasmas in reactor-relevant regimes of small ρ^* (many Larmor orbits) and high β_N (plasma pressure), and with the capability of full non-inductive current drive sustained in near steady state conditions.
  2. Exploration of high self-driven current regimes with a flexible array of heating, current drive, and rotational drive systems.
  3. Exploration of alpha particle-driven instabilities in a reactor-relevant range of temperatures.
  4. Investigation of temperature control and removal of helium ash and impurities with strong exhaust pumping.

- **TECHNOLOGY**
  5. Integration of steady-state reactor-relevant fusion technology: large-scale high-field superconducting magnets; long-pulse high-heat-load plasma-facing components; control systems; heating systems.
  6. Testing of blanket modules for breeding tritium.

Conclusion #5 - ITER Development Path

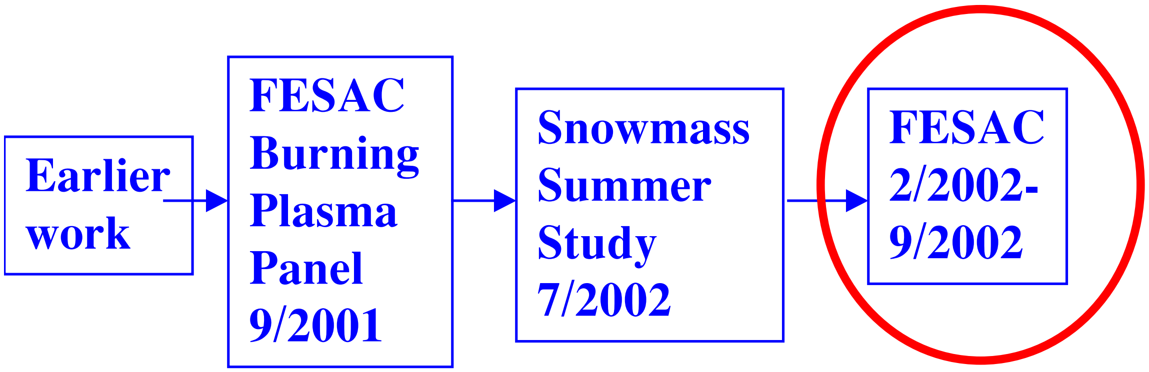


General Observations from Snowmass 2002

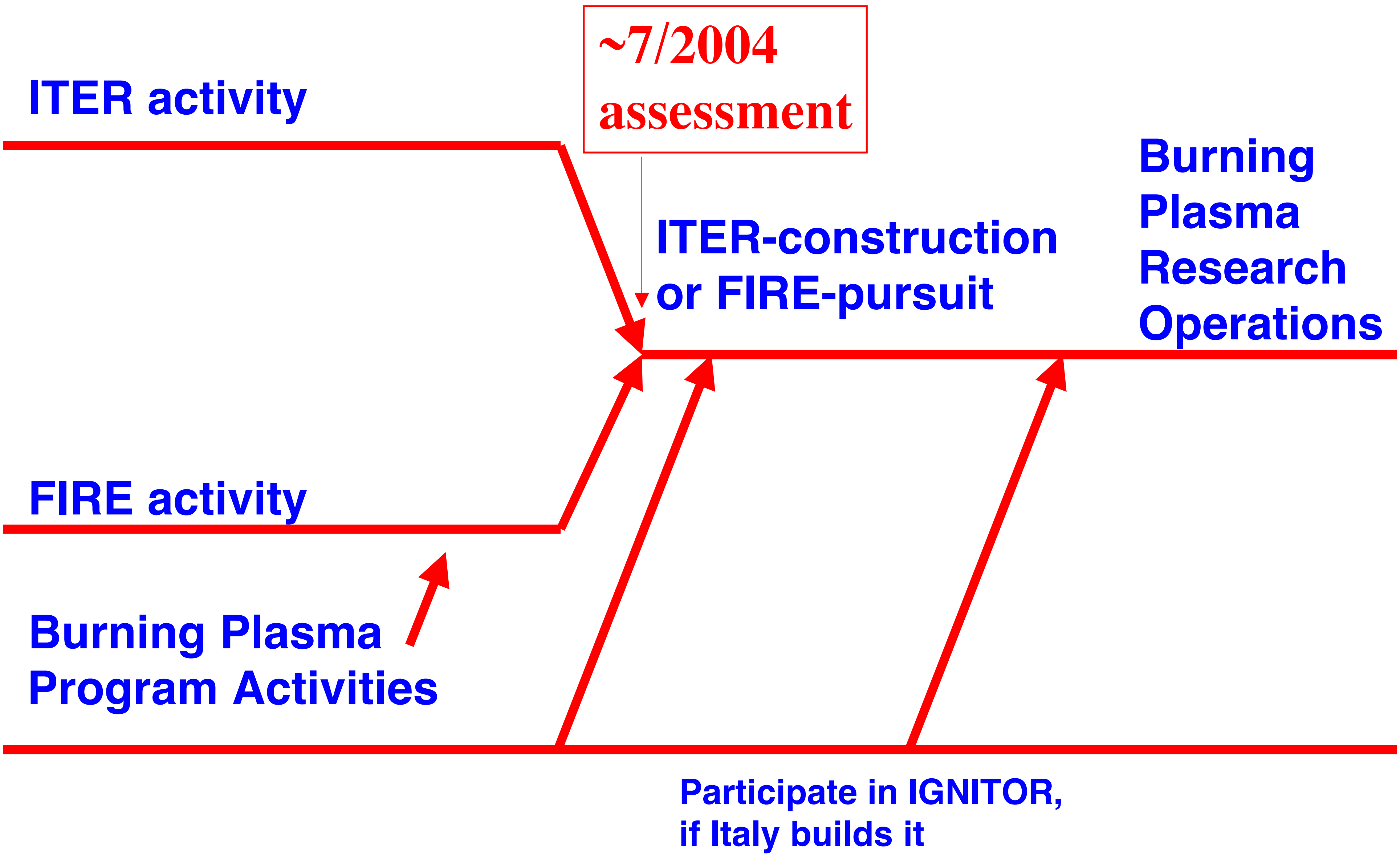
- **Strong sense of excitement and unity in the community for moving forward with a burning plasma step**

- **Overwhelming consensus that**
  – Burning plasmas are opportunities for good science --- exploration and discovery
  – Tokamaks are ready to proceed -- the science-technology basis is sufficient
  – Other toroidal configurations (ICCs) would benefit from a burning tokamak plasma
  – The base program and the ICC elements play a critical role in the overall fusion energy science program which includes a burning plasma

The path to the US decision on Burning Plasmas and participation in ITER negotiations



The FESAC US Burning Plasma Plan



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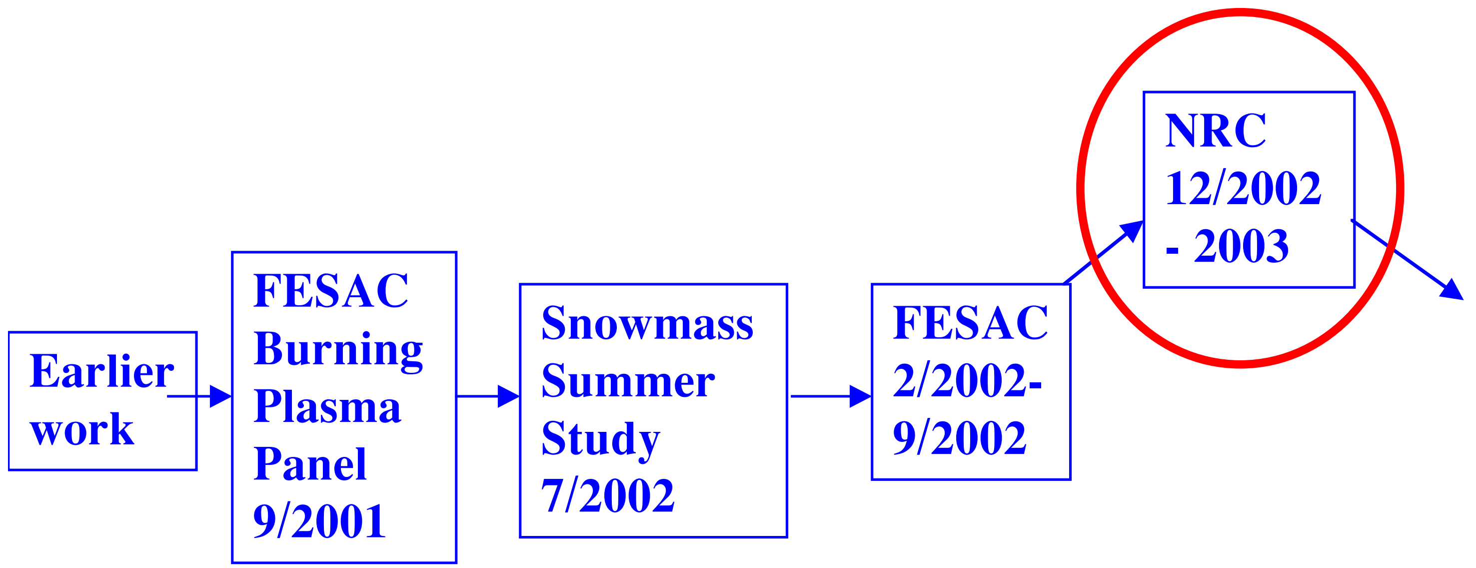
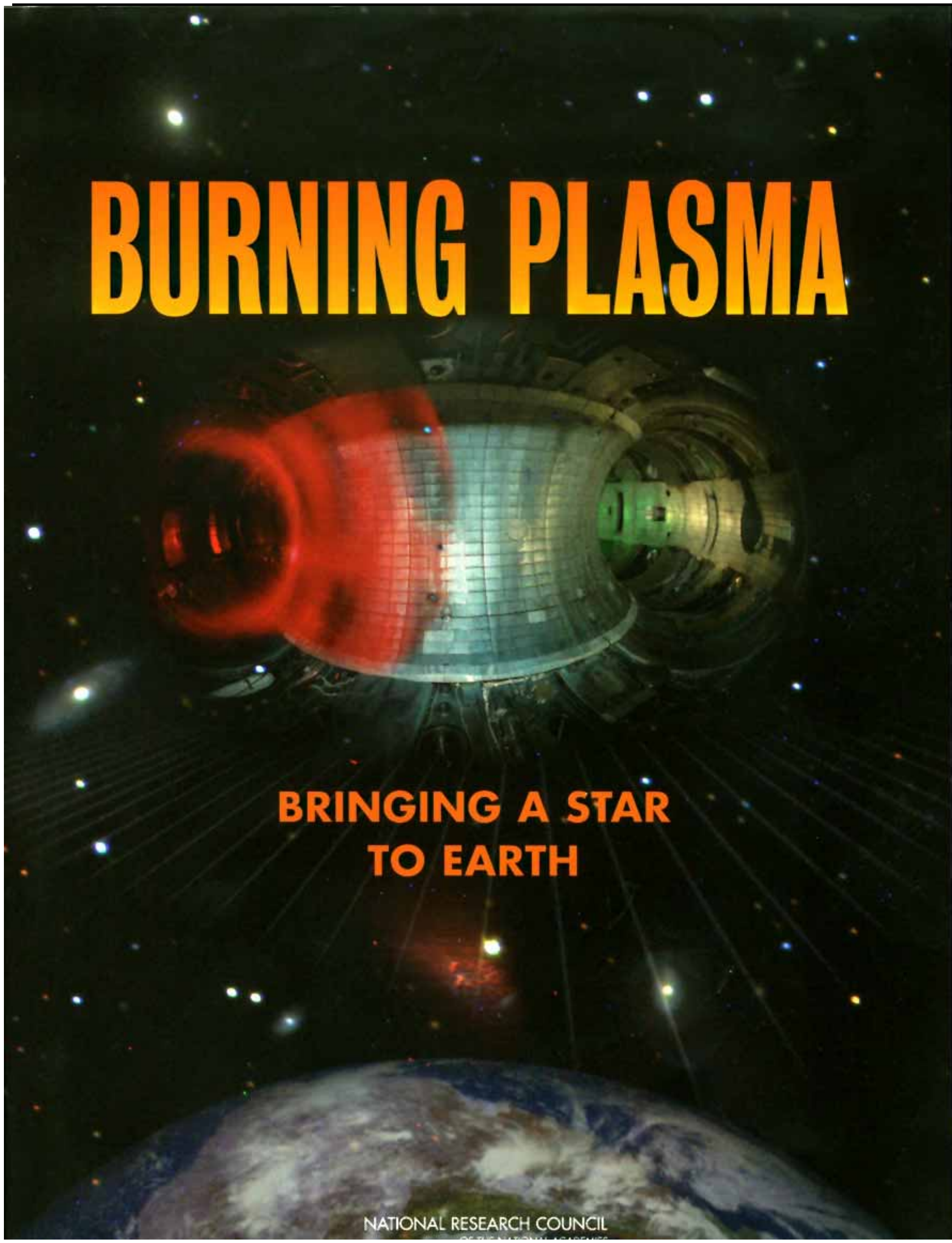


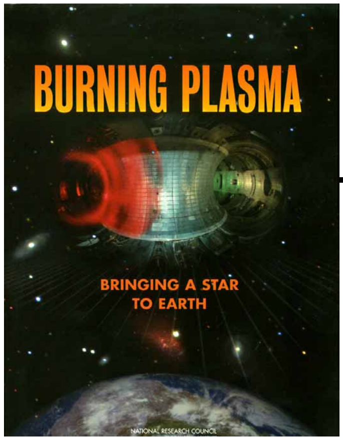
NRC Burning Plasma Report

“Burning Plasma: Bringing a Start to Earth”



- The United States should participate in ITER.
  If an international agreement to build ITER is reached, fulfilling the U.S. commitment should be the top priority in a balanced fusion science program.

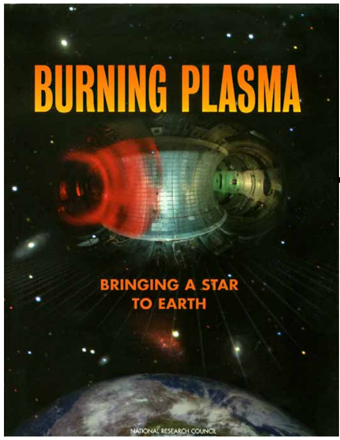
- The United States should pursue an appropriate level of involvement in ITER, which at a minimum would guarantee access to all data from ITER, the right to propose and carry out experiments, and a role in producing the high-technology components of the facility consistent with the size of the U.S. contribution to the program.



Scientific Benefits from "Burning Plasma: Bringing a Start to Earth" (NRC)

- **Contributions to Understanding for Fusion Energy Science**
  – Behavior of Self-Sustaining Burning Plasmas
  – Plasma Turbulence and Turbulent Transport
  – Stability Limits to Plasma Pressure
  – Controlling Sustained Burning Plasmas
  – Power and Particle Exhaust

- **Contributions to Understanding for Basic Plasma Physics**
  – Magnetic Field Line Reconnection
  – Abrupt Plasma Behavior
  – Energetic Particles in Plasmas

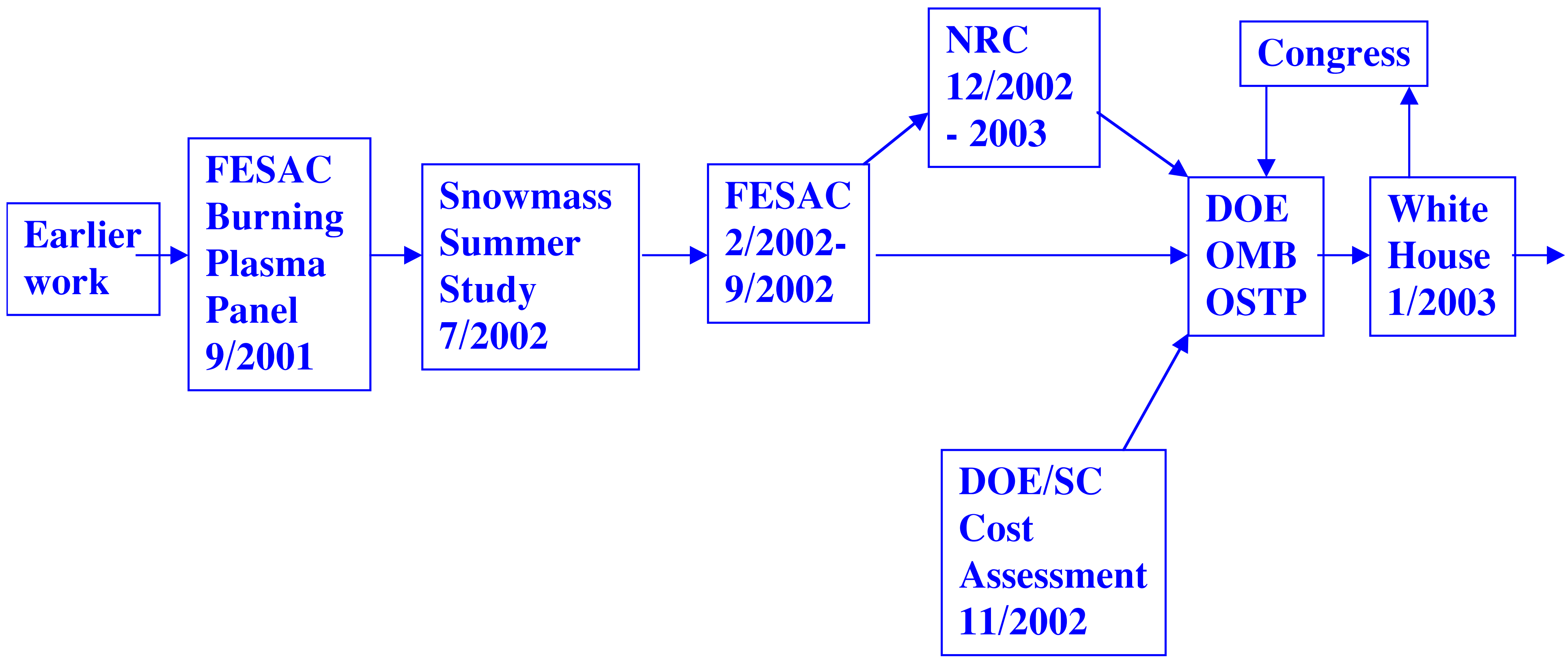


Scientific Readiness from "Burning Plasma: Bringing a Start to Earth" (NRC)

- **Areas assessed:**
  - Confinement projections
  - Operational boundaries
  - Mitigation of abnormal events
  - Maintenance of plasma purity
  - Characterization techniques
  - Plasma control techniques

- **"It is clear that ongoing research can be expected to adequately address issues requiring continued attention, but no issues remain that would undermine the fusion community's assertion that it is ready to undertake a burning plasma experiment."**

The path to the US decision on Burning Plasmas and participation in ITER negotiations



ITER-Requested 2004 Physics Tasks (2/27/04)

– **Neoclassical Tearing Mode control in Inductive and Hybrid Scenario in ITER**

– **Resistive Wall Mode in Steady State Scenario in ITER**

3) Vertical Displacement Events, Disruptions and their mitigation in ITER

4) Plasma position and shape control with 3D model of vacuum vessel

5) Error Field Control in ITER

6) ITER Plasma Integrated Model for ITER

7) Development of Steady State Scenarios in ITER

8) Evaluation of Fast Particle Confinement of ITER

9) Assessment of Edge Pedestal and ELMs of ITER

Roadmap

Very brief overview of toroidal magnetic confinement, burning plasmas, and ITER

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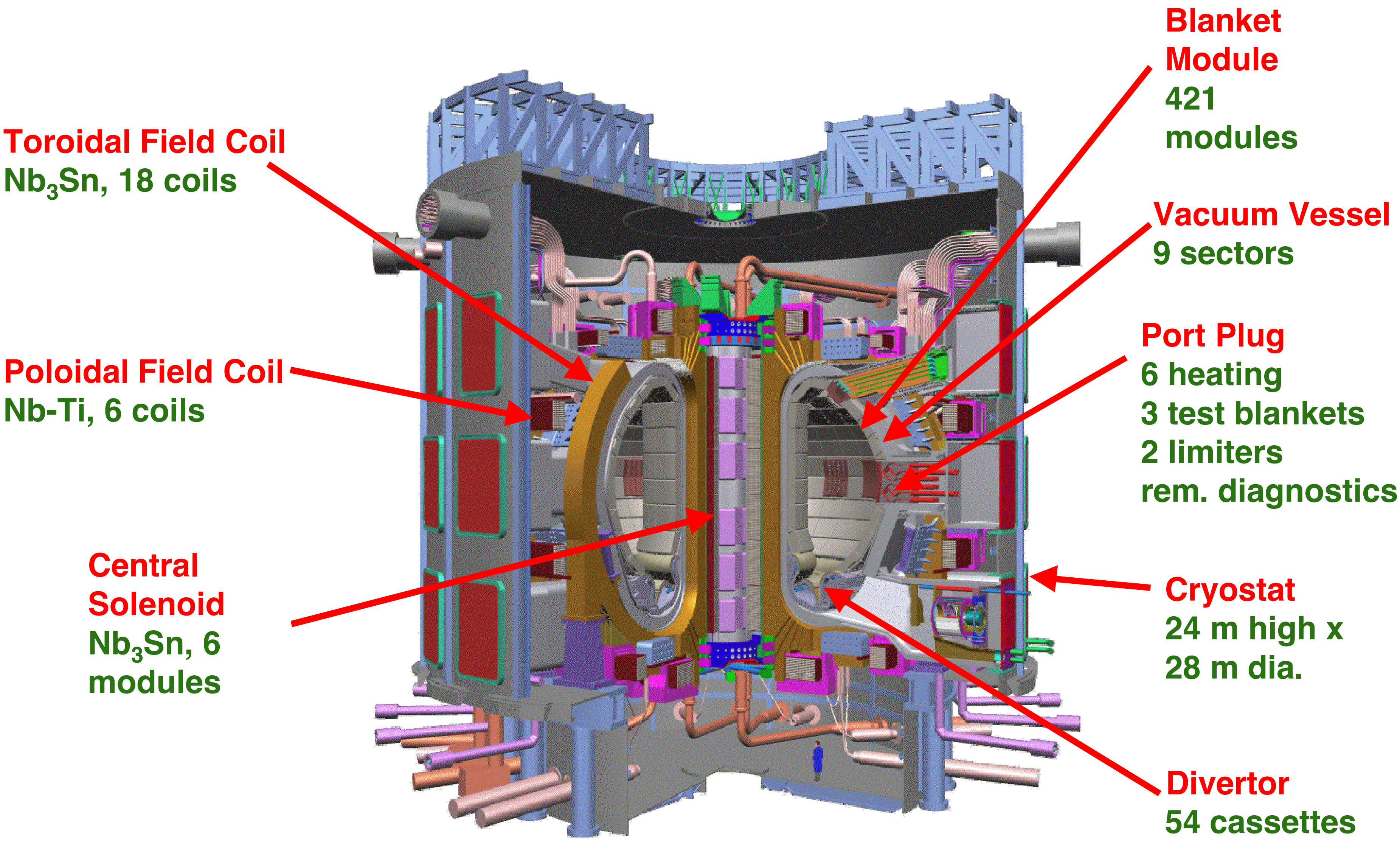
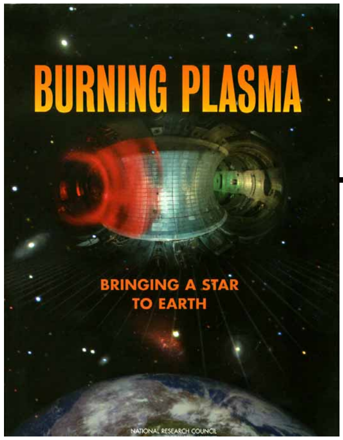
ITER as an experiment in … Technology

ITER as an experiment in … International Collaboration

A look to the future

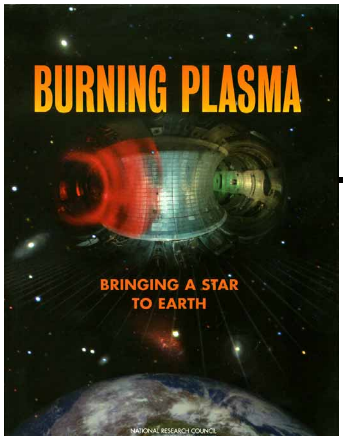
Major Components of ITER





Technological Benefits from "Burning Plasma: Bringing a Start to Earth" (NRC)

- Breeding Blanket Development
- Tritium Processing
- Magnet Technology
- High-Heat-Flux Component Development
- Remote Handling Technology

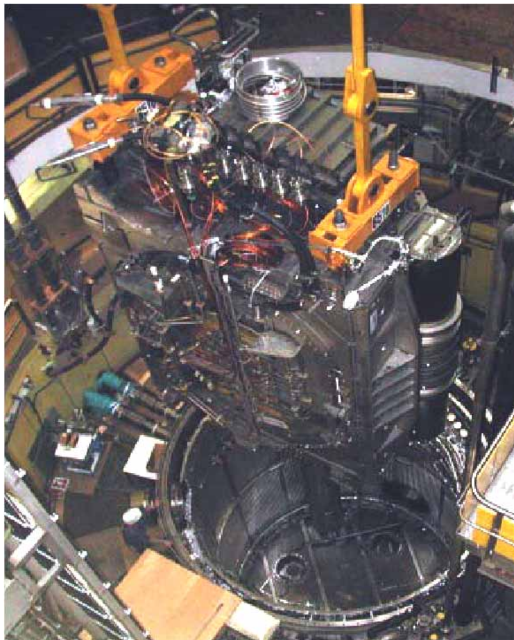


Technological Readiness from "Burning Plasma: Bringing a Start to Earth" (NRC)

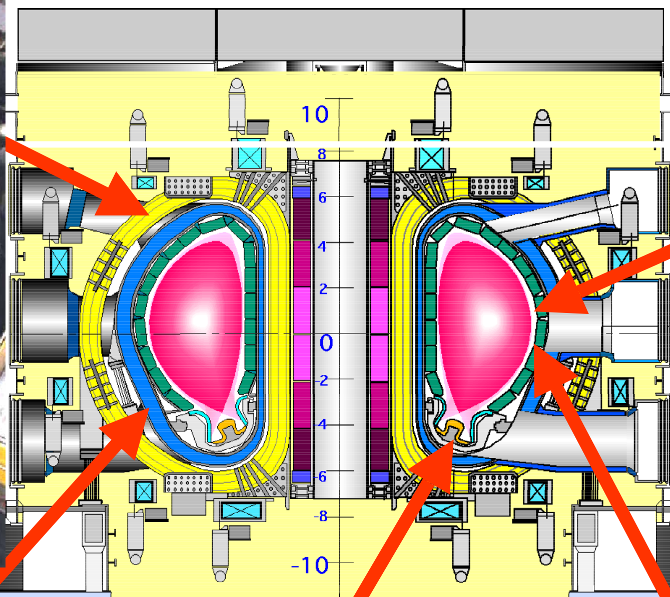
- **Areas assesed:**
  - Fabrication of necessary components
  - Component lifetime in a nuclear environment
  - Lifetime of plasma-facing components
  - Tritium inventory control
  - Remote maintenance
  - Fueling, heating, and current drive control

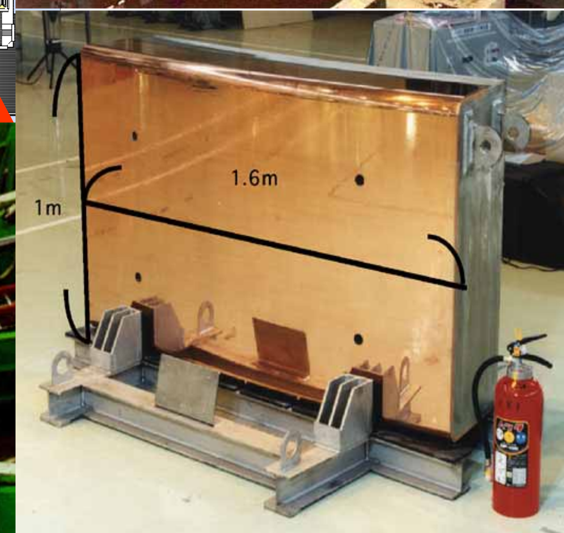
- **"It is clear that ongoing research can be expected to adequately address issues requiring continued attention, but no issues remain that would undermine the fusion community's assertion that it is ready to undertake a burning plasma experiment."**

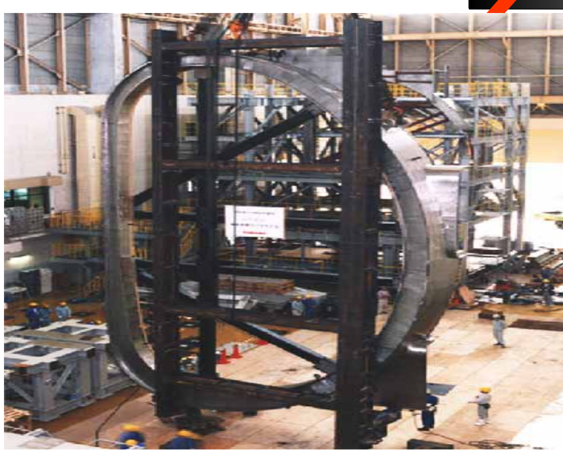
Key tokamak components have been prototyped



TFModel Coil





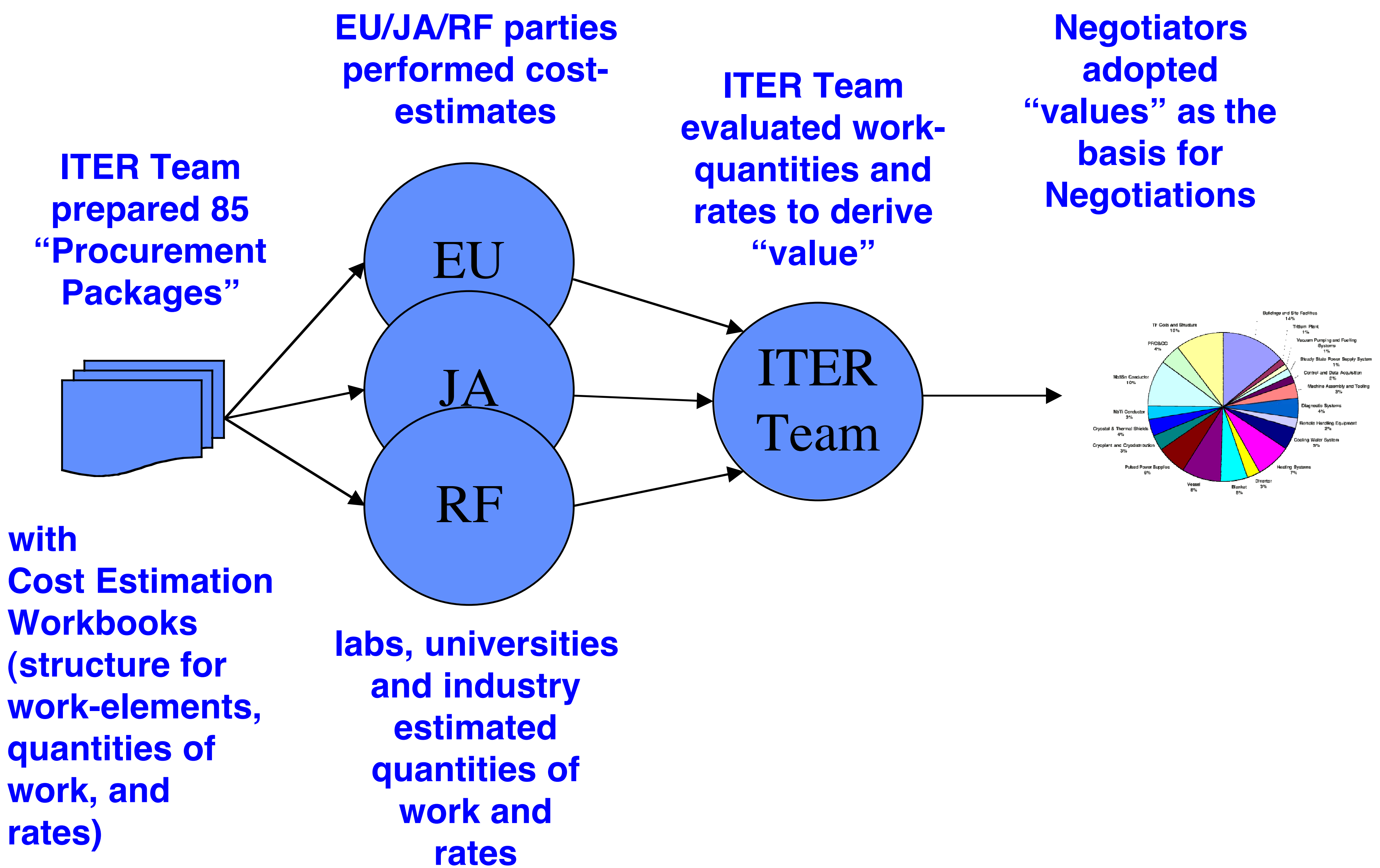


Vacuum Vessel Sector

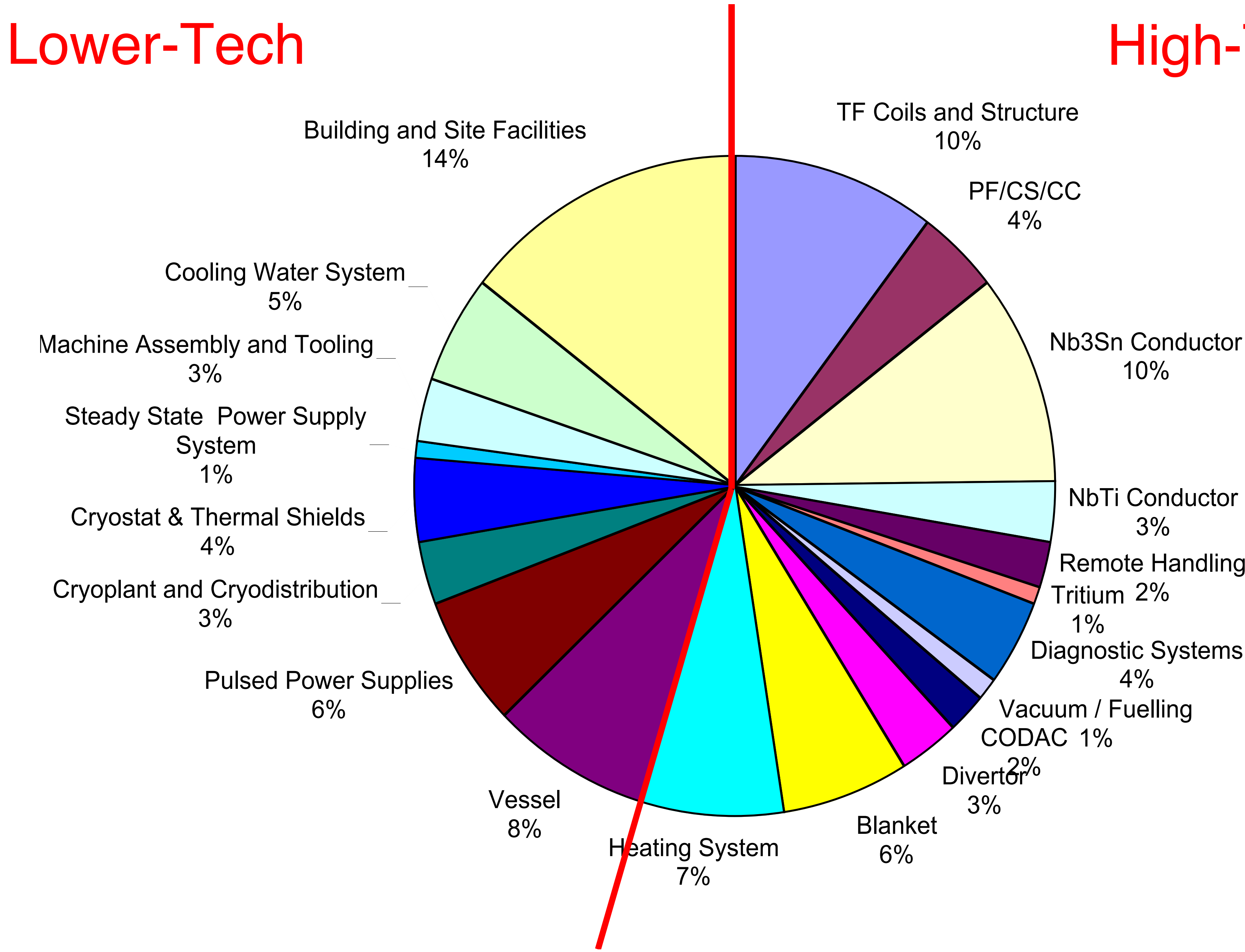
Remote Handling Tool of Divertor

Blanket and its Remote Handling Tool

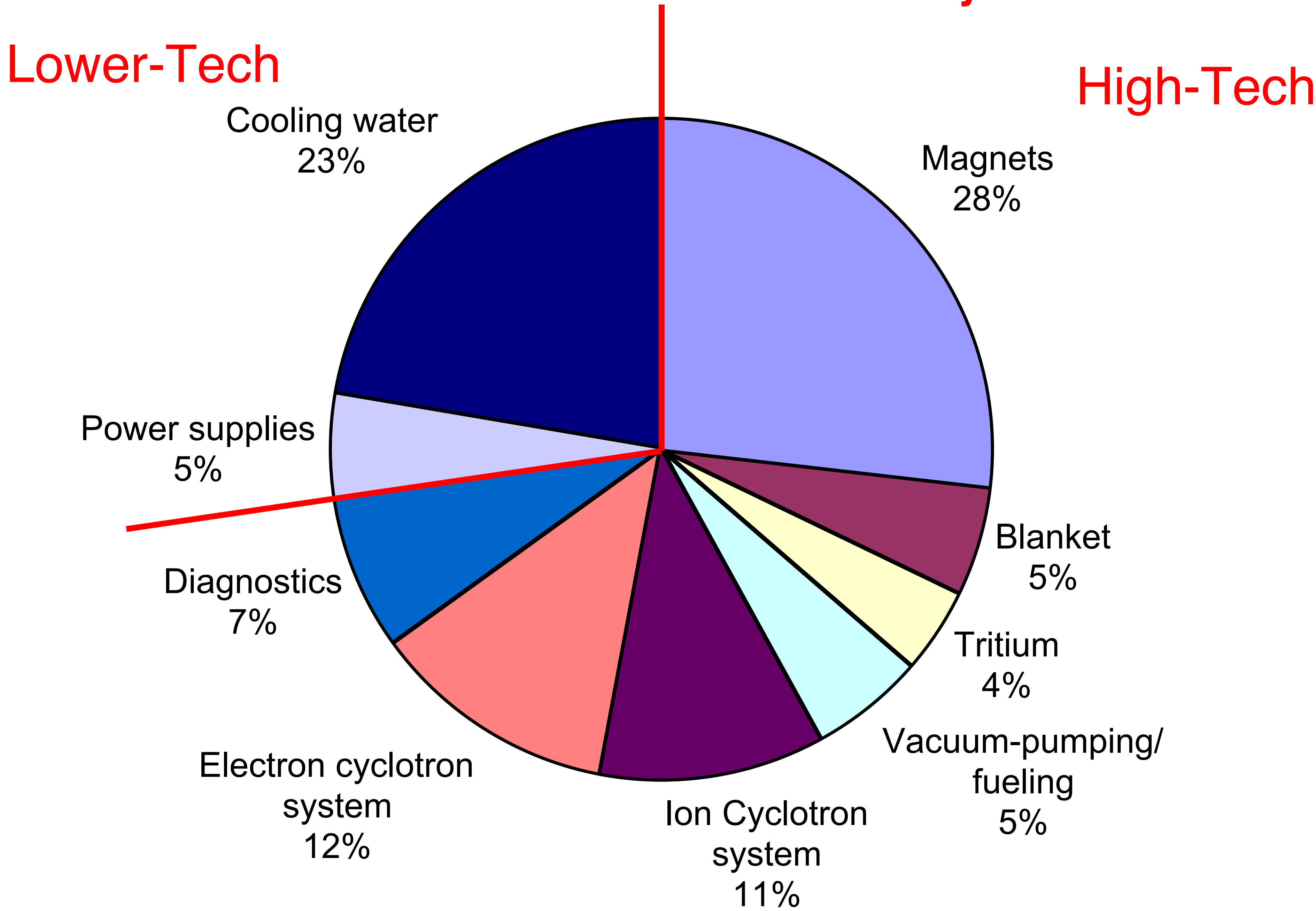
ITER “Value”


EU/JA/RF parties performed cost-estimates
ITER Team evaluated work-quantities and rates to derive “value”
Negotiators adopted “values” as the basis for Negotiations
ITER Team prepared 85 “Procurement Packages”
EU
JA
RF
ITER Team
with Cost Estimation Workbooks (structure for work-elements, quantities of work, and rates)
labs, universities and industry estimated quantities of work and rates
Buildings and Site Facilities 14%
Tritium Plant 1%
Vacuum Pumping and Fuelling Systems 1%
Steady State Power Supply System 1%
Control and Data Acquisition 2%
Machine Assembly and Tooling 3%
Diagnostic Systems 4%
Remote Handling Equipment 2%
Cooling Water System 5%
Heating Systems 7%
Divertor 3%
Blanket 6%
Vessel 8%
Pulsed Power Supplies 6%
Cryoplant and Cryodistribution 3%
Cryostat & Thermal Shields 4%
NbTi Conductor 3%
Nb3Sn Conductor 10%
PF/CS/CC 4%
TF Coils and Structure 10%

ITER value is about 50% in "high-tech systems"



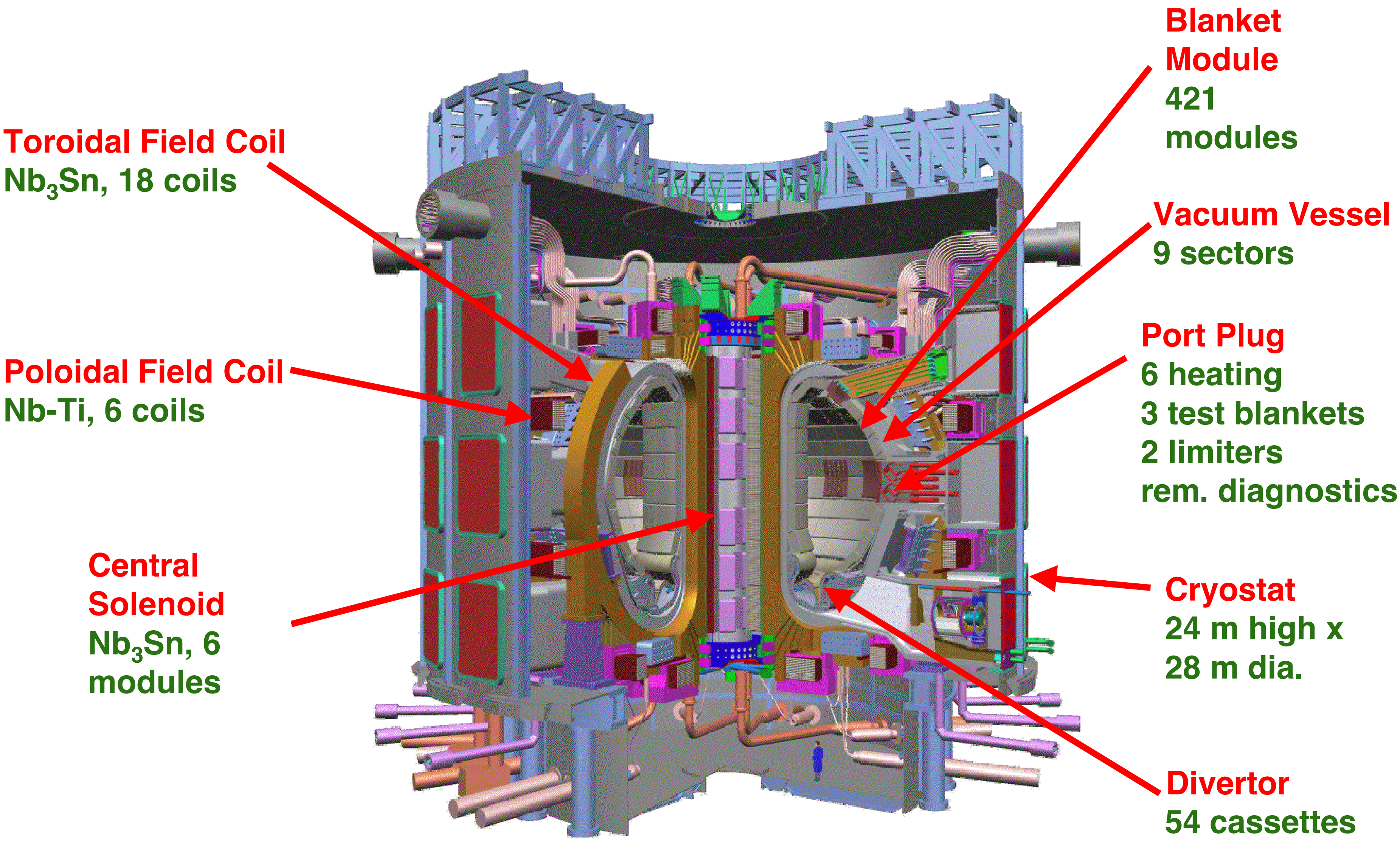
Tentative US in-kind contributions by Value



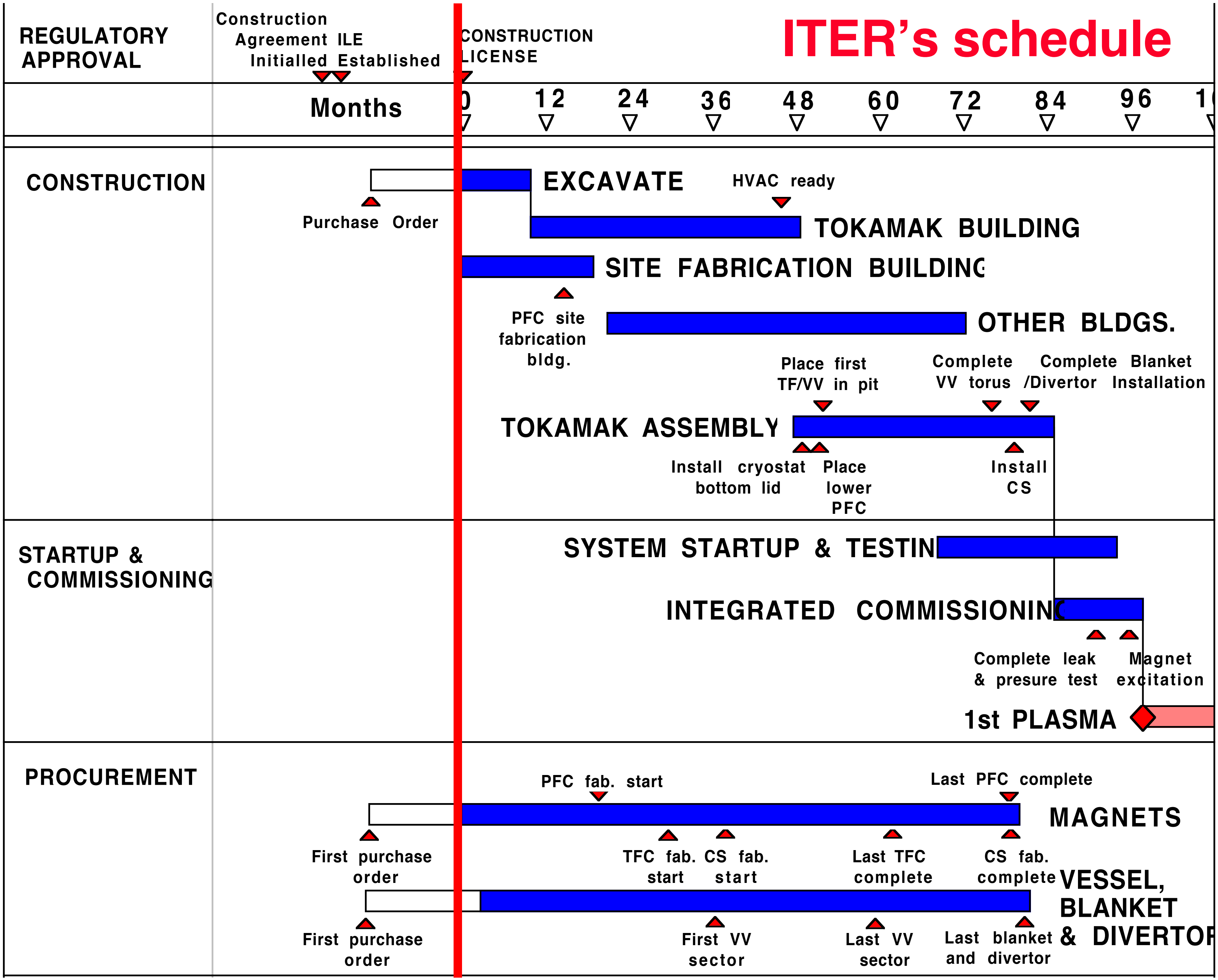
Overview of tentative US in-kind contributions: Not including Heating & Current Drive and Diagnostics

System	Description of US portion
Magnets	4 of 7 Central Solenoid Modules
Blanket/Shield	Module 18 (baffle)
Vacuum-pumping/ fueling	Roughing pumps, standard components, pellet injector
Tritium	Tokamak exhaust processing system
Cooling water	Cooling for divertor, vacuum vessel, …
Power supplies	Steady-state power supplies
Ion Cyclotron system	44% of antenna + all transmission/RF-sources/power supplies
Electron cyclotron system	Start-up gyrotrons, all transmission lines and power supplies
Diagnostics	Allocations being discussed

Major Components of ITER



ITER's schedule



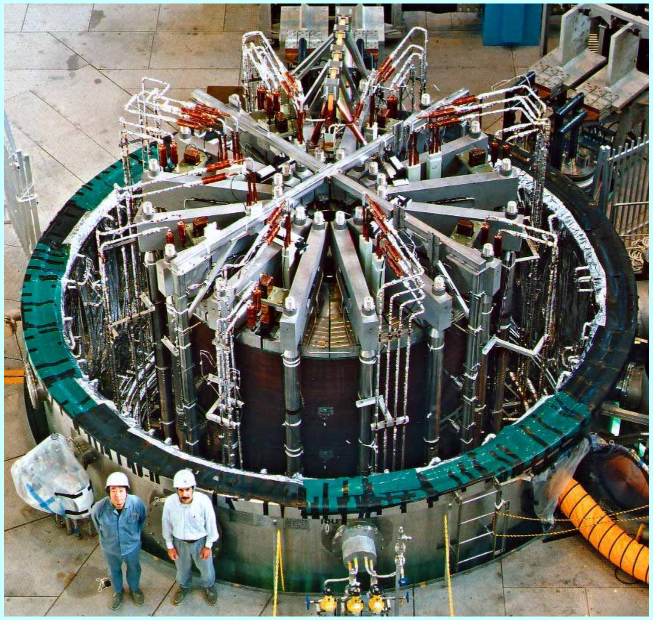
Magnets:
Central Solenoid

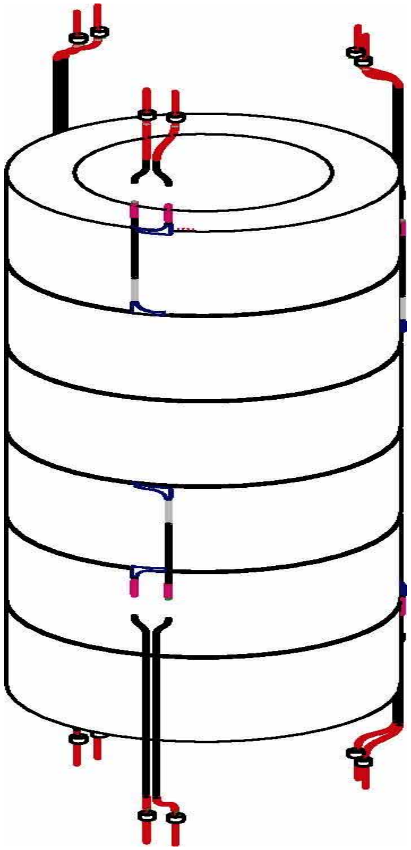
Description of US portion	US fraction of system (by ITER value)	US Value (kIUA) [$M]
4 of 7 Central Solenoid Modules	9% of full system; 57% of central solenoid	74.2 [$107M]

Overview of Central Solenoid

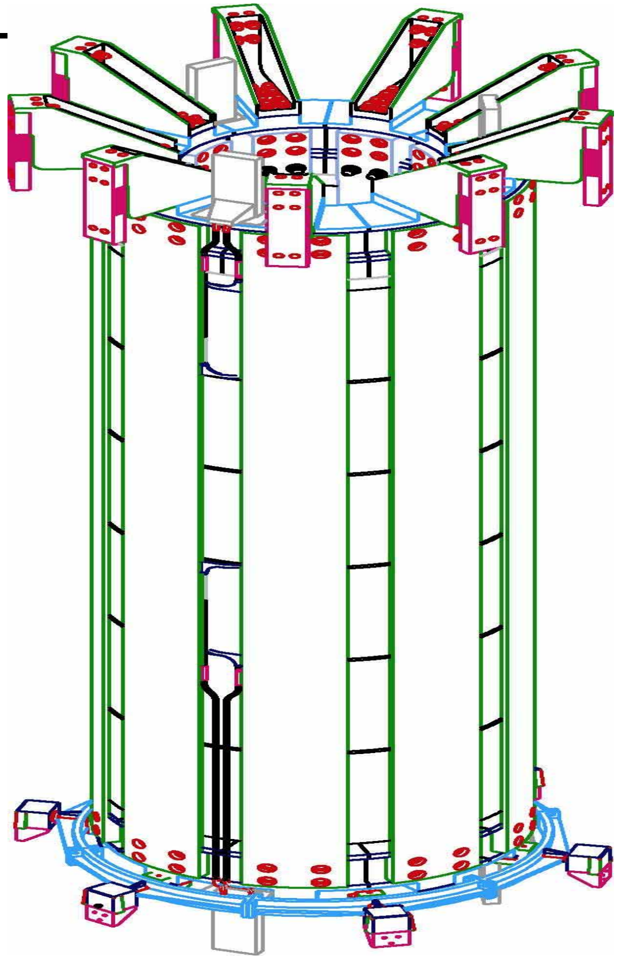
- Max. B: 13.0 T (IM)
- Max. I: 45.0 kA (EOB)
- Nb_3Sn CICC,
- Conduit: JK2LB
- 6 independent modules
- 9 tie-plates (SS316LN)

Each Module is slightly larger than the complete CS Model Coil



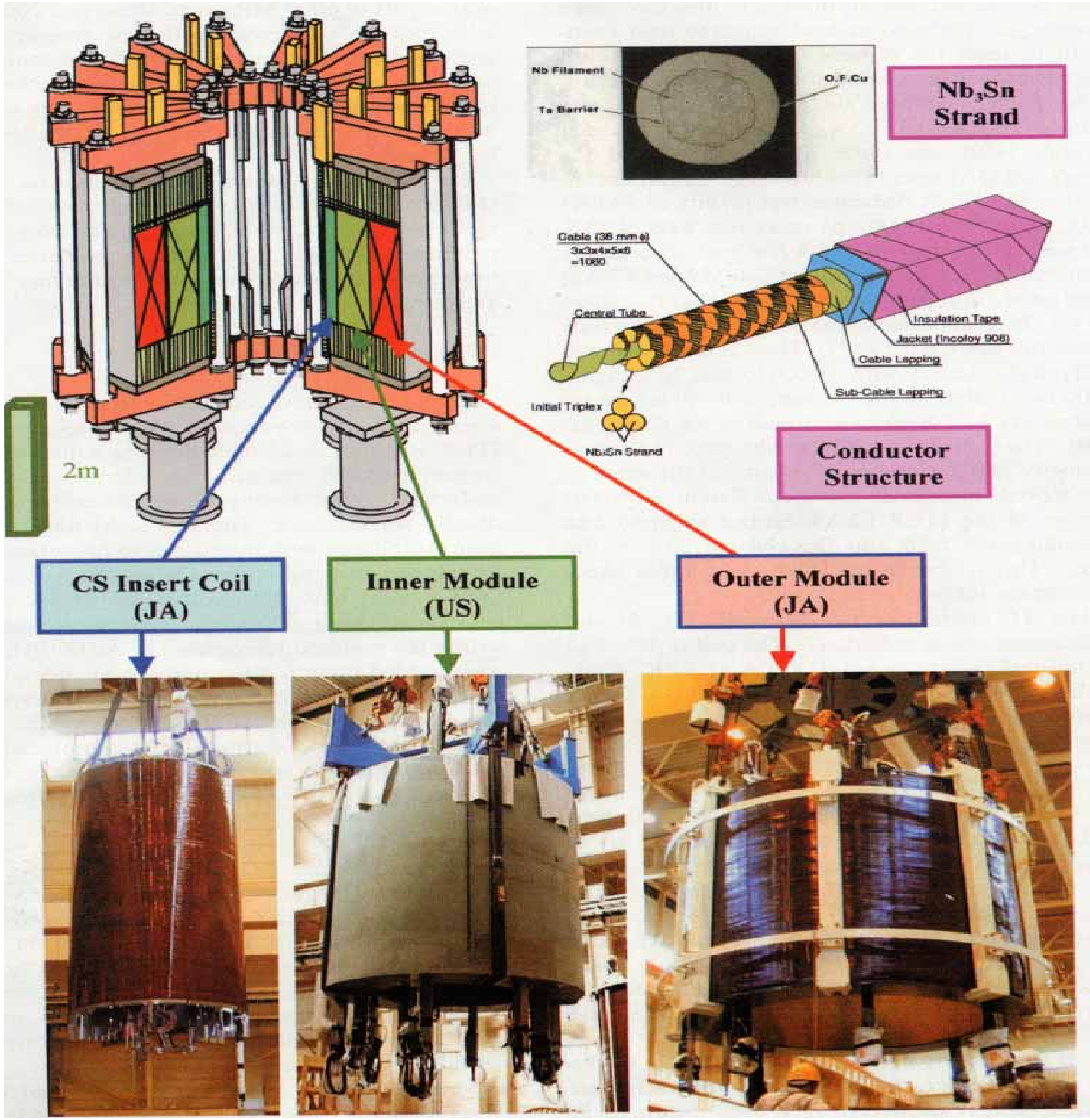


Before assembling structure

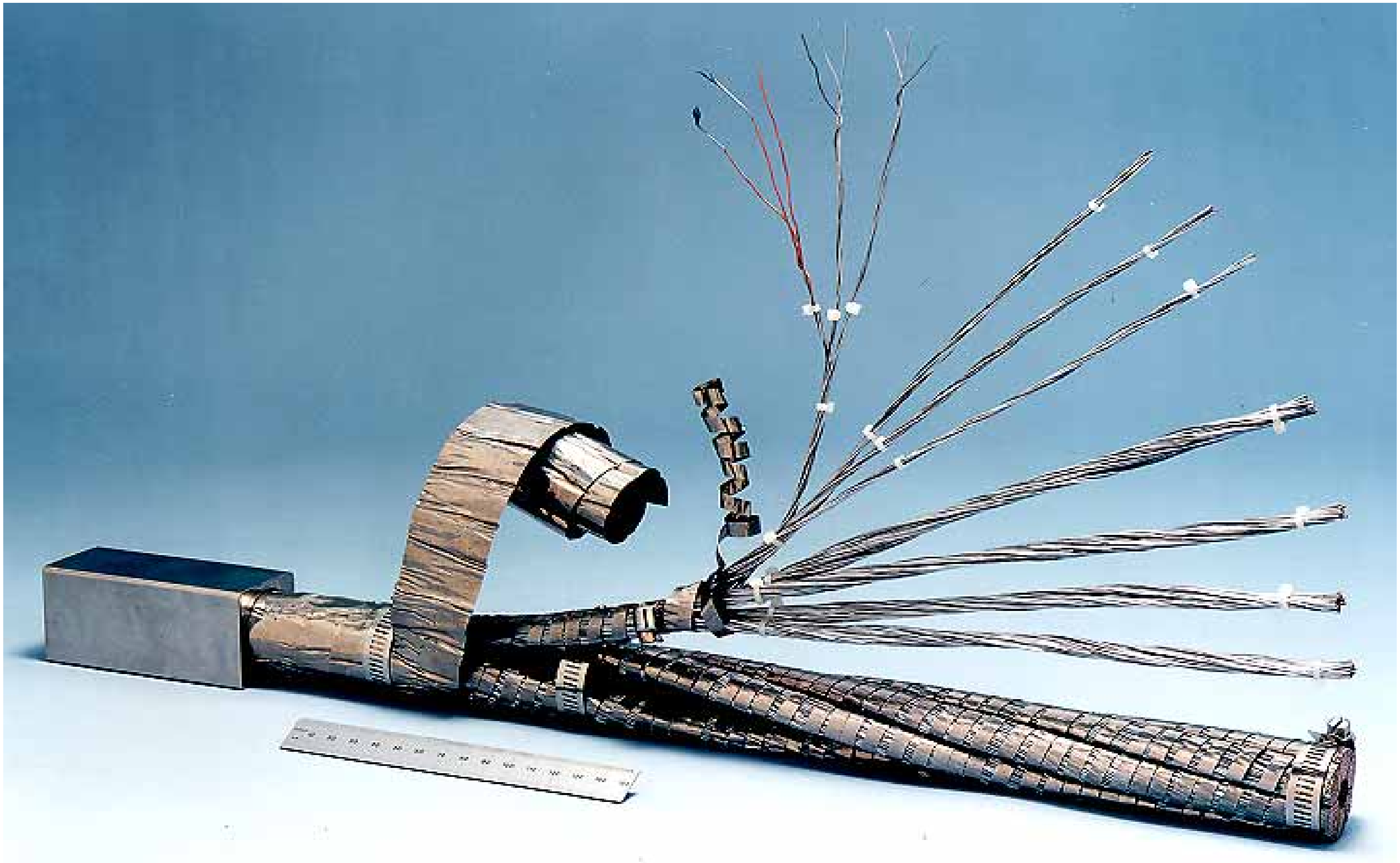


After installation in Tokamak

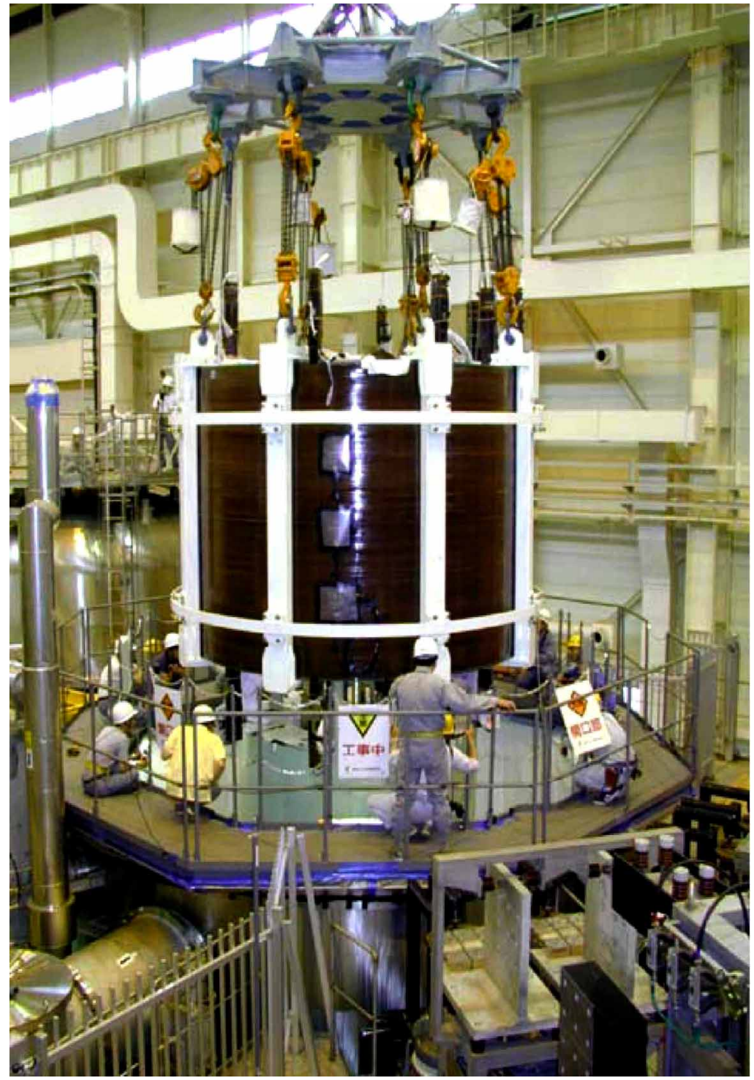
Central Solenoid Model Coil



Central Solenoid Conductor



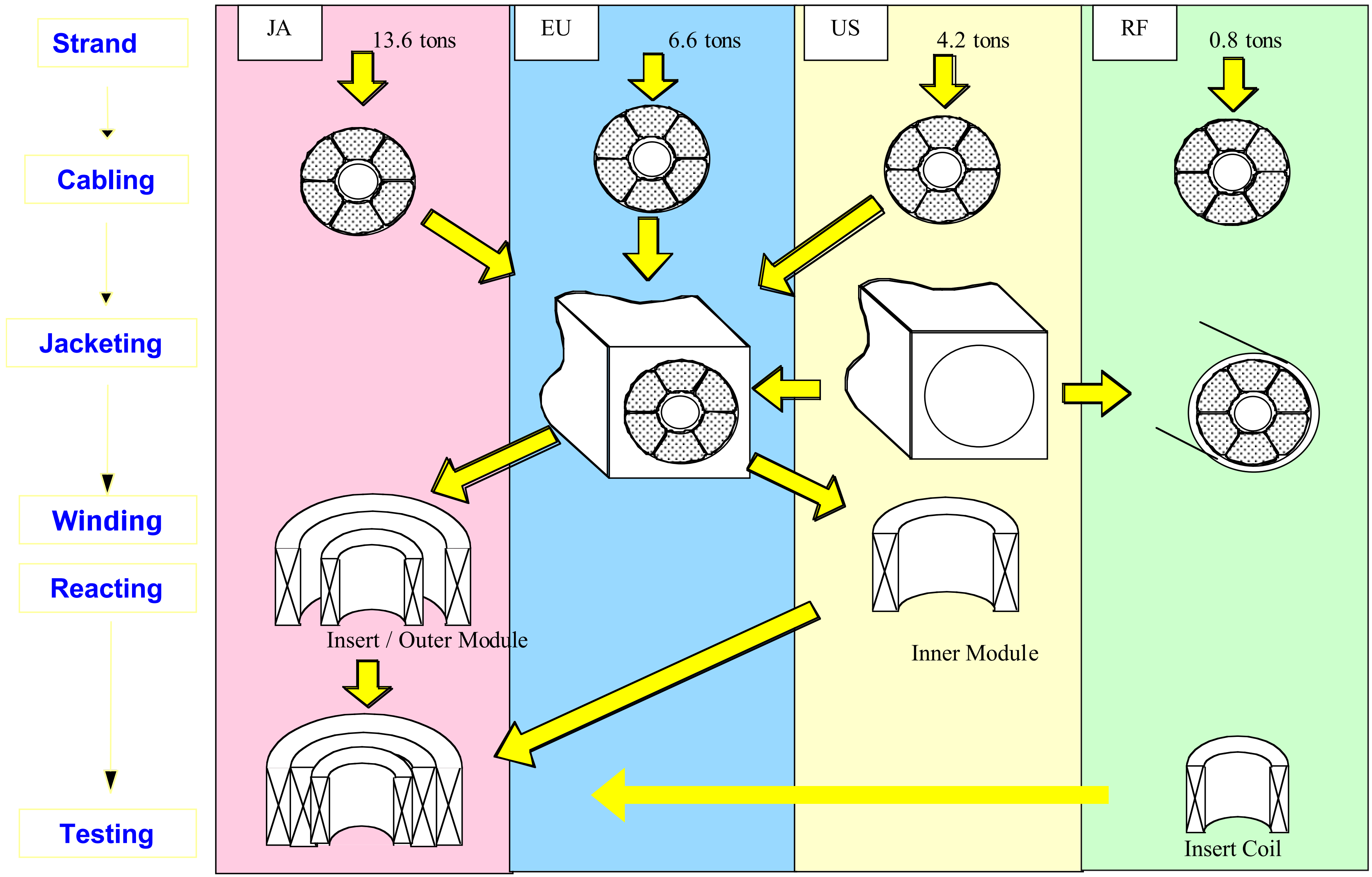
Central Solenoid Model Coil



Max. field 13.5T, max. current 46kA, stored energy 640MJ
(max. in Nb_3Sn)

Ramp-up 1.2T/s (goal 0.4) and rampdown rates of -1.5T/s (goal -1.2) in insert coils, and 10,000 cycle test.

International Fabrication of the Central Solenoid Model Coil



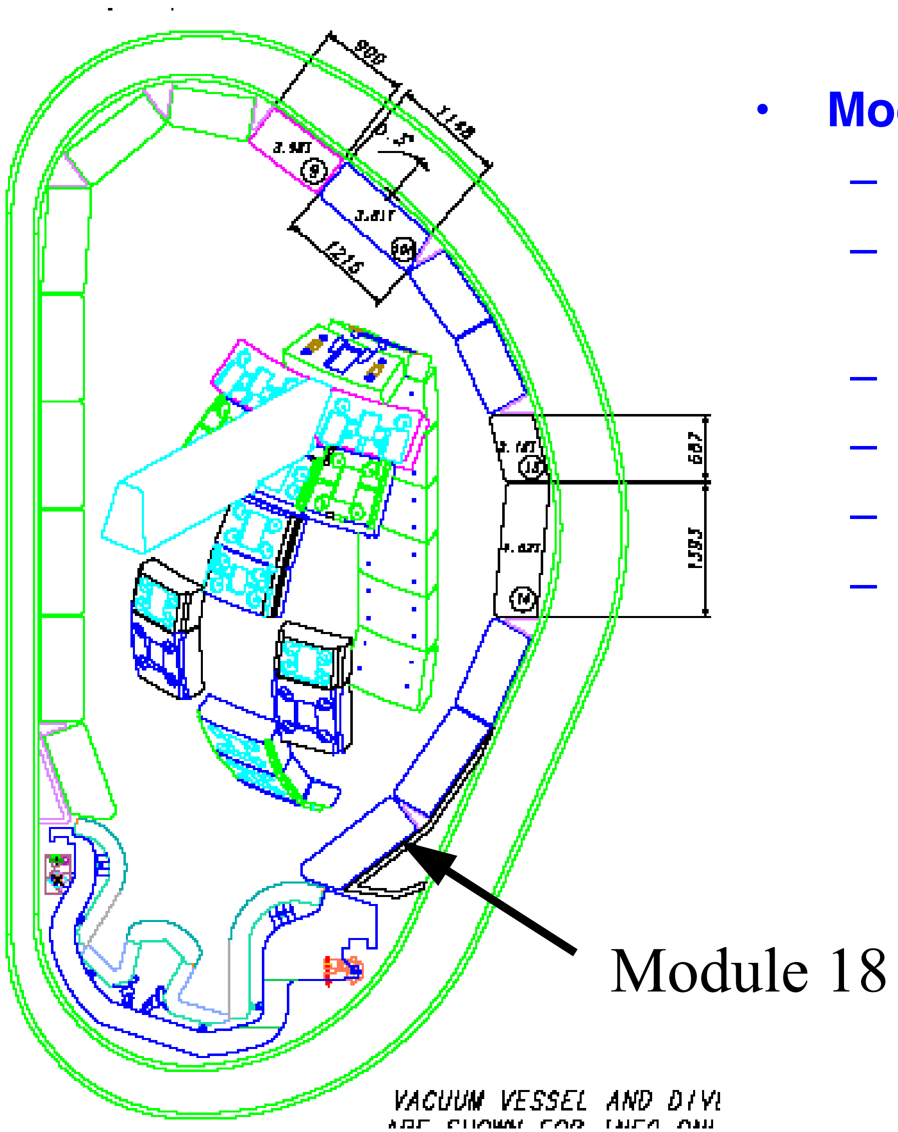
Changes from the FDR drive need for R&D and design

FDR	Present Design
Continuous Solenoid ~12m Tall	Segmented Solenoid 6 Modules
Bucked by TF Coils Conductor in Compression	Free-Standing Solenoid Conductor in Tension
Layer Winding 4-In-Hand/Series Connected	Pancake Winding 6 Hexa-Pancakes and 1 Quad-Pancake Separate Power Supplies
Lap or Butt Joints	Butt Joints
Incoloy Alloy 908 Jacket SS was an option	JK2LB Stainless Steel Jacket 49 mm x 49 mm
Nb_3Sn Strand 650 A/mm^2 J_c CSC Ratio - 1.5:1	Nb_3Sn Strand > 700 or 800 A/mm^2 J_c CSC Ratio - 1.0:1
2 K Temperature Margin	< 1 K Temperature Margin

Plasma-Facing Components: Baffle

Description of US portion	US fraction of system (by ITER value)	US Value (kIUA) [$M]
Module 18 (baffle)	10% of full system; 8.6% of full blanket	14.5 [$21M]

ITER FW/Shield Design



- **Module 18 of the FW/Shield**
  - 36 modules around torus
  - Shield module weight 3.6 Tonnes (316 LNIG steel)
  - PFC area 1.6m^2
  - PFC weight 0.8Tonnes (Cu+316)
  - 10% of the first wall area
  - 45 cm thick (PFC +shield)

R&D - Divertor Cassette (L-5) (4)

Outboard integration mockup prior to installation of liner (EU)

Inboard divertor channel integration mockup undergoing flow tests (US)

Several middle and large scale CfC and W-armoured divertor mock-ups have been successfully tested at heat fluxes ~20 MW/m^2 x 1000 cycles, which is consistent with ITER operational needs.

Roadmap

Very brief overview of toroidal magnetic confinement, burning plasmas, and ITER

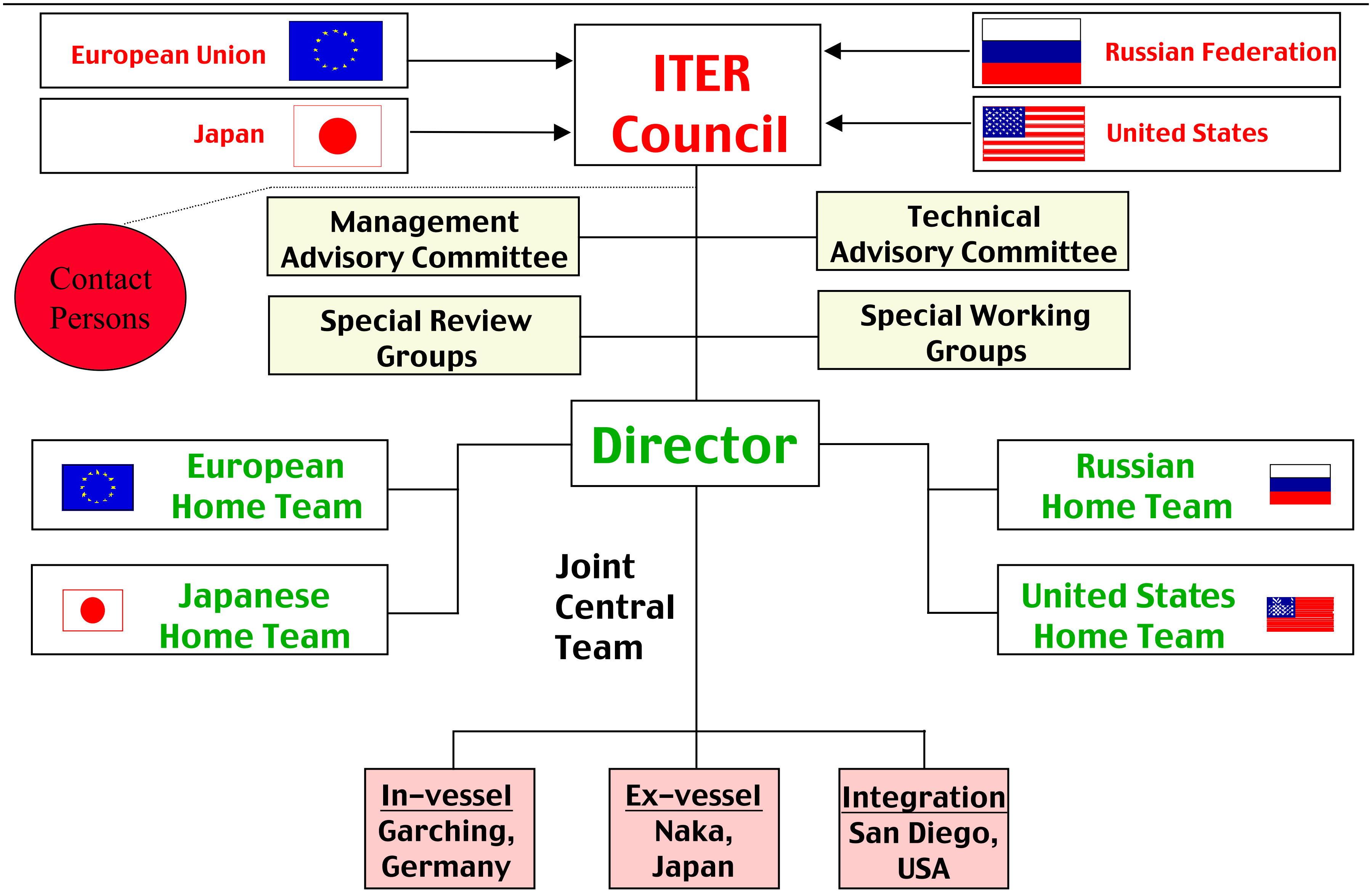
ITER as an experiment in … Science

ITER as an experiment in … Technology

ITER as an experiment in … International Collaboration

A look to the future

Organization for the ITER Engineering Design Activities



US ITER Home Team Organization

U.S. Home Team Leader
Charles C. Baker, UCSD

Deputy Home Team Leader
Thomas R. James, UCSD

Quality Coordinator
Kenneth Sowder, INEEL

Advisory Committees
ISCUS, W. Stacey, GIT, Ch.

ITER Industrial Council
W. Ellis, Raytheon, Ch.

Project Coordinator
Terrence Davies, UCSD

Project Office Manager
Patricia Stewart, UCSD

Physics Manager
Ned Sauthoff, PPPL

- Plasma Performance
  - N. Uckan, ORNL
- Divertor and Disruption Physics
  - Vacant
- Physics/ Engineering Interface
  - H. Neilson*, PPPL
- Plasma Systems
  - W. Nevins, LLNL
- Plasma Diagnostics
  - K. Young, PPPL

In-Vessel Systems Manager
Kenneth Wilson, SNL

- Divertor and FW
  - M. Ulrickson, SNL
- Blanket and Shield
  - R. Mattas, ANL
- Vacuum Vessel
  - B. Nelson, ORNL
- Fueling and Vacuum
  - M. Gouge*, ORNL
- RF Systems
  - D. Swain, ORNL
- Structural Materials
  - A. Rowcliffe, ORNL

Ex-Vessel Systems Manager
Bruce Montgomery, UCSD

- Magnets
  - J. Jayakumar*, LLNL
- PF Magnetics
  - R. Bulmer, LLNL
- Tritium Systems
  - S. Willms*, LANL
- Remote Handling
  - J. Herndon, ORNL

Engineering Manager
James Doggett, LLNL

- Design Integration
  - B. Nelson*, ORNL
- Systems Analysis
  - L. Perkins, LLNL
- Facilities and Site
  - S. Thomson, Bechtel
- Safety/Standards
  - D. Petti, INEEL
- Test Program
  - M. Abdou, UCLA

*Acting

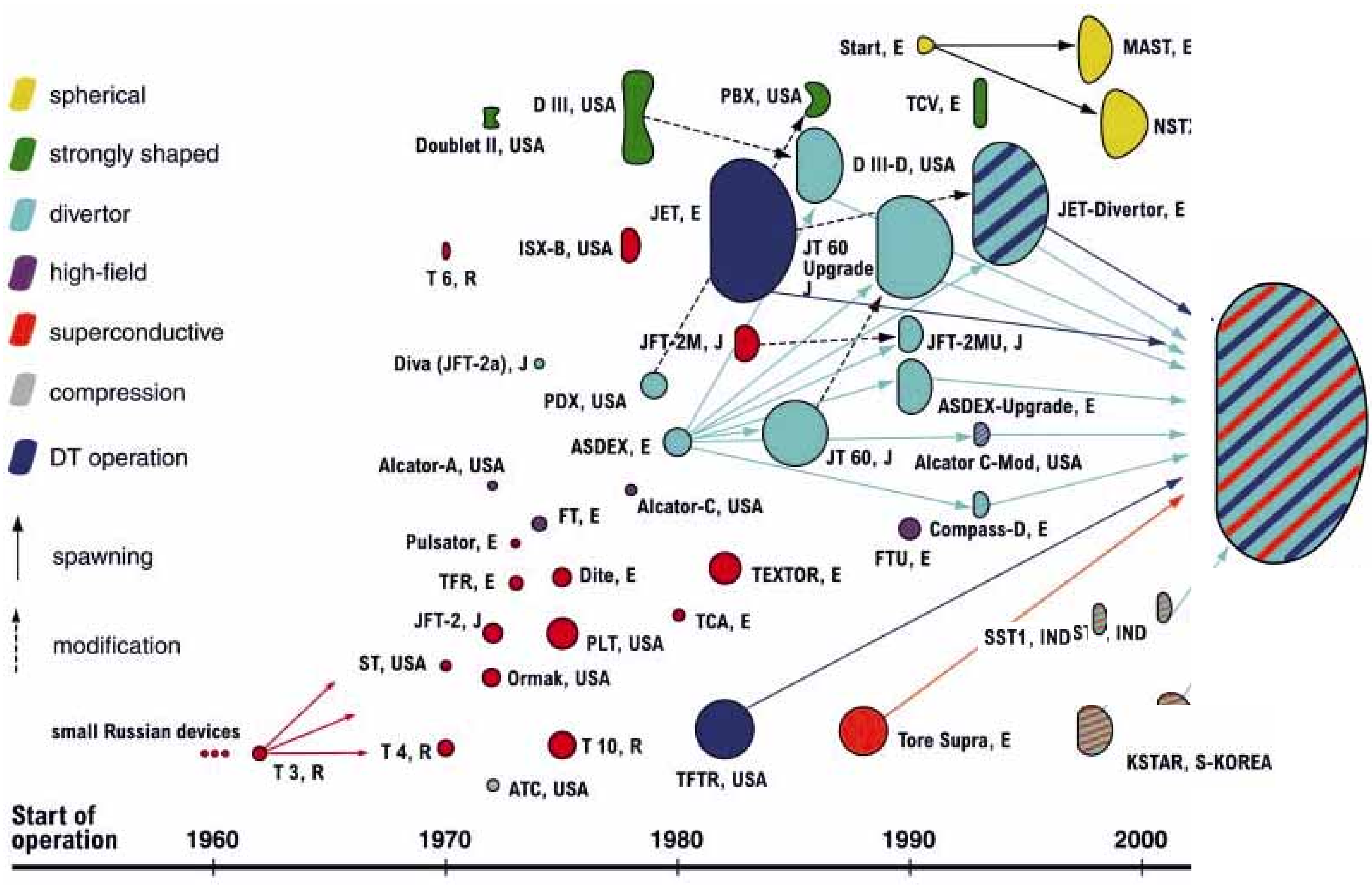
The International Tokamak Physics Activity (ITPA) and the paradigm for ITER research

- **International topical groups have facilitated coordinated topical research throughout the ITER engineering design**
  - Diagnostics
  - MHD, Disruption and Control
  - Steady State Operation, Heating and Current Drive and Energetic Particles
  - Internal Transport Barriers and Transport
  - Confinement Database and Modeling
  - Pedestal and Edge
  - Scrape-off Layer and Divertor

- **IEA Tokamak Cooperative Research Agreements have enabled focused joint experiments**

- **ITPA may be a forum for developing the ITER research management and operations environment, practices, tools, …**
  - Prototype tools and procedures

The range of worldwide tokamaks have provided the physics basis for ITER



The US ITER Time Line (2 of 2)

2/2003-11/2003	Exploratory discussions
	EU selects France as its site; Canada withdraws

Site Selection Sequence/Schedule:
Activities WAY beyond our pay grades…

France
(Cadarache)

Spain
(Vandellòs)

Nov 26, 2003

EU site
(Cadarache)

Japan
(Rokkasho)

withdrew

Canada
(Clarington)

The US ITER Time Line (2 of 2)

2/2003-11/2003	Exploratory discussions EU selects France as its site; Canada withdraws
12/2003	Vice-ministerial meeting to discuss cost-allocations
12/2003	Ministerial meeting to choose site failed to reach agreement
12/31/2003	Parties submit site-questions to EU and Japan
1/2004	Parties meet to explore broader approaches (Garching, Naka)
1/31/2004	EU and Japan submit answers to site-questions
2/2004	EU and Japan meet with individual parties to address site questions
2/2004	Vice-ministerial meeting (Vienna)
3/2004	Parties meet (Vienna) to discuss sites in “common terms” Individual parties compile data for their Negotiators

Roadmap

Very brief overview of toroidal magnetic confinement, burning plasmas, and ITER

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A look to the future

Situation Assessment

- All 6 parties support the ITER mission and its scientific and technological design
- The ITER parties are at an impasse, with 2 fully-funded site proposals
- The technical aspects of the selection-process have been completed
- The next step appears to be in the hands of the political level…
- High-level political support cannot be sustained indefinitely

Lessons Learned

- **At the scientific and engineering level, a dedicated multi-national team can work together effectively and overcome significant barriers.**
- **For international partnership on a large-scale science facility to succeed:**
  - High-level political support for the mission is essential
  - Involvement of all parties from the earliest project stages is best
  - Community involvement is essential to sustain interest and support
    - The community must be view the facility as an opportunity, rather than a threat
  - Project management of a project with a large-fraction of in-kind contributions is quite challenging
    - strong central management is essential
  - It may be necessary to address difficult political choices early in the process
- **It remains to be seen whether "the ITER model" for international large-scale science is viable**
  - Partnership without a single "responsible party" is quite different from collaboration where junior-partners accelerate or enhance a project for which the senior partner is responsible

The bottom line…

- **Over the past decade, the ITER parties have conducted R&D and design sufficient to enable start of construction**
- **There is apparent high-level political support for ITER in all 6 parties**
- **Difficulties with siting and cost-sharing decisions have brought the ITER negotiations to an impasse**
- **Prompt resolution is needed**
  – to enable sustainment of both political and community support and
  – to retain project effectiveness