iter

china eu india japan korea russia usa

Accelerator Reliability Workshop
The ITER Interlock System: Project Status

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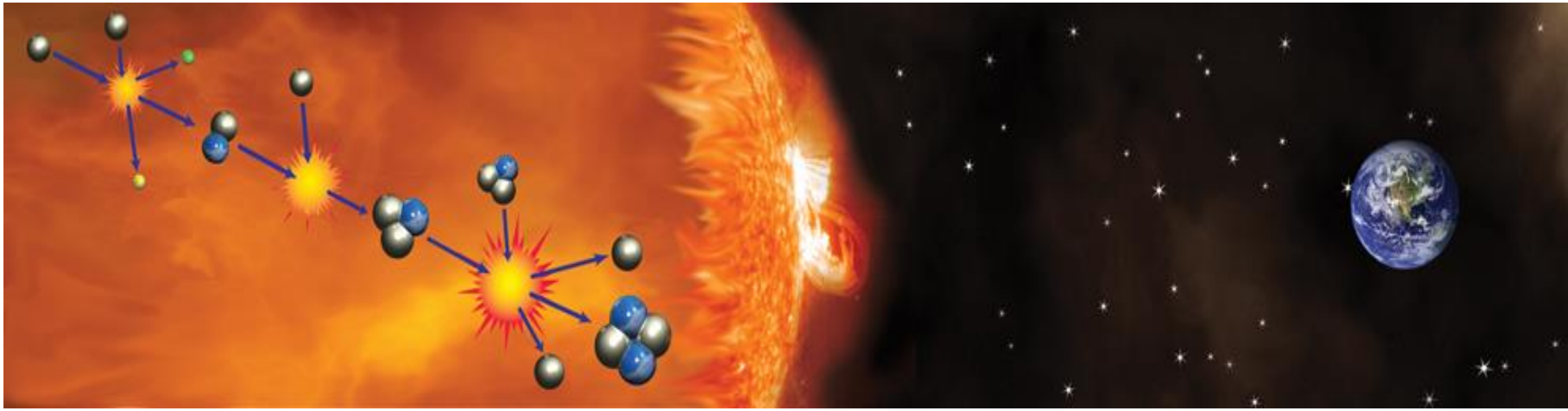
Control Systems Division
ITER International Organization

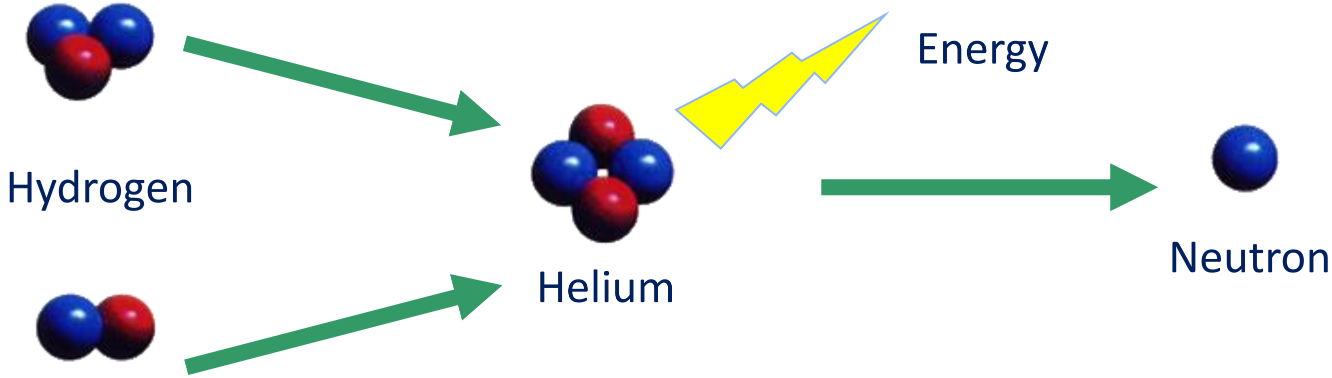
ARW-2015 26th April – 1st May 2015 Knoxville (USA)

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

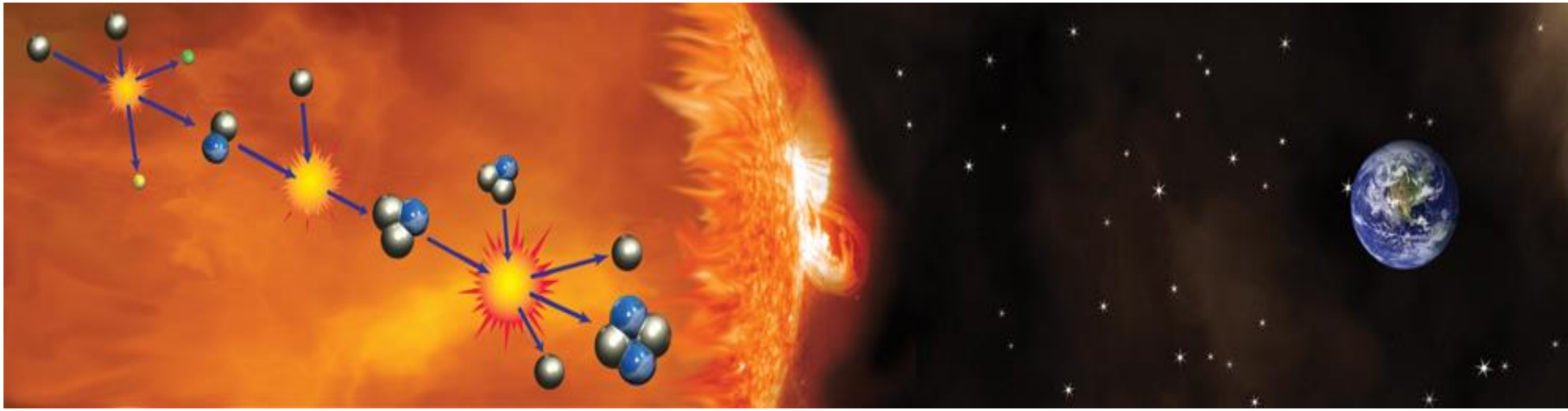
The ITER Project

the way to new energy




Energy
Hydrogen
Helium
Neutron


A huge global increase in energy use is inevitable



Attractions:

- unlimited fuel
- no CO_2 or air pollution
- intrinsic safety
- no radioactive ash or long-lived nuclear waste,
- cost will be reasonable ***if* we can get it to work reliably**

Disadvantages:

not yet available

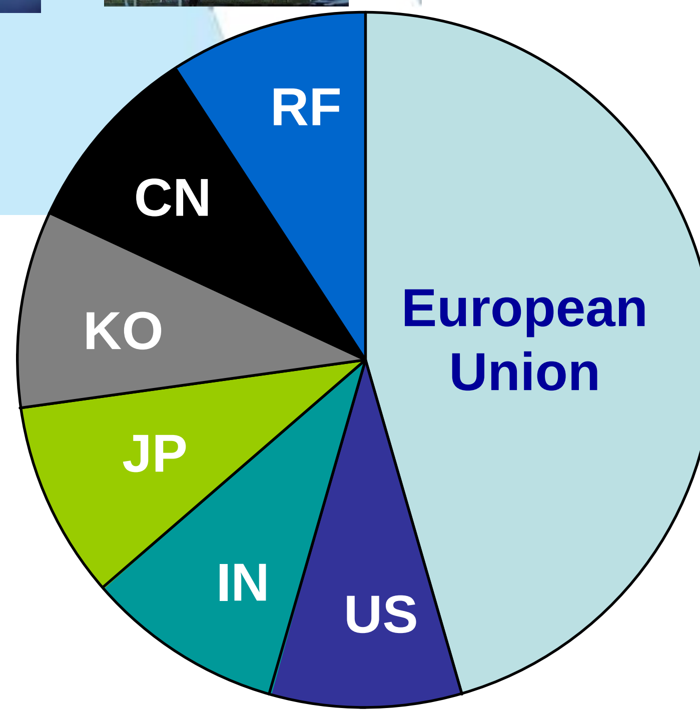
walls gets activated (but could recycle after 100 years)

“*For the benefit of mankind* ”

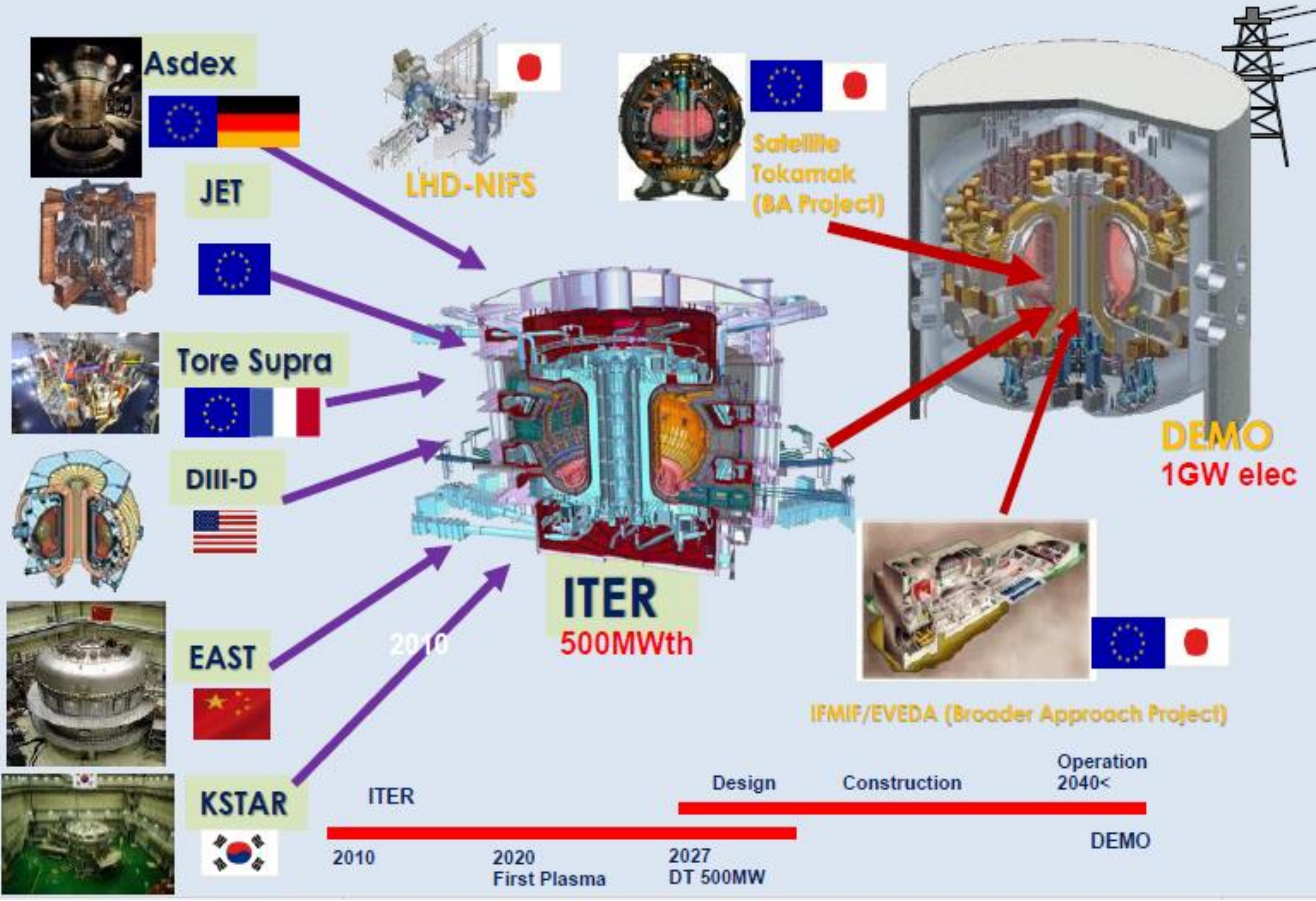
The idea for ITER originated from the Geneva Superpower Summit in 1985 where Presidents Gorbachev and Reagan proposed international effort to develop fusion energy…

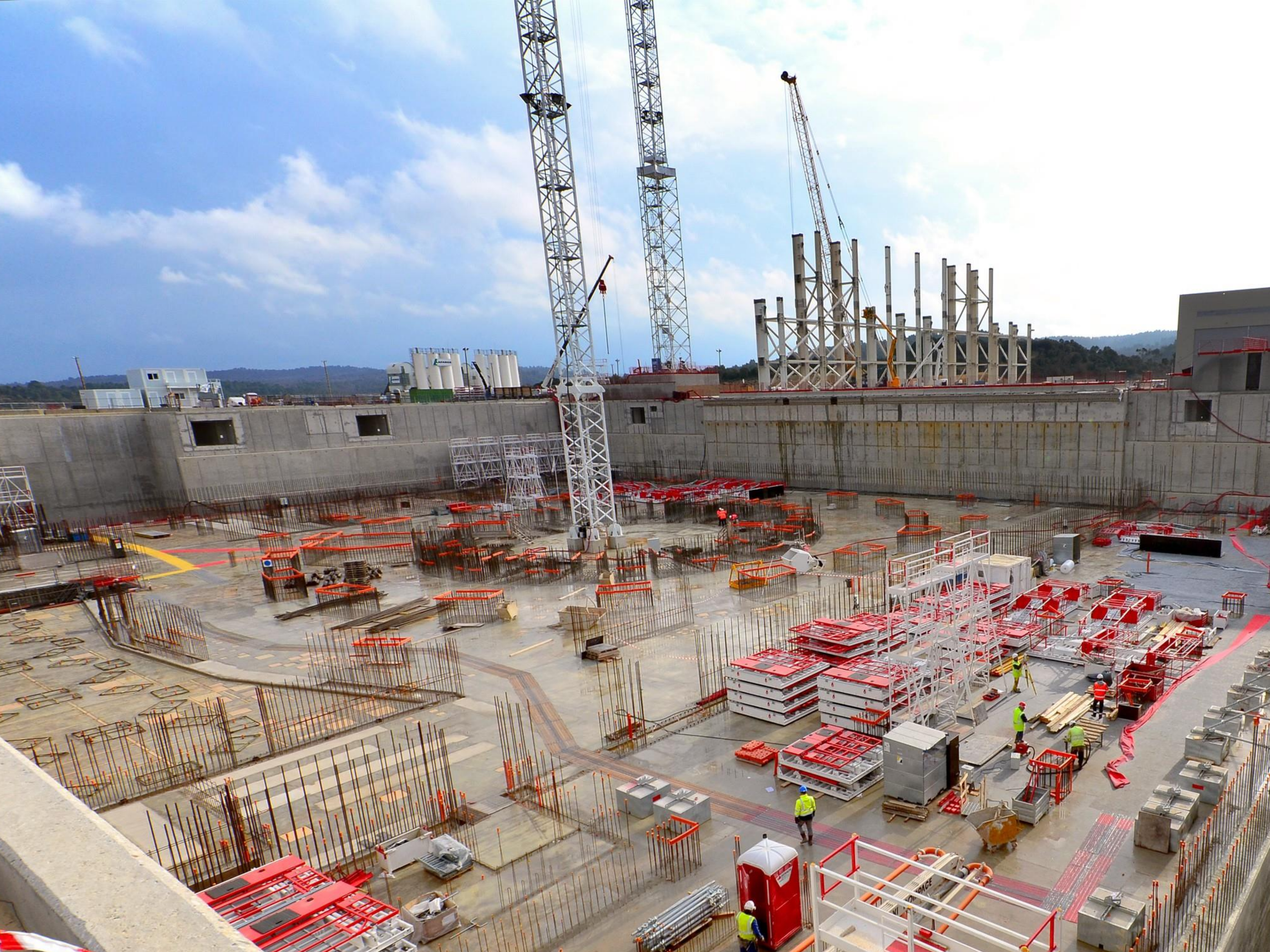
…“*as an inexhaustible source of energy for the benefit of mankind*”.

China, Europe, India, Japan, Korea, Russian Federation and the United States of America signed the ITER Agreement on 21 November 2006 in the Elysee Palace, Paris



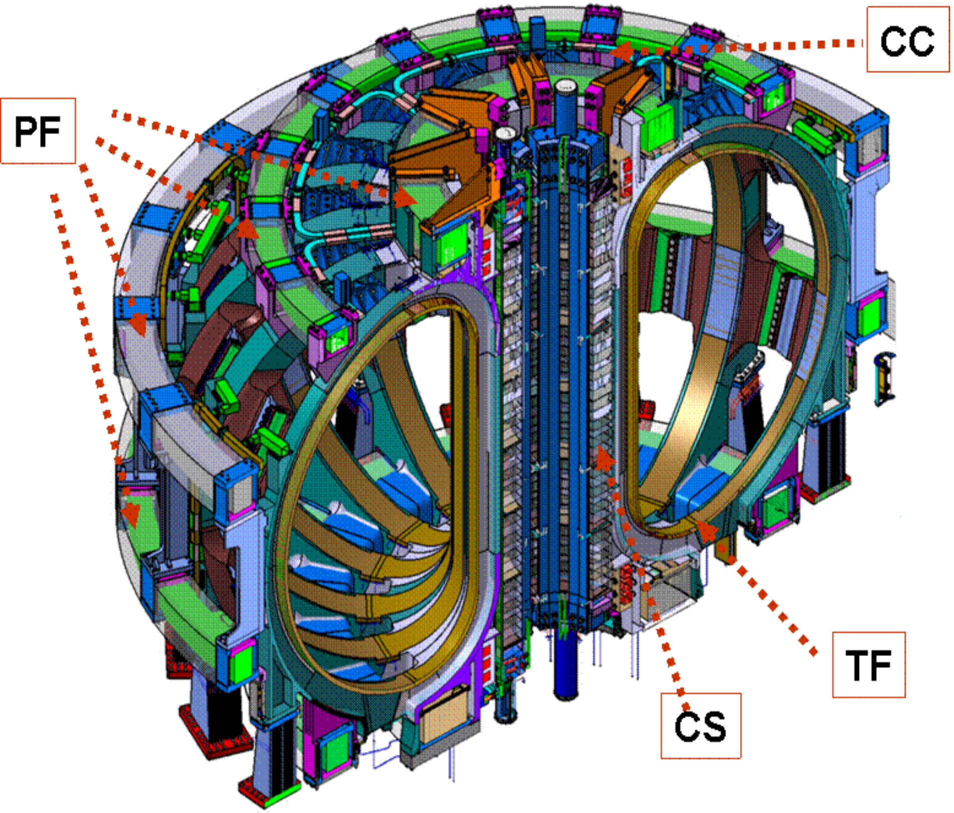
The ITER Domestic Agencies are responsible for implementing the procurement activities under each Member's responsibility


Asdex
JET
Tore Supra
DIII-D
EAST
KSTAR
LHD-NIFS
Satellite Tokamak (BA Project)
ITER
500MWth
2010
DEMO
1GW elec
IFMIF/EVEDA (Broader Approach Project)
ITER
Design
Construction
Operation 2040<
DEMO
2010
2020 First Plasma
2027 DT 500MW



Main Sources of Risk at ITER

Superconducting Magnets

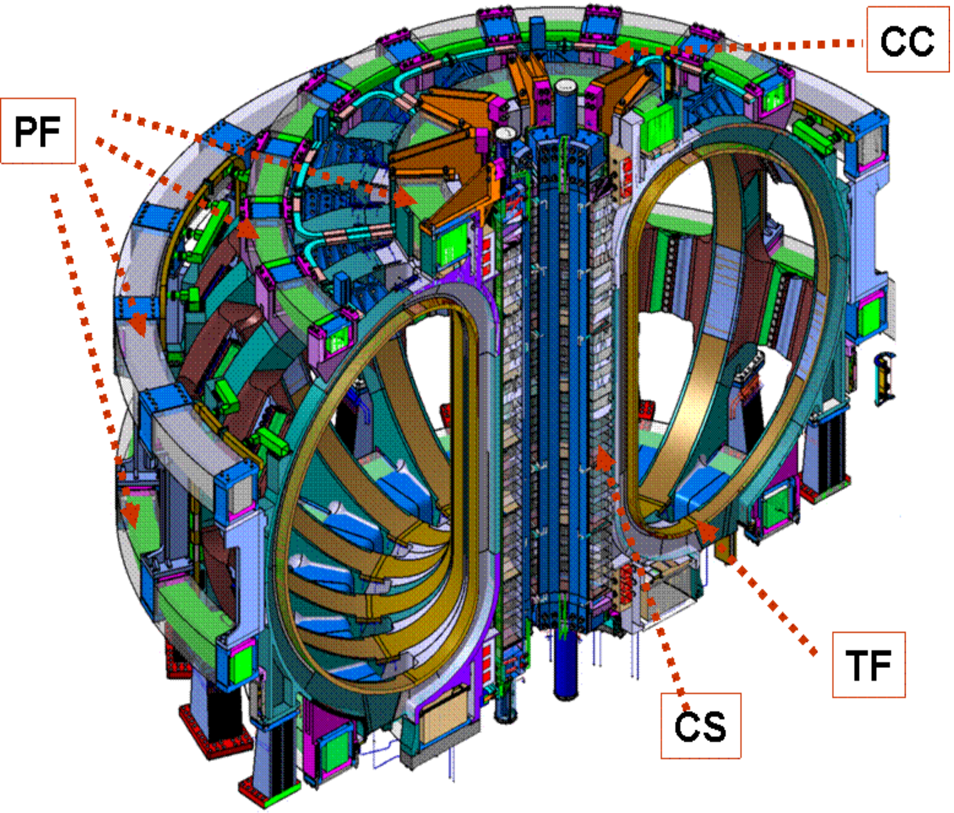


10 GJoule: the energy of an A380 at 700 km/hour corresponds to the energy stored in the CERN Large Hadron Collider magnet system.

Sufficient to heat up and melt 12 tons of Copper (*)

(*) Rudiger Schmidt (CERN)

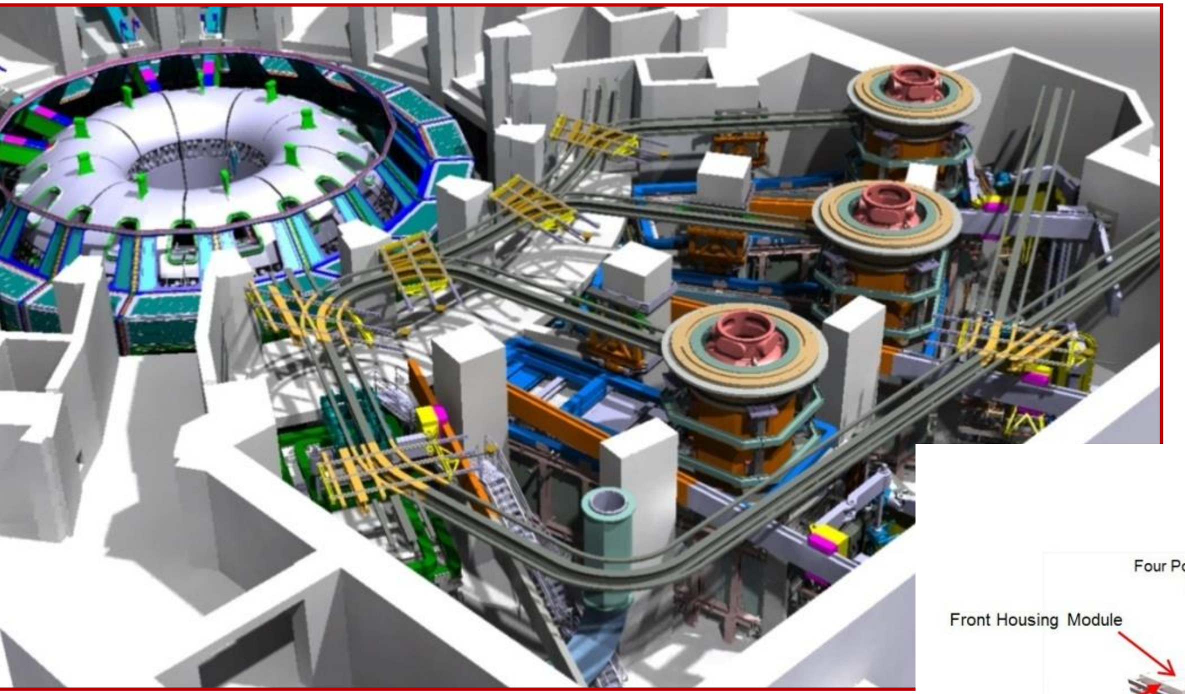
Superconducting Magnets

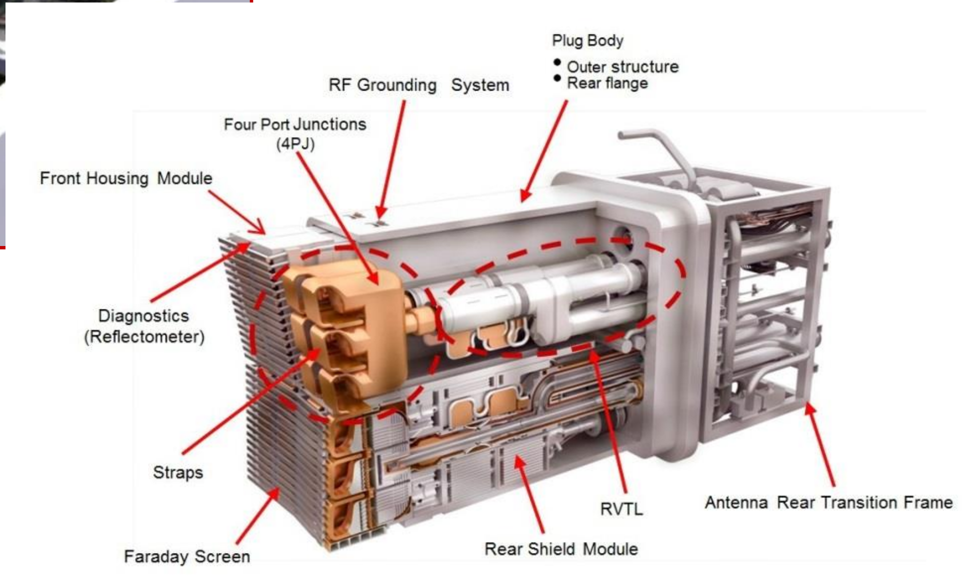


Total Magnetic Energy around 100 GJ

Interaction of strong magnetic fields
5T and up to 17 MA plasma

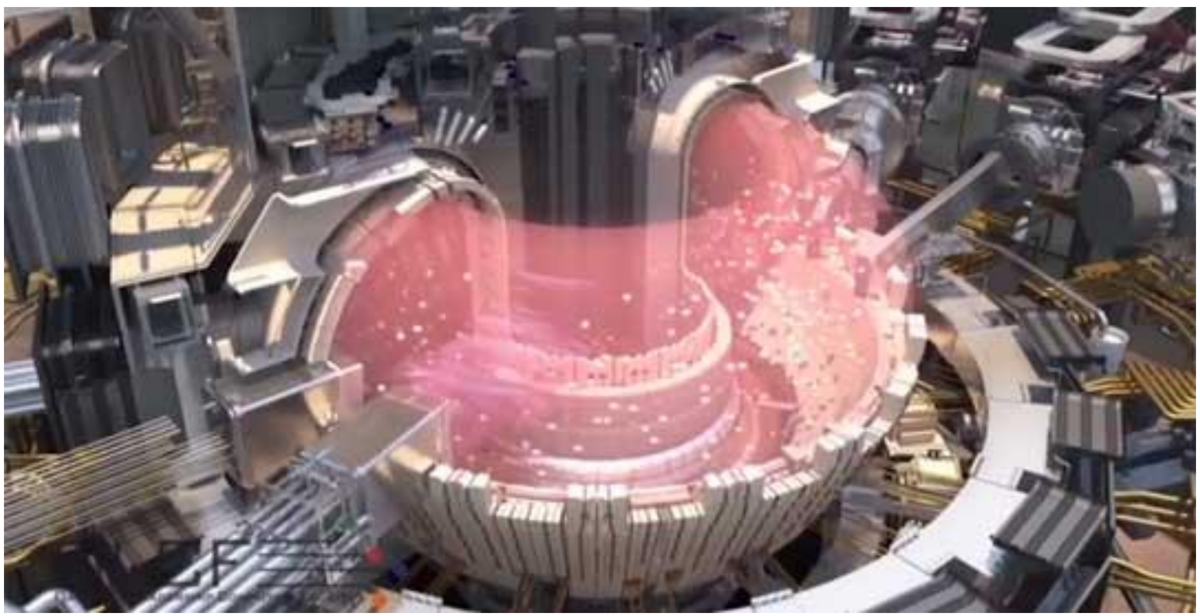
Plasma Heating & FuellingSystems

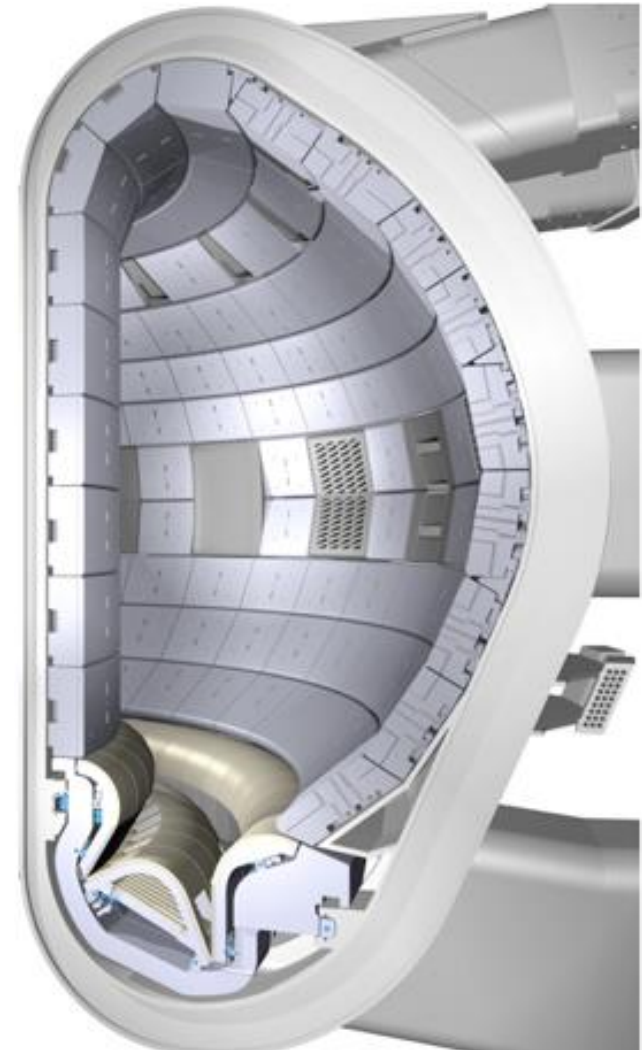




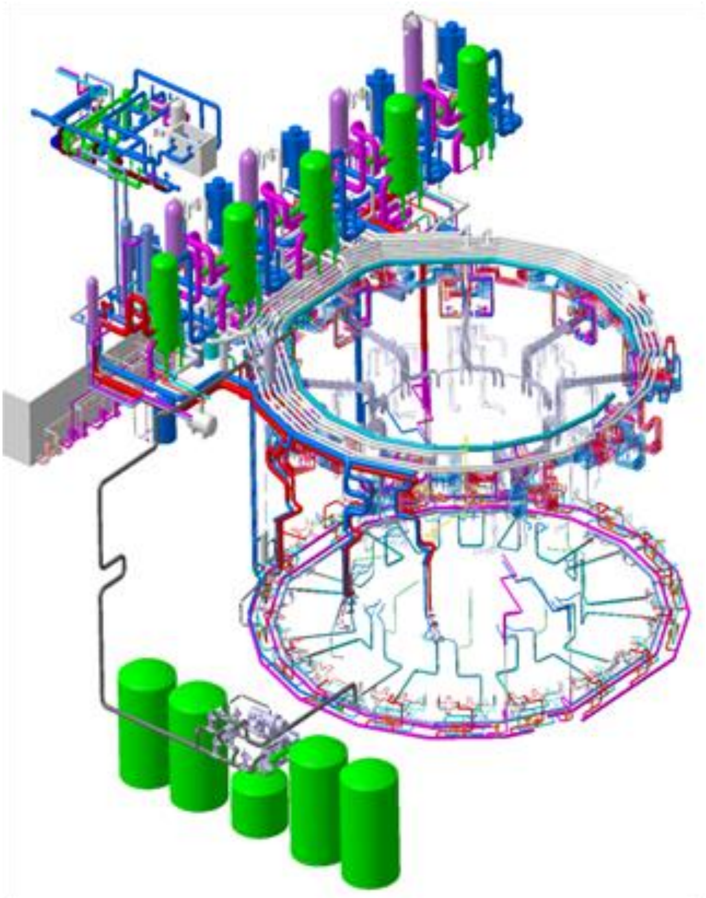
The Plasma

- Energy, Temperature – Internal Components
- Current - Disruptions

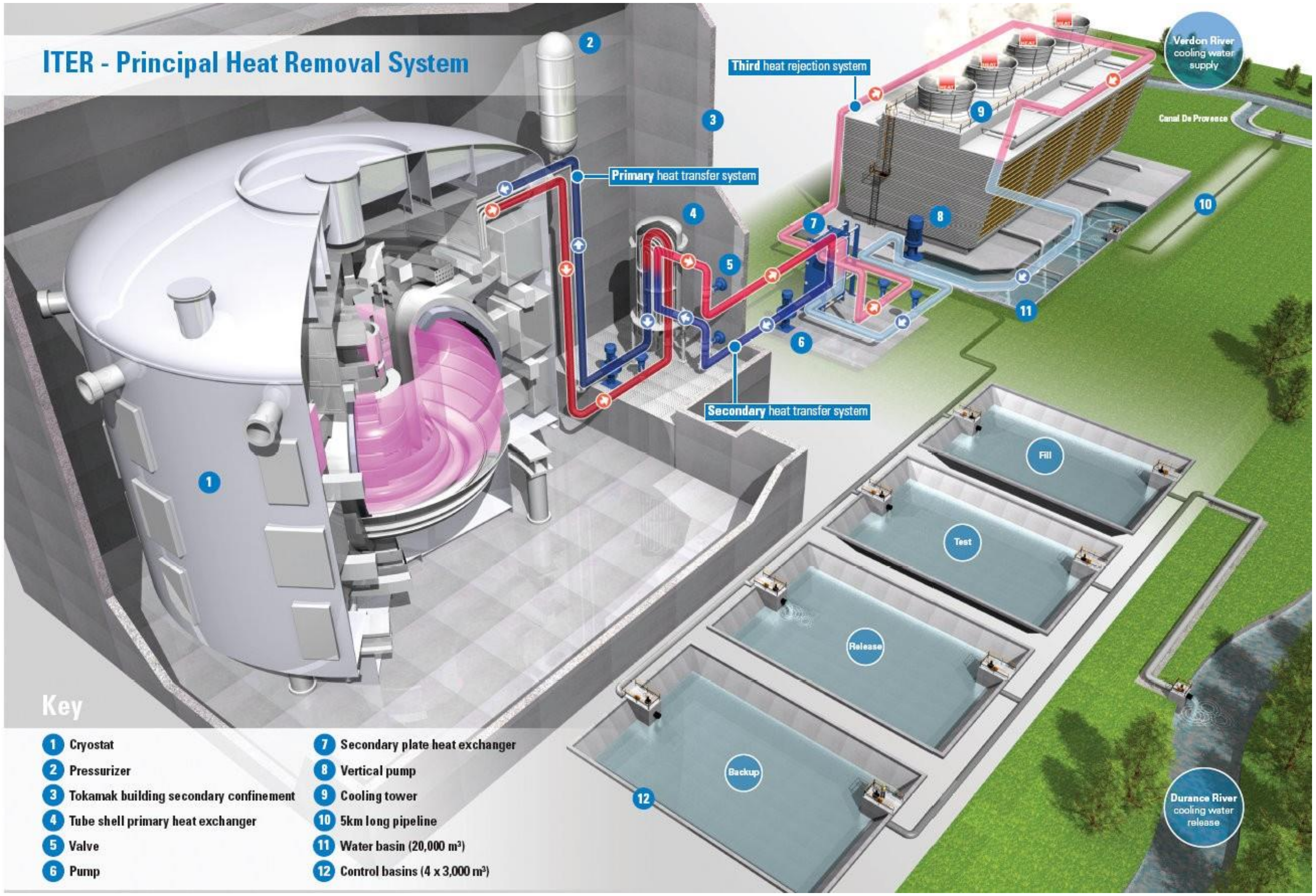




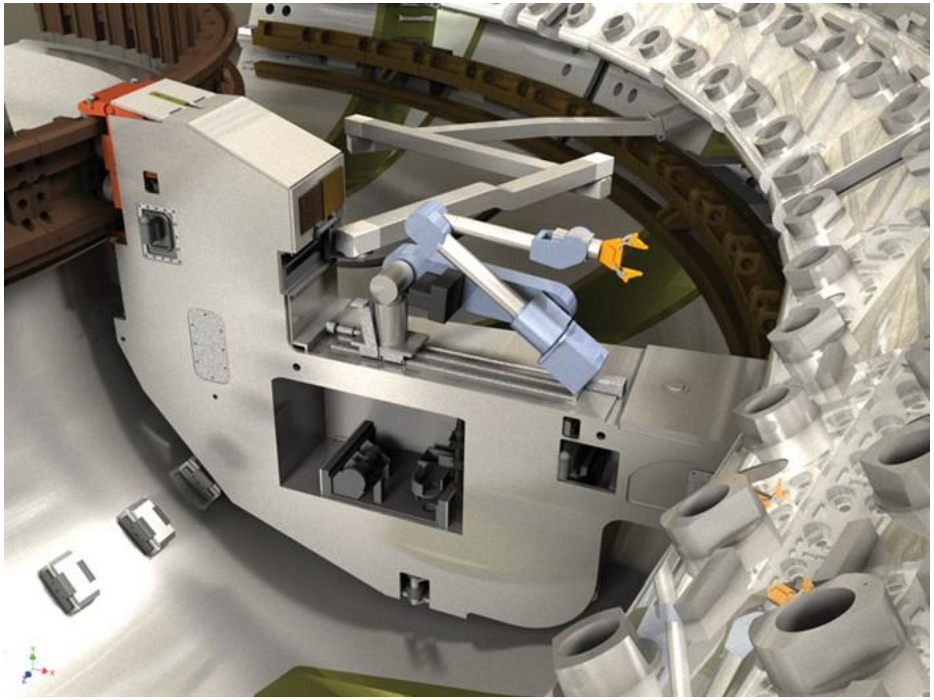
Vacuum and Cryogenic Systems

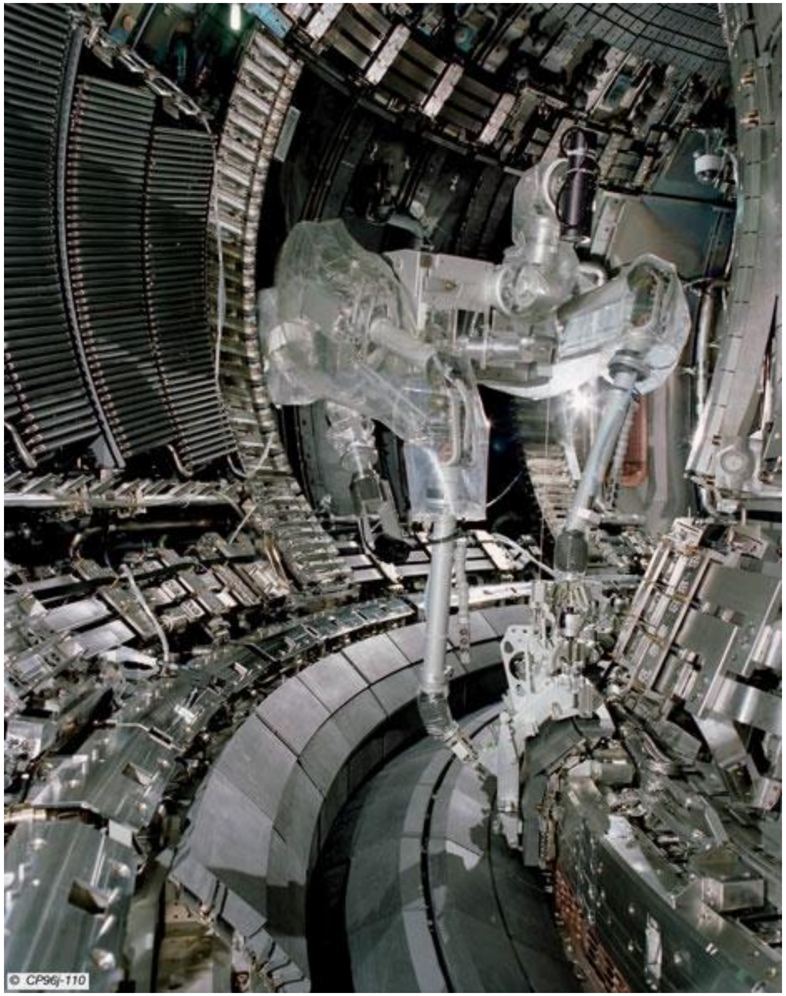


Cooling (and Heating) Water System

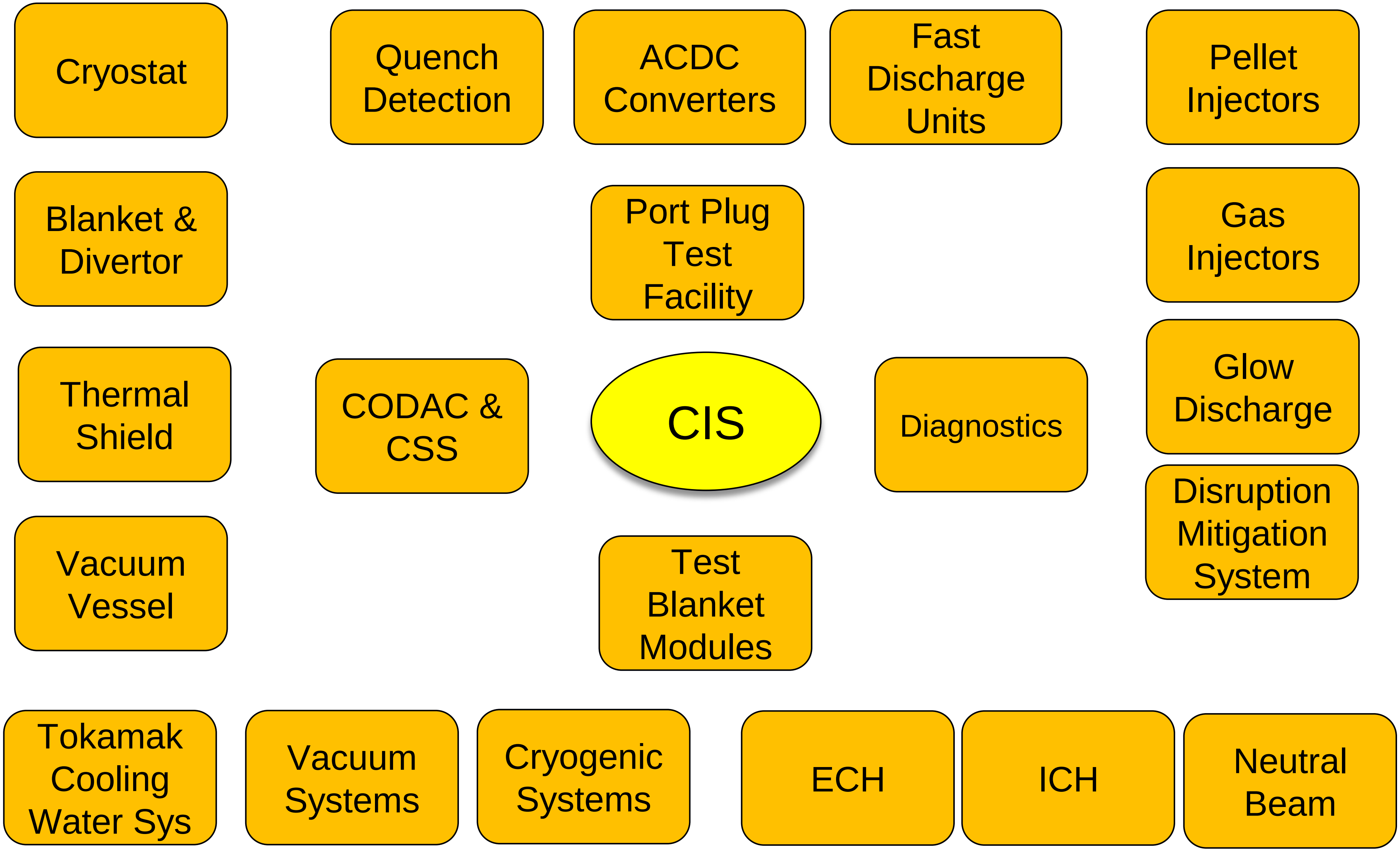


Remote Handling





Central Interlocks: Plant Systems



ITER Interlocks: Particularities

Interlock Functions

Particularities of ITER interlock systems

1. An eclectic collection of actions

Time Response

Slow (> 300 ms)
Fast (100 μs to 300 ms)

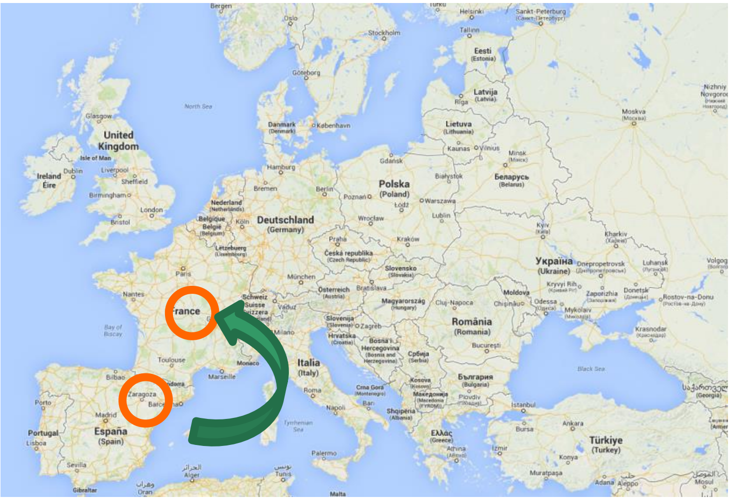
Action Complexity

Low
Medium
High

Four Architectures

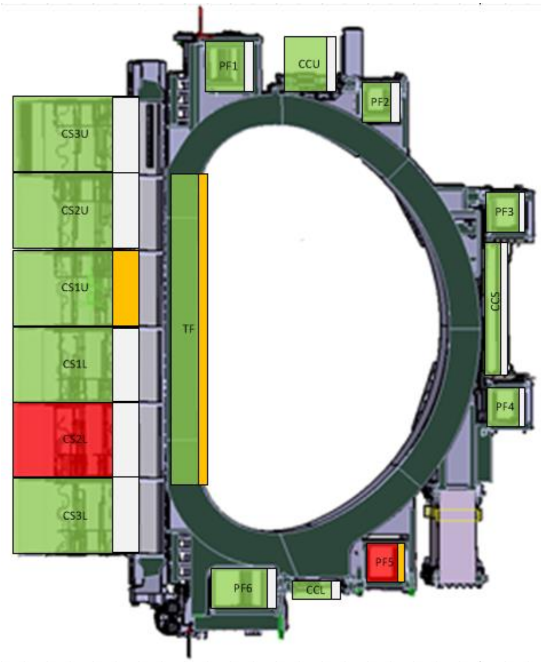
1. Slow & Medium Complexity → PLC
2. Fast & Medium Complexity → FPGA
3. Slow/Fast & Low Complexity → Current loops
4. Slow/Fast & High Complexity → R&D going on (tbc)

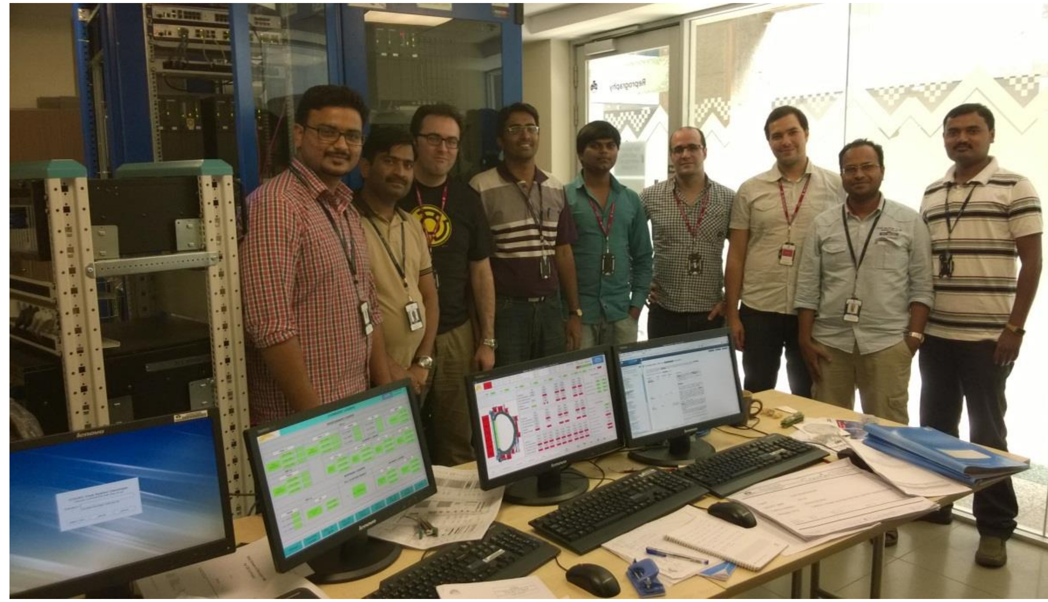
Safety PLC solution - Prototypes

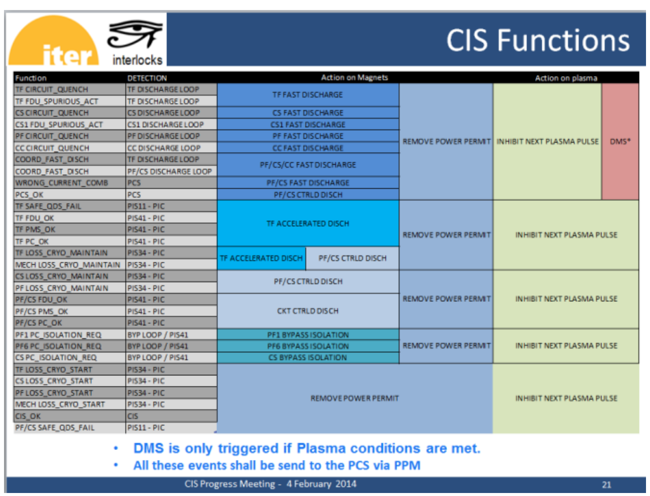


Test Platform Evolution

CIS Prototypes in India





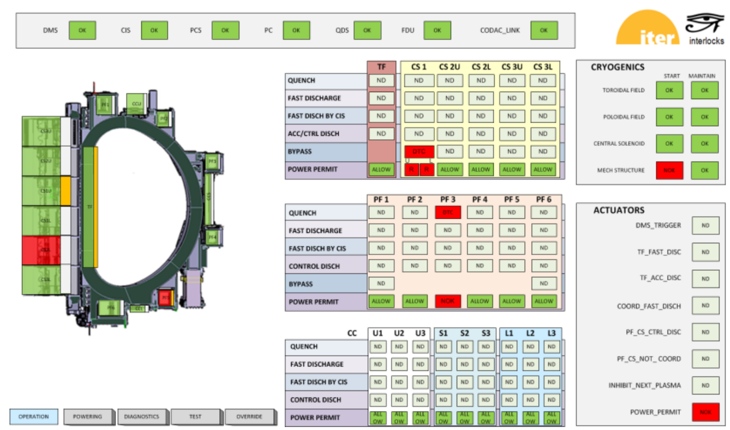


Function	DETECTION	Action on Magnets			Action on plasma	
TF CIRCUIT_QUENCH	TF DISCHARGE LOOP	TF FAST DISCHARGE		REMOVE POWER PERMIT	INHIBIT NEXT PLASMA PULSE	DMS*
TF FDU_SPURIOUS_ACT	TF DISCHARGE LOOP					
CS CIRCUIT_QUENCH	CS DISCHARGE LOOP	CS FAST DISCHARGE				
CS1 FDU_SPURIOUS_ACT	CS1 DISCHARGE LOOP	CS1 FAST DISCHARGE				
PF CIRCUIT_QUENCH	PF DISCHARGE LOOP	PF FAST DISCHARGE				
CC CIRCUIT_QUENCH	CC DISCHARGE LOOP	CC FAST DISCHARGE				
COORD_FAST_DISCH	TF DISCHARGE LOOP	PF/CS/CC FAST DISCHARGE				
COORD_FAST_DISCH	PF/CS DISCHARGE LOOP					
WRONG_CURRENT_COMB	PCS	PF/CS FAST DISCHARGE				
PCS_OK	PCS	PF/CS CTRLD DISCH				
TF SAFE_QDS_FAIL	PIS11 - PIC	TF ACCELERATED DISCH		REMOVE POWER PERMIT	INHIBIT NEXT PLASMA PULSE	
TF FDU_OK	PIS41 - PIC					
TF PMS_OK	PIS41 - PIC					
TF PC_OK	PIS41 - PIC					
TF LOSS_CRYO_MAINTAIN	PIS34 - PIC	TF ACCELERATED DISCH	PF/CS CTRLD DISCH			
MECH LOSS_CRYO_MAINTAIN	PIS34 - PIC					
CS LOSS_CRYO_MAINTAIN	PIS34 - PIC	PF/CS CTRLD DISCH		REMOVE POWER PERMIT	INHIBIT NEXT PLASMA PULSE	
PF LOSS_CRYO_MAINTAIN	PIS34 - PIC					
PF/CS FDU_OK	PIS41 - PIC	CKT CTRLD DISCH				
PF/CS PMS_OK	PIS41 - PIC					
PF/CS PC_OK	PIS41 - PIC					
PF1 PC_ISOLATION_REQ	BYP LOOP / PIS41	PF1 BYPASS ISOLATION		REMOVE POWER PERMIT	INHIBIT NEXT PLASMA PULSE	
PF6 PC_ISOLATION_REQ	BYP LOOP / PIS41	PF6 BYPASS ISOLATION				
CS PC_ISOLATION_REQ	BYP LOOP / PIS41	CS BYPASS ISOLATION				
TF LOSS_CRYO_START	PIS34 - PIC	REMOVE POWER PERMIT			INHIBIT NEXT PLASMA PULSE	
CS LOSS_CRYO_START	PIS34 - PIC					
PF LOSS_CRYO_START	PIS34 - PIC					
MECH LOSS_CRYO_START	PIS34 - PIC					
CIS_OK	CIS					
PF/CS SAFE_QDS_FAIL	PIS11 - PIC					

- DMS is only triggered if Plasma conditions are met.
- All these events shall be send to the PCS via PPM

CIS Progress Meeting - 4 February 2014 21

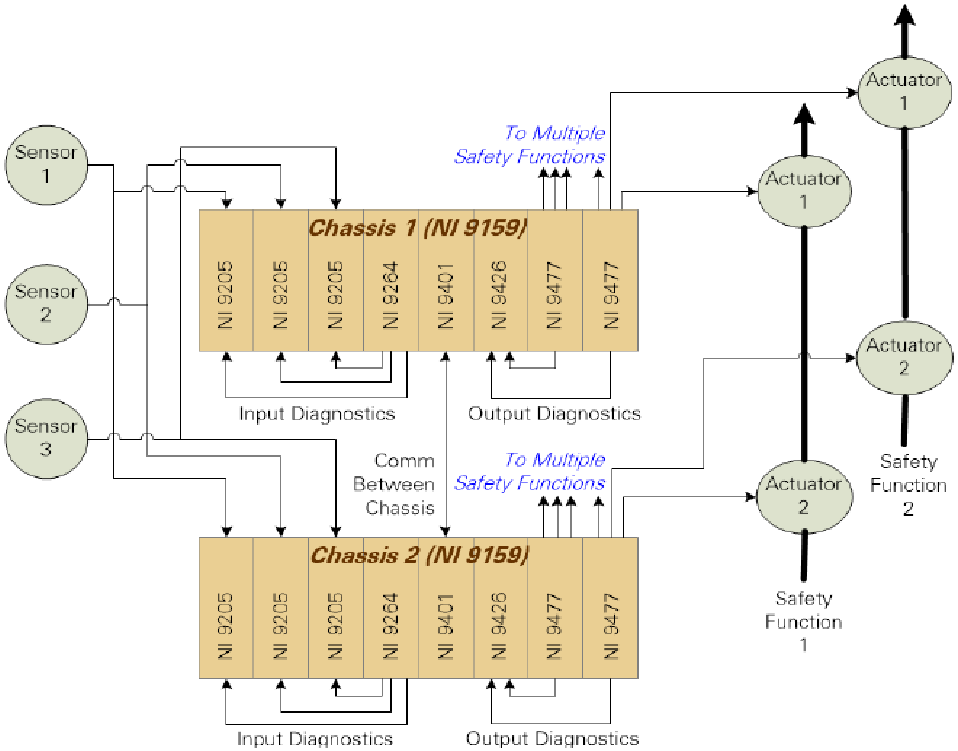
Implementation of the Magnet Protection Functions



CIS Final Construction in Korea

CIS V.0 arrival at Seoul

FPGA-based solution – customized COTS



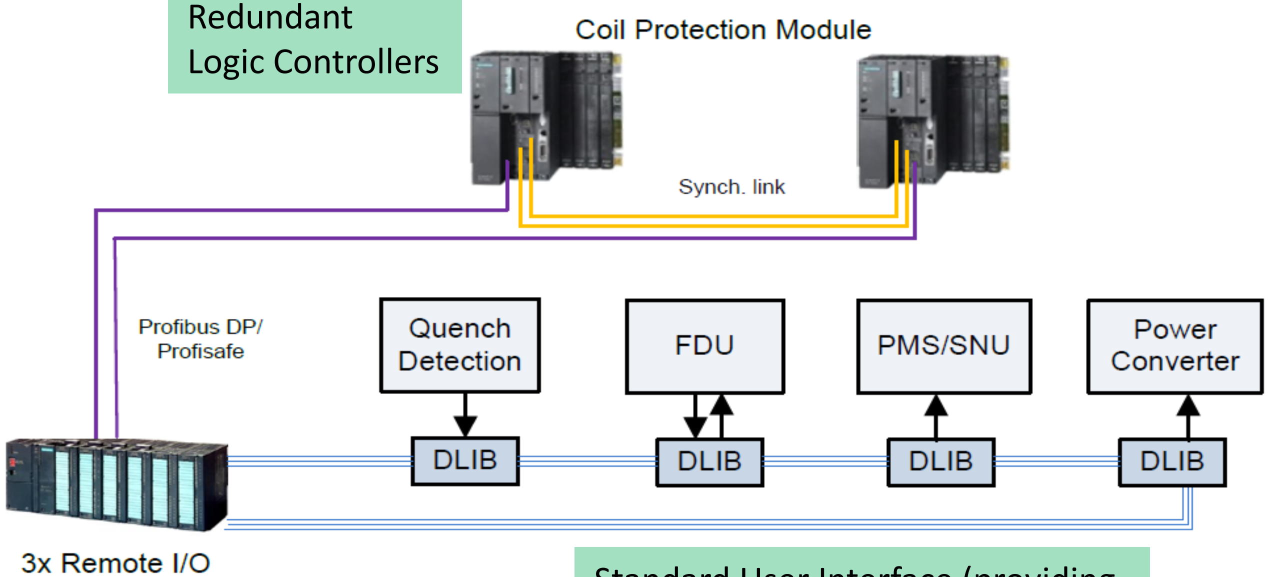
Hardwired Interlocks

The Hardwired Loop (Discharge Loop and Bypass Loop) allows the coordination of the different elements involved in the protection function, via a common current loop in a 2oo3 (or 1oo2) configuration.

The Interface Boxes (DLIBs/BLIBs) are used to connect the different elements to the loop, providing a reliable interface so the user can either read the DL status or open the loop, to trigger the protection actions.

*The user is defined as the protection equipment: QDS, FDU, PMS, PC.

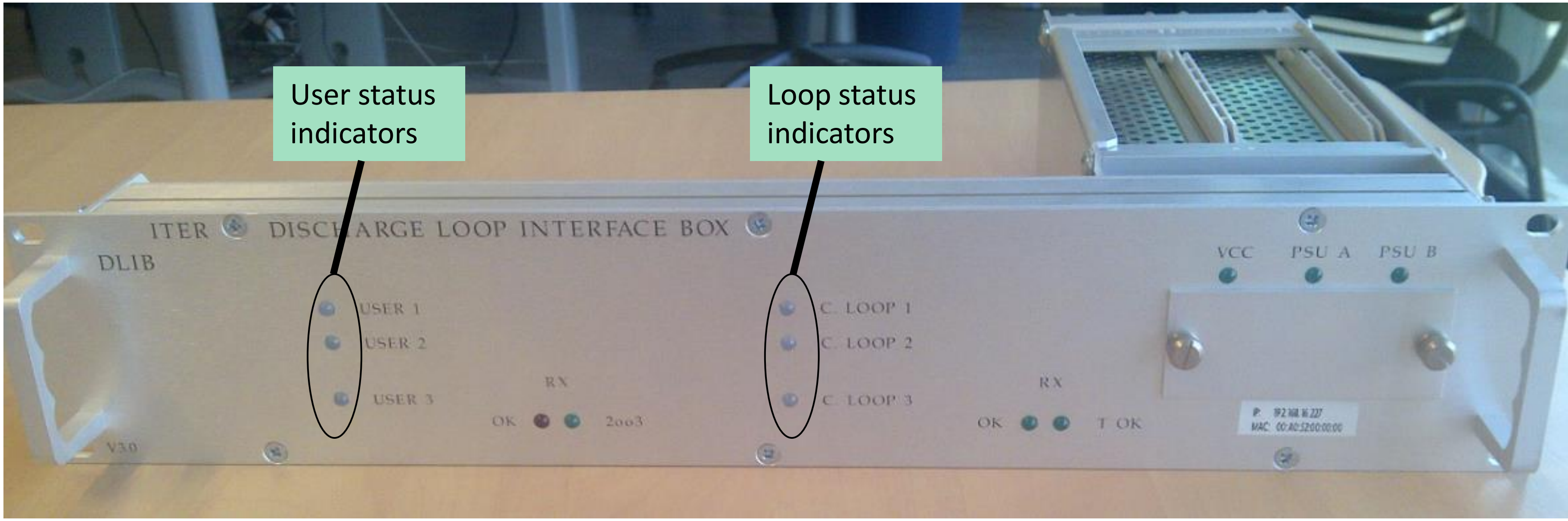
Redundant Logic Controllers

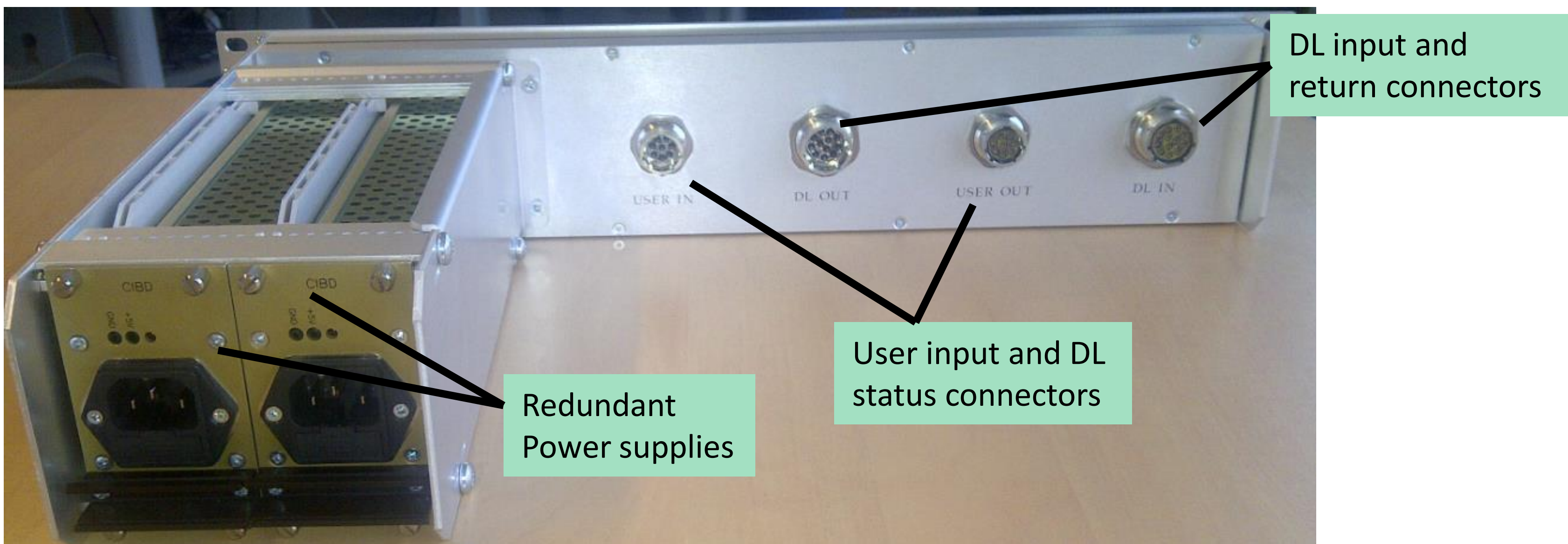


I/Os for loop current, Reading, open & diagnostics

Standard User Interface (providing client connectivity and monitoring)

CERN-based User Interface Box: DLIB





HTS Current Lead Test Bench

Current Lead Control System

From India to China

First Real Case Application - ASIPP

Quench Protection System ASIPP

Particularities of ITER interlock systems

1. An eclectic collection of actions

2. The not-so-safe fail safe states

→ Identification of safe states after a degradation of the interlock components is not always obvious and even impossible sometimes without implying long machine downtimes.

→ Interlocks design shall allow early internal failure detection followed by a controlled sequence of actions

→ Setting the interlock outputs in their fail-safe sates is the last option to be taken

→ Intelligent redundancy + self-diagnostics

Particularities of ITER interlock systems

1. An eclectic collection of actions

2. The not-so-safe fail safe states

3. Expensive interlock actions (or when the cure is worse than the disease)

→ Triggering interlocks not only reduces the ITER operation availability but also the tokamak lifetime

→ Example: limited total number of coil fast discharges or unmitigated disruptions

→ ‘Soft’ interlock actions performed in collaboration with conventional controls and always backed-up by ‘hard’ interlocks

Particularities of ITER interlock systems

1. An eclectic collection of actions

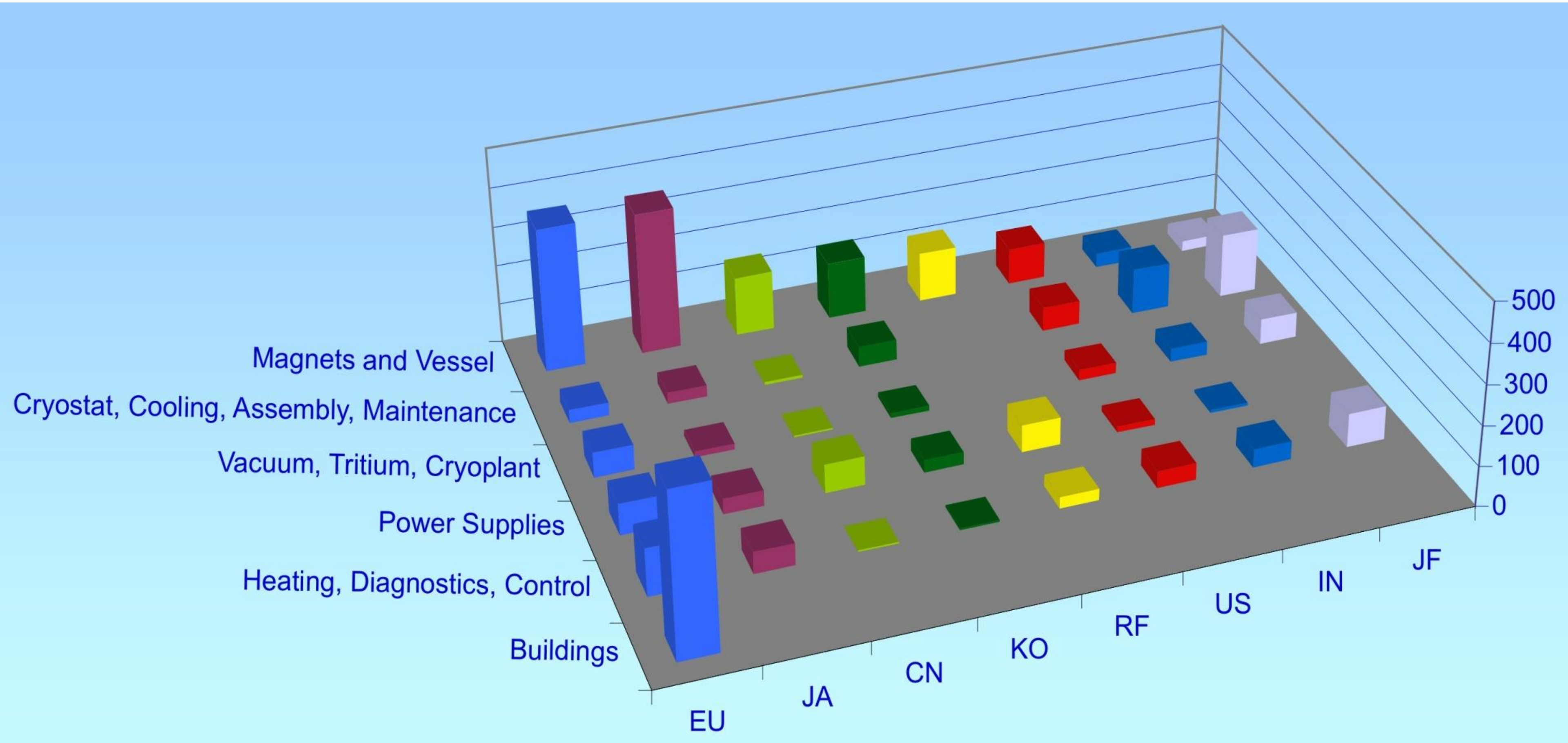
2. The not-so-safe fail safe states

3. Expensive interlock actions (or when the cure is worse than the disease)

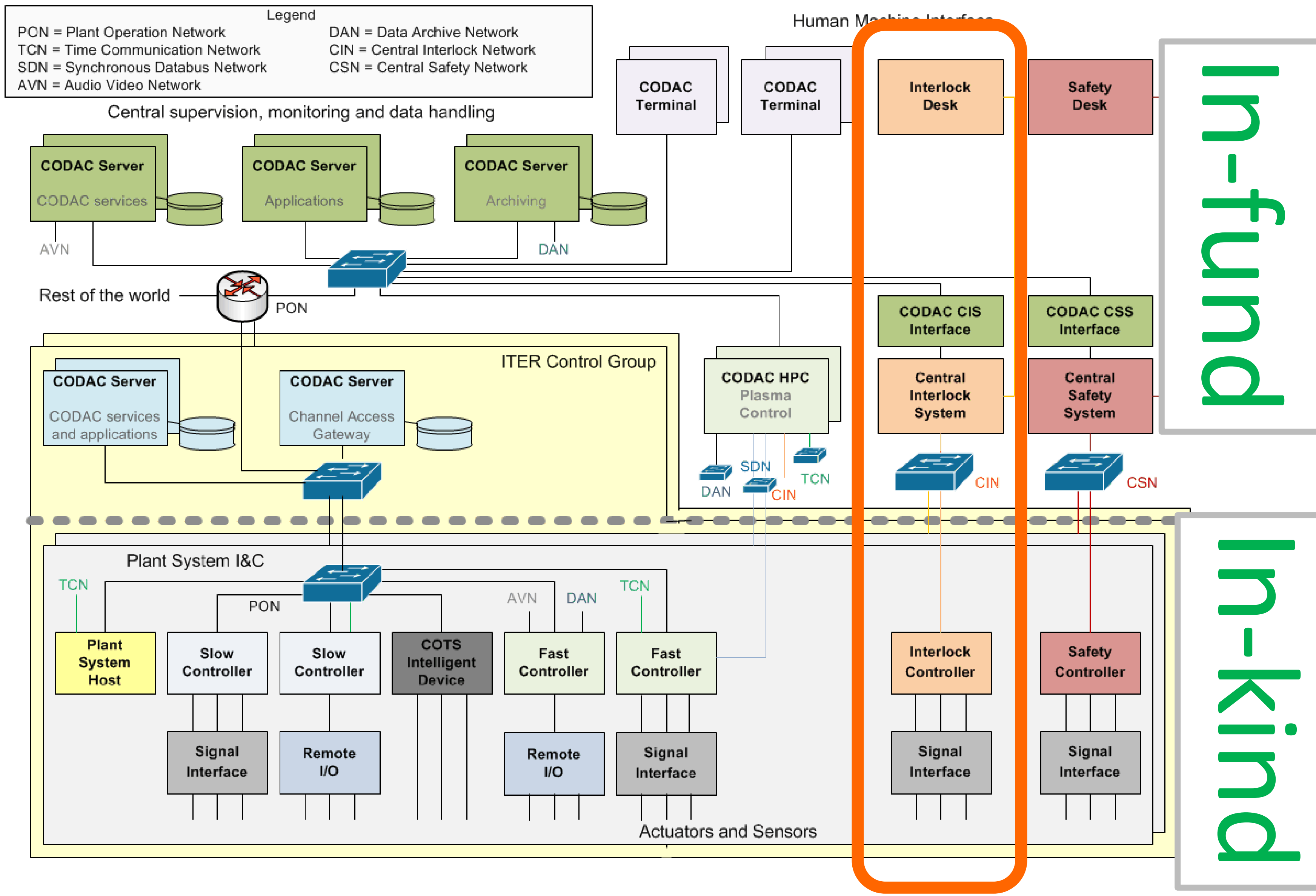
4. ITER complex procurement strategy

ITER Procurement Strategy

A unique feature of ITER is that almost all of the machine will be constructed through *in kind procurement* from the Members



In-fund and in-kind procurement

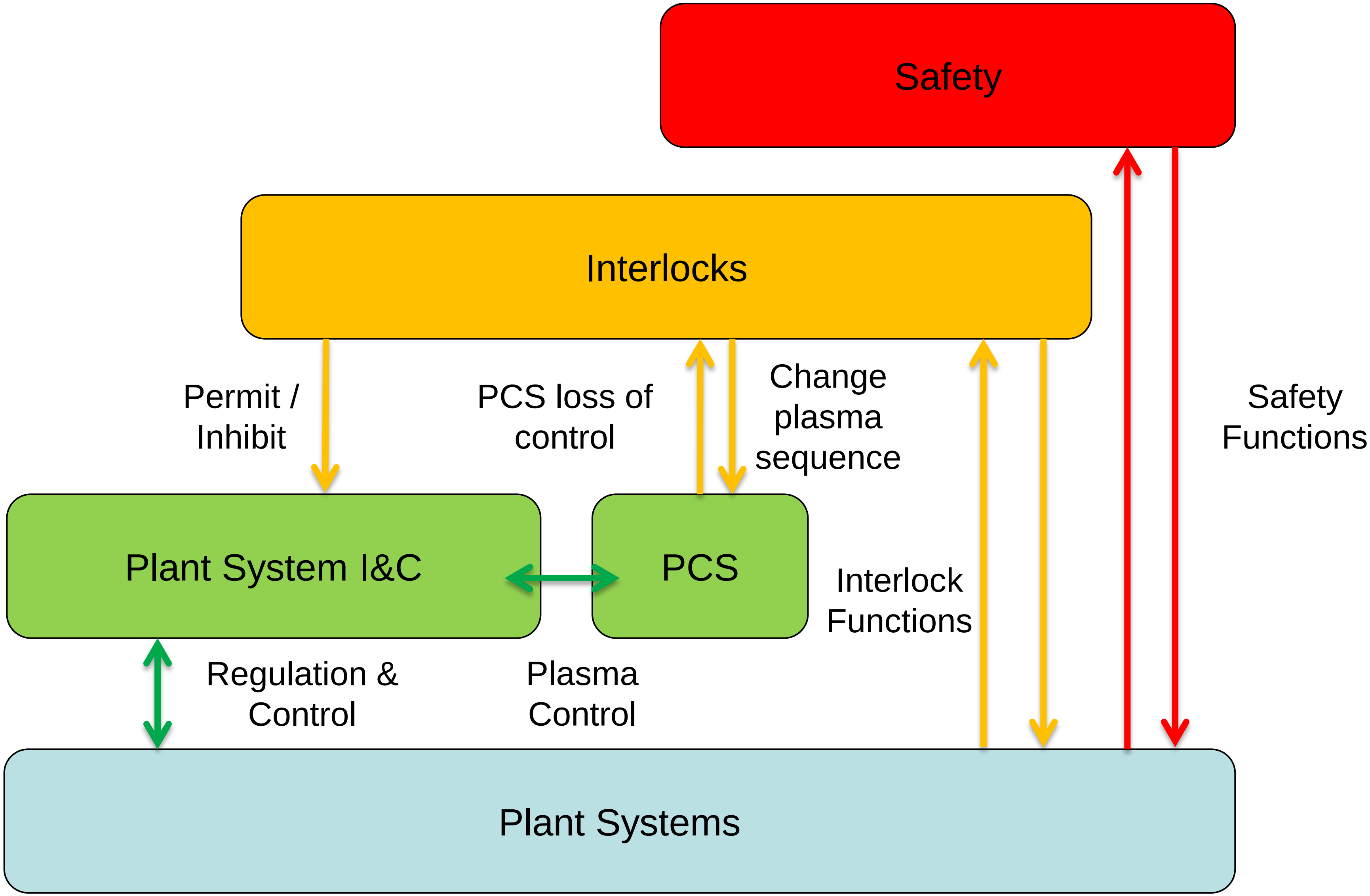


Interlocks Integration

Mitigation of risks related to integration of the interlocks

- Segregation Safety – Interlocks

ITER Defense-in-depth Approach



Mitigation of risks related to integration of the interlocks

- Segregation Safety – Interlocks
- Common strategy for interlock identification and classification

What is an Interlock?

	Machine/System Unavailability						
Cost	< 1h	< 1 day	< 1 week	< 2 month	< 1 year	< 2 year	> 2 year
< 0.1 M€	Mi	Se	Se	Se	Ma	Ma	Ca
< 1 M€	Se	Se	Se	Se	Ma	Ma	Ca
< 10 M€	Se	Se	Se	Ma	Ma	Ma	Ca
< 50 M€	Ma	Ma	Ma	Ma	Ma	Ma	Ca
<500 M€	Ma	Ma	Ma	Ma	Ma	Ca	Ca
> 500 M€	Ca	Ca	Ca	Ca	Ca	Ca	Ca

Category	Criteria
Catastrophic (Ca)	Disastrous threat to ITER's mission, abandonment of the project and goals
Major (Ma)	Loss of a full operational campaign, moderate threat to ITER's mission
Severe (Se)	Significant reduction of an operational campaign program
Minor (Mi)	No significant impact on the operational campaign program

Category	Description	Yearly frequency level
Frequent	Event occurs very likely	> 5
Probable	Event is likely to occur	0.5 – 5
Occasional	Event possible and expected	0.05 – 0.5
Remote	Event possible but not expected	0.005 – 0.05
Improbable	Event unlikely to occur	0.0005 – 0.005
Negligible	Event extremely unlikely	< 0.0005

Event Likelihood	**Consequence**			
	Catastrophic	Major	Severe	Minor
Frequent	3IL-4	3IL-3	3IL-3	3IL-1 (no interlock)
Probable	3IL-4	3IL-3	3IL-3	3IL-1 (no interlock)
Occasional	3IL-3	3IL-3	3IL-2	3IL-1 (no interlock)
Remote	3IL-3	3IL-2	3IL-2	3IL-1 (no interlock)
Improbable	3IL-3	3IL-2	3IL-1 (no interlock)	3IL-1 (no interlock)
Negligible	3IL-2	3IL-1 (no interlock)	3IL-1 (no interlock)	3IL-1 (no interlock)

Mitigation of risks related to integration of the interlocks

- Segregation Safety – Interlocks
- Common strategy for interlock identification and classification
- Segregation Central – Local interlocks

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- Segregation Safety – Interlocks
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- Segregation Central – Local interlocks
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- Design and configuration guidelines
- Mini-CIS

Mitigation of risks related to integration of the interlocks

- Segregation Safety – Interlocks
- Common strategy for interlock identification and classification
- Segregation Central – Local interlocks
- Hardware and software standarisation
- Design and configuration guidelines
- Mini-CIS
- Team spirit and many flight hours

Domestic Agencies

Preliminary Dependability Analysis

Dependability Analysis

Principle

Future fusion power plants will be only possible if ITER proves that the reactor and associated systems can run **long plasma discharges reliably.**

Consequences

The ITER interlocks shall:

1. **Protect the tokamak integrity**
2. **Maximise scientific operation time**
3. **Anticipate and test interlock solutions for future industrial fusion reactors**

Interlock Dependability Analysis Strategy

3 Steps

1. **What we can control: Central Interlock System**
2. **What we can coordinate: Plant Interlock Systems**
3. **All together**

Interlock Dependability Analysis Strategy

3 Steps

1. **What we can control: Central Interlock System**

CIS Integrity Requirements (from Project Baseline):

I. Overall availability (99,9%)
II. reliability (99,6% over two 8h shifts)
III. probability of a dangerous failure of less than 10^{-7} per hour

Strategy

1. Standard architectures well defined in terms of dependability
   - IEC 61508 Certified equipment whenever possible
   - Non certified equipment with detailed reliability analysis and prototyping
2. Continuous long-term dependability monitoring/assessment

Interlock Dependability Analysis Strategy

3 Steps

1. What we can control: Central Interlock System

2. **What we can coordinate: Plant Interlock Systems**

   Tools for the plant systems currently under design:

   i. RAMI
      - Functional Analysis - FMECA
      - Reliability Block Diagrams

   ii. HAZOP

   iii. 3IL Assesments

   Support Life Cycle Management

Interlock Dependability Analysis Strategy

3 Steps

1. **What we can control: Central Interlock System**
2. **What we can coordinate: Plant Interlock Systems**
3. **All together**

- Machine Protection Panel – Qualitative Analysis
- Models for Interlock functions - 17 representative cases analyzed
- Progressive take over of the local plant system interlocks by the CIS team
- R&D: Systems Theoretic Process Analysis (STPA)

Conclusions

The unprecedented technical and managerial complexity of ITER requires an interlock design where the traditional simplicity of tokamak investment protection systems has been replaced by a **4-architecture solution** with different technological choices

The ITER Interlock System will most likely be the first machine protection system built with most of its components provided **in-kind from up to 36 different countries**

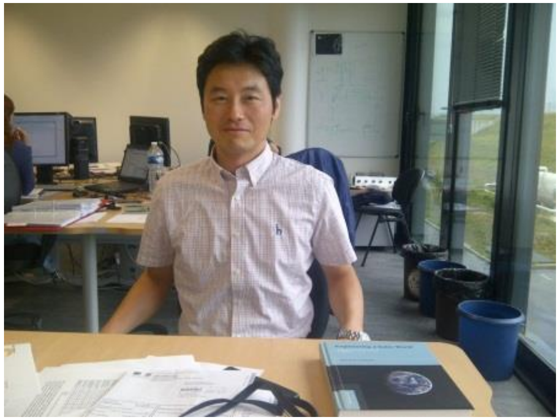
A strong effort is being put in place to ensure that **all actors around the globe** design, build and configure the parts of the puzzle to be **properly integrated** with the central system

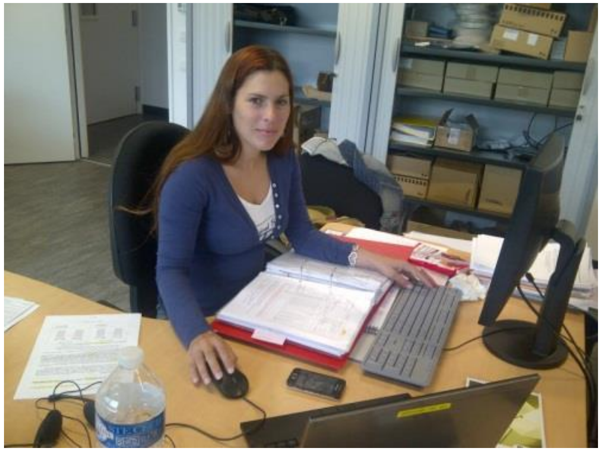
While a detailed **dependability analysis** of the Central Interlock System has been already performed, a final strategy has still to be put in place to continuously monitor the progressive growth the overall interlock system.

The ITER interlock system will complete its final design in **March 2016**. Construction of **CIS V.1** will be done in Korea during 2016 and 2017.

CIS V.1 will be tested in the Korean superconducting **tokamak KSTAR** before being shipped to **Cadarache by 2019**

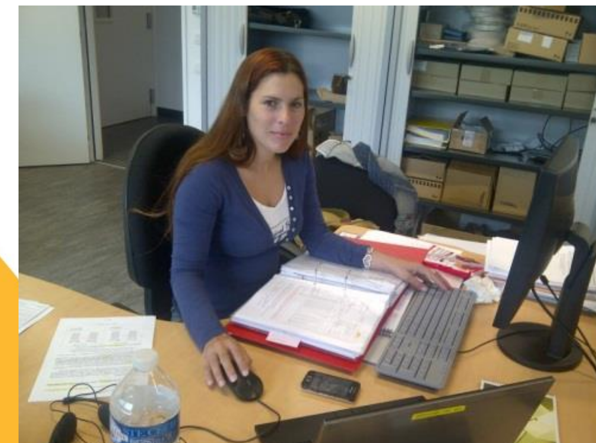
Thank you







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