ITER and its Control System – Status and Perspectives

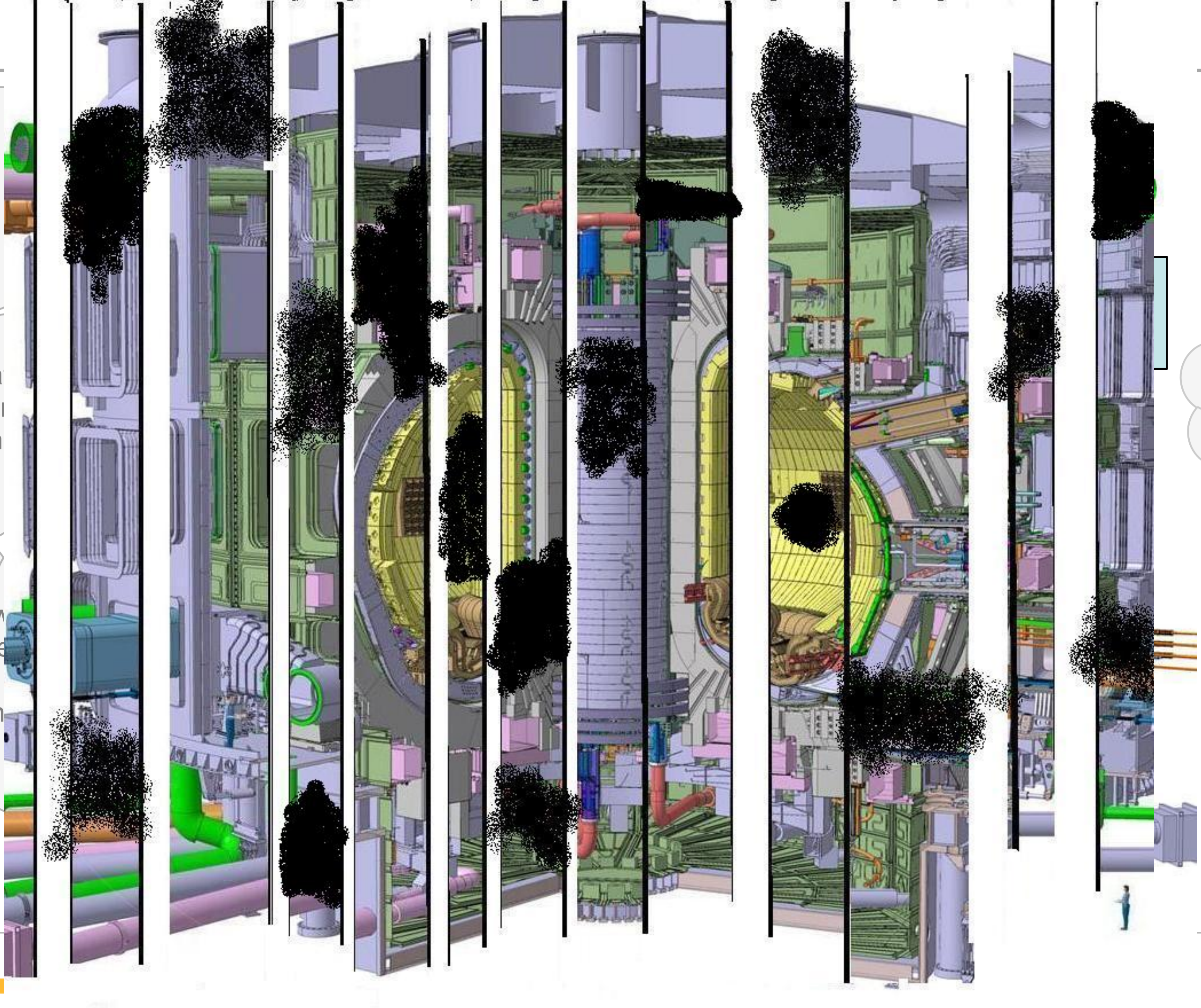
Ralph Lange
Control System Division
ITER Organization

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

We forgot there is an interface between A and B

I forgot tha need that i my system

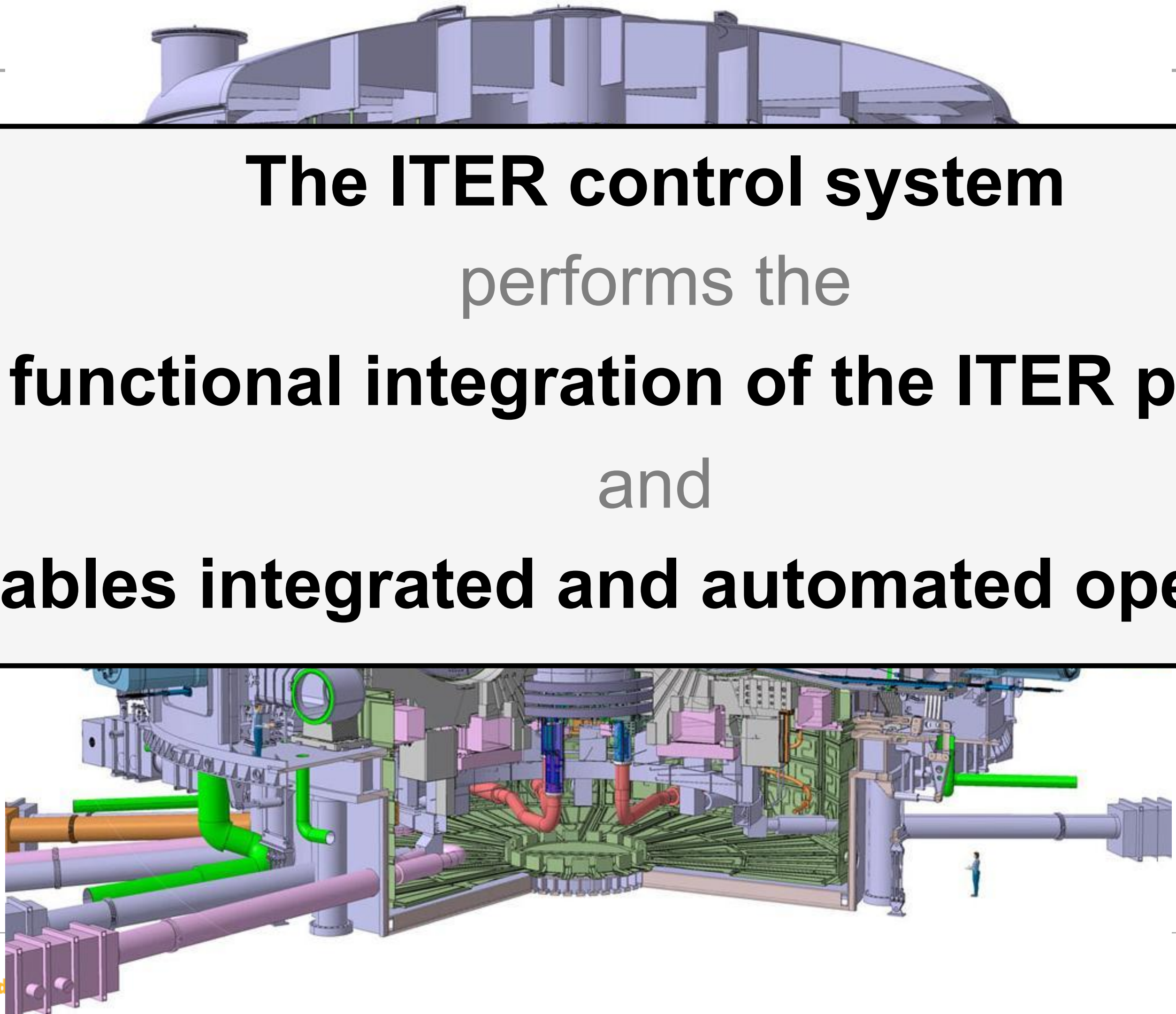
I did not know the others are doing the same thing in a different way



We changed the design so the interface does not exist anymore

That should be implemented in your system, not mine

I do care what the others do. I build my system.



The ITER control system

performs the

functional integration of the ITER plant

and

enables integrated and automated operation

Outline

- Introduction and Architecture
  - System Breakdown, Networks, Structure
  - Key Parameters
- CODAC Core System
  - Standardization: Specification, Hardware, Software, Support
- CODAC Operation Applications
- Infrastructure and Protection Systems
- Schedule
- Early Integration Approach

High Level Requirements

The ITER control system

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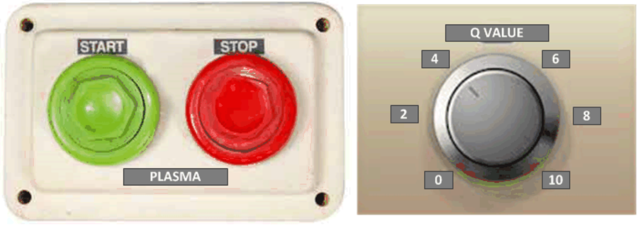
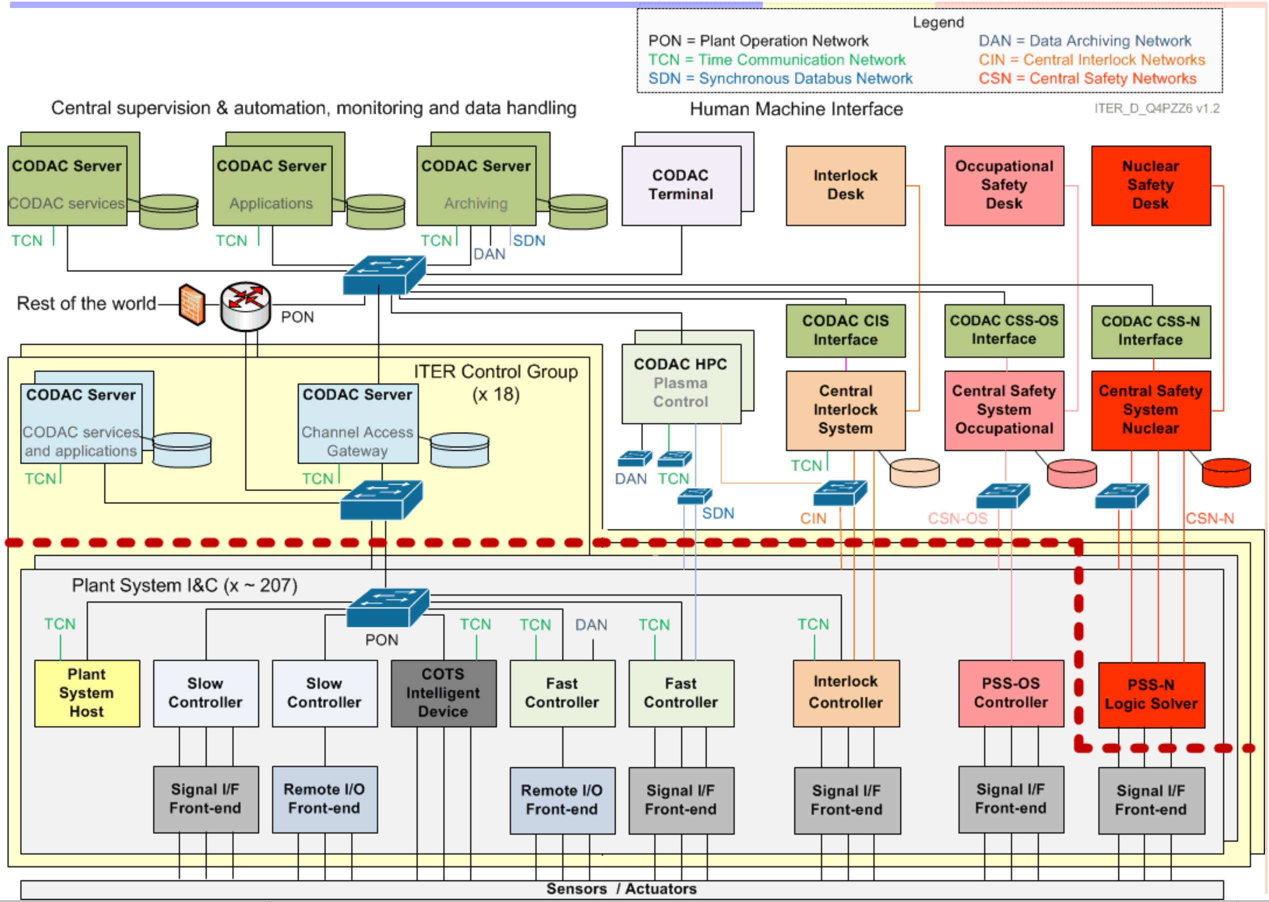
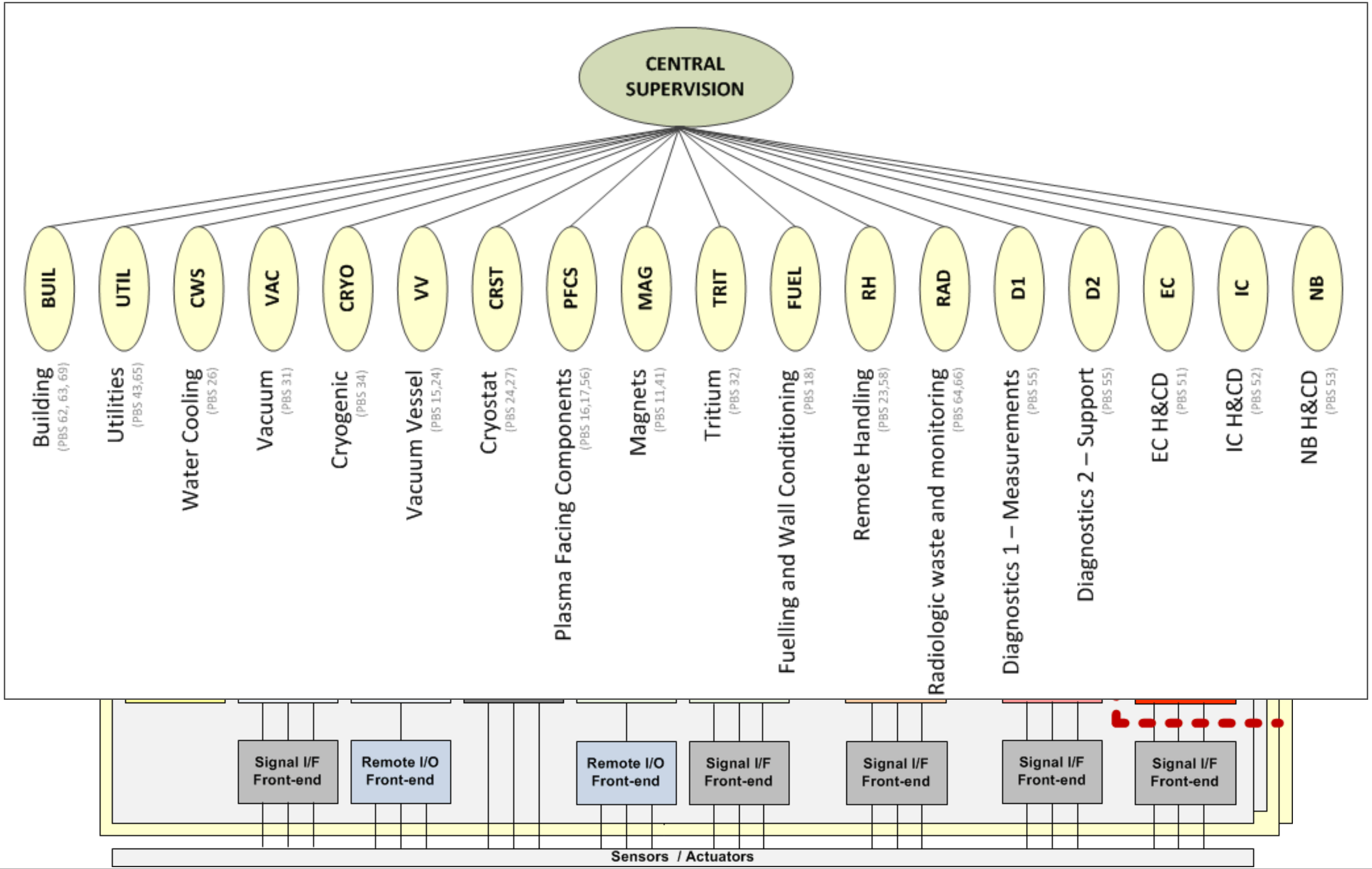


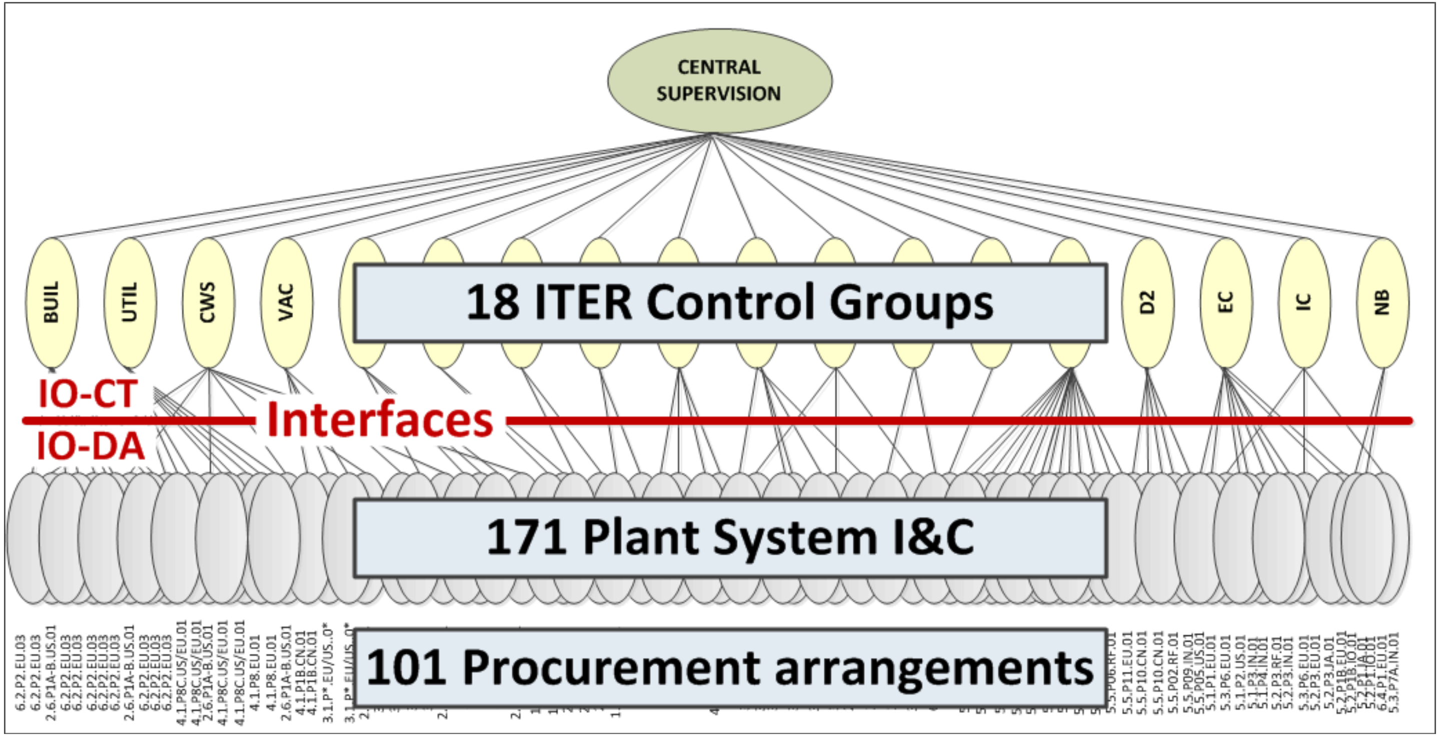
Architecture



Architecture



Architecture



CBS 1

CBS 2

CBS = Control Breakdown Structure

- Breakdown in 18 **ITER control groups** (CBS level 1) covering 28 PBS
- An ITER control group contains many **Plant System I&C**, total no. 171 (CBS level 2)
- A Plant System I&C is a deliverable from a **procurement arrangement (IN-KIND)**
- A procurement arrangement delivers a part, one or many Plant System I&C

Some Key Parameters (Quantities)

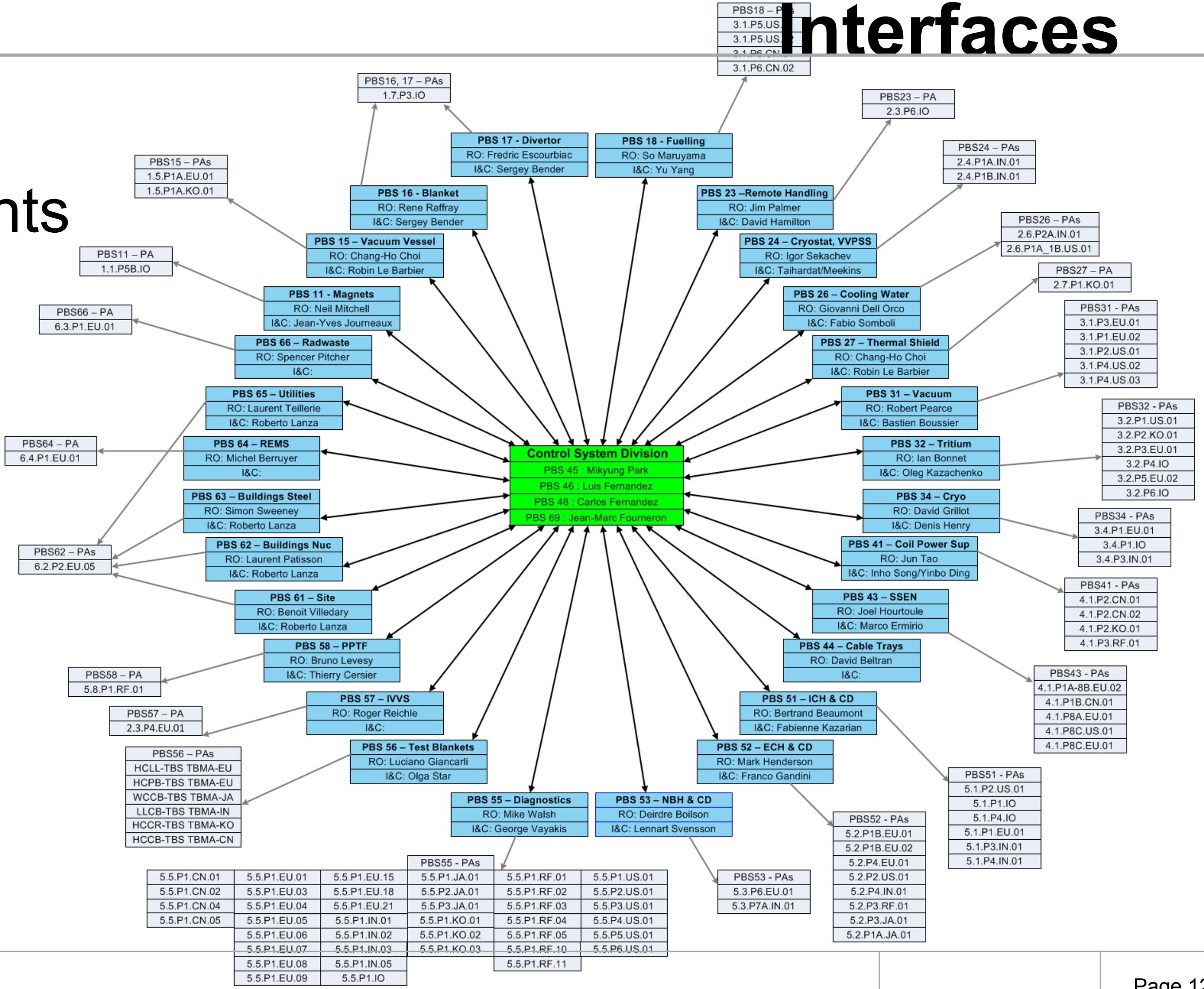
Parameter	Value
Total number of I&C cubicles/racks	>5.000
Total number of plant I&C signals (wires)	>100.000
Total number of process variables (PV)	>1.000.000
Total number of active operator stations	100
Physical size of ITER site	900*600 m
Number of buildings and plant areas with I&C equipment	90
Number of central-plant I&C interfaces	330
I&C cables (sensors/actuators to controllers)	6000 km
Multi-core single mode fiber optic network cables	300 km
Multi-pair copper network cables	170 km
Number of identified machine protection I&C functions	150
Number of identified nuclear safety I&C functions	252

Some Key Parameters (Performance)

Parameter	Value
Update rate per operator station (200 PVs)	5 Hz
Maximum sustained data flow on Plant Operation Network (PON)	50 MB/s
Total PON archive rate	25 MB/s
Total Data Archive Network (DAN) archive rate (initial)	2 GB/s
Total DAN archive rate (final)	50 GB/s
Total archive capacity	90-2200 TB/day
Accuracy of time synchronization	<50 ns RMS
Number of nodes on Synchronous Data Network (SDN)	100
Maximum latency asynchronous events	1 ms
Maximum latency sensor to actuator (SDN)	500 μs
Maximum jitter sensor to actuator (SDN)	50 μs RMS
Maximum sustained data flow on SDN	25 MB/s
Maximum latency sensor to actuator for “slow” interlock	1 sec
Maximum latency sensor to actuator for “fast” interlock	1 ms

Interfaces

- Interface and integrate 28 plants supplied by 101 procurement arrangements

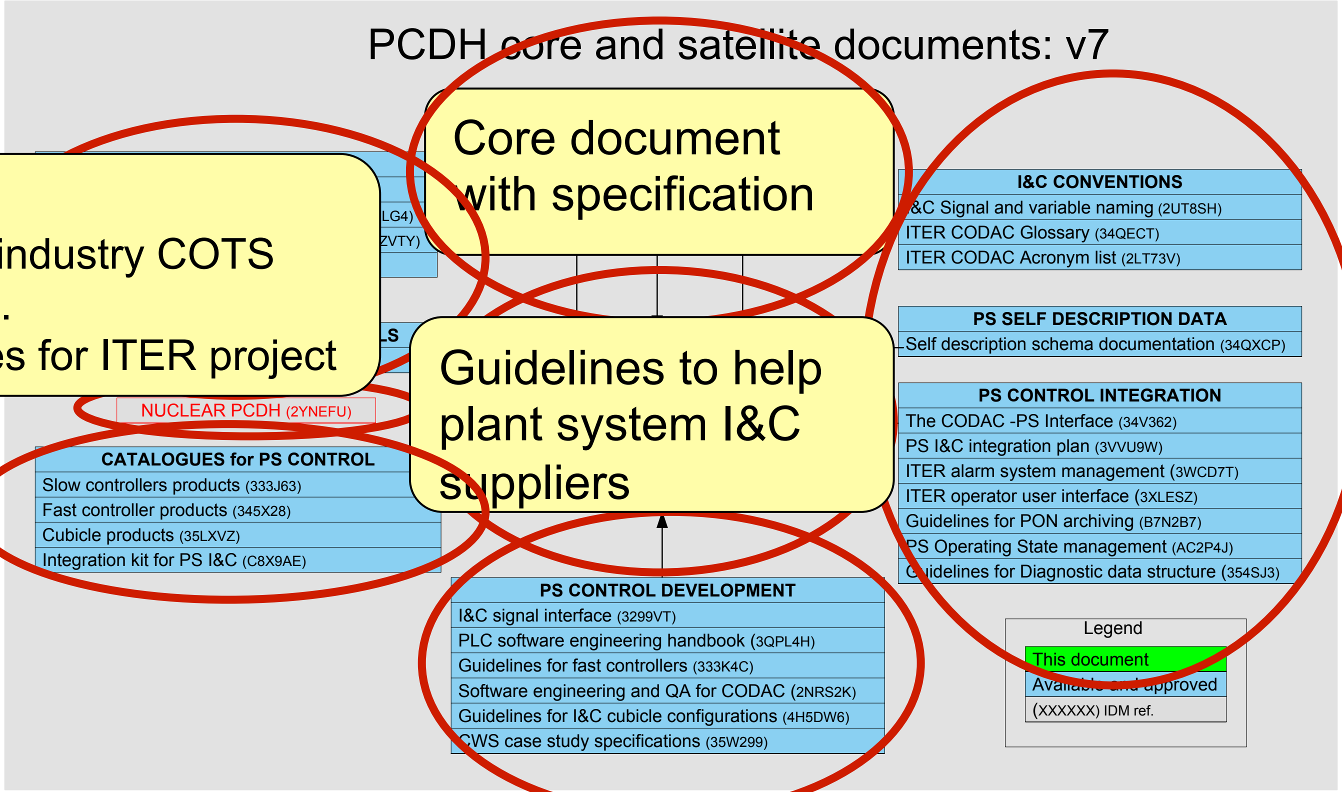


Standardization – Specifications

Catalogues.
Mainstream industry COTS technologies.
Special prices for ITER project

Core document with specification

Guidelines to help plant system I&C suppliers



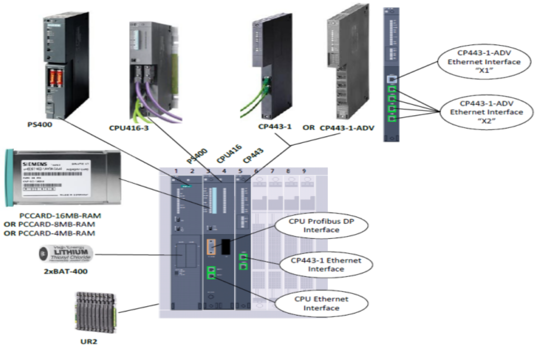
Full documentation set available on public web

Standardization – Hardware

Slow control

- ✓ Siemens S7-300/400 products (1500 series soon)
- ✓ ET200M and ET200S for remote I/O
- ✓ Covering standard industrial systems

SIEMENS



Schneider Electric

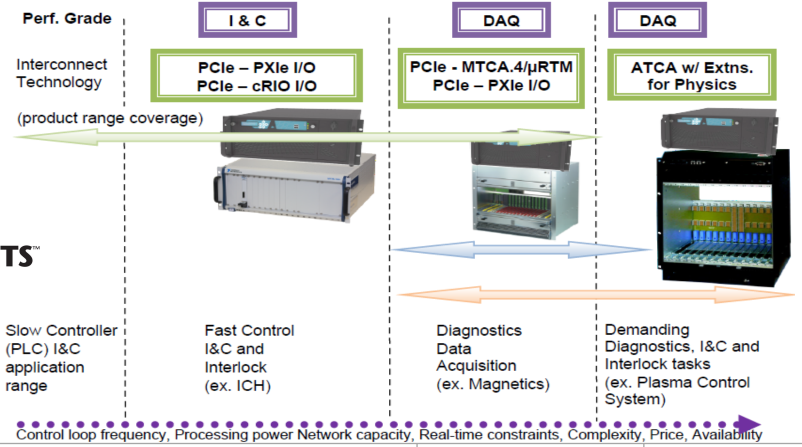
Cubicles

- ✓ Schneider Electric products
- ✓ Address floor standing and wall mounted cubicles
- ✓ Address Standard and EMC protected.

Fast control

- ✓ PCI Express. CPU and I/O segregated
- ✓ Mainly National Instruments products
- ✓ Covering acquisition and control > 50 Hz

NATIONAL INSTRUMENTS



Standardization – Software

- OS: **Red Hat Enterprise Linux** (RHEL x86_64) with **MRG-R** real-time extensions on fast controllers
- Infrastructure: **EPICS**, control system tool set used in hundreds of projects world-wide: light sources, high energy physics, fusion (KSTAR, NSTX)
- CODAC services layer: **Control System Studio** used at many EPICS and other sites and including HMI, alarming, archiving etc.
- ITER **specific software** such as configuration (system description), state handling, drivers, networking, etc.
- Fixed **1 year release cycle** (maintenance releases when needed), extensive testing procedures

Infra	2013	2014	2015	2016	2017	2018	2019	2020	2021
RHEL 6.3 MRG-R 2.1 EPICS 3.14	4.0 4.1	4.2 4.3		Support					
RHEL 6.5 MRG-R 2.5 EPICS 3.15			5.0 5.1	5.2 5.3	5.4			Support	
RHEL 7.x MRG-R x.x EPICS 7.x						6.0	6.1	6.2	6.3

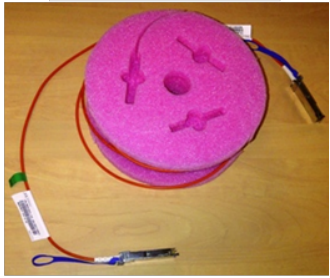
Standardization – I&C Integration Kits

Distributed for free to all plant system I&C (171)

Contains:

- An industrial computer hosting:
  - Plant System Host
  - mini-CODAC

  as virtual systems

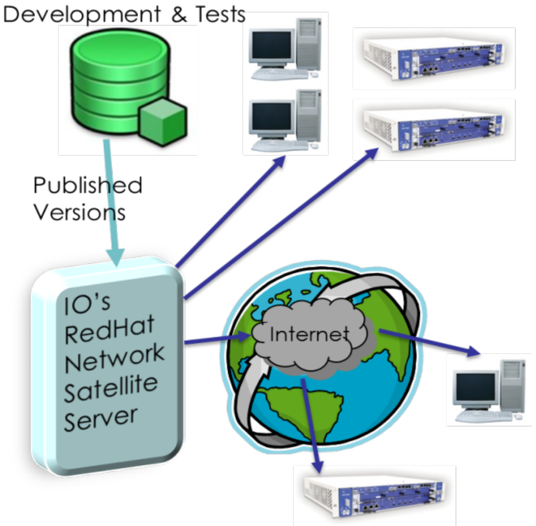


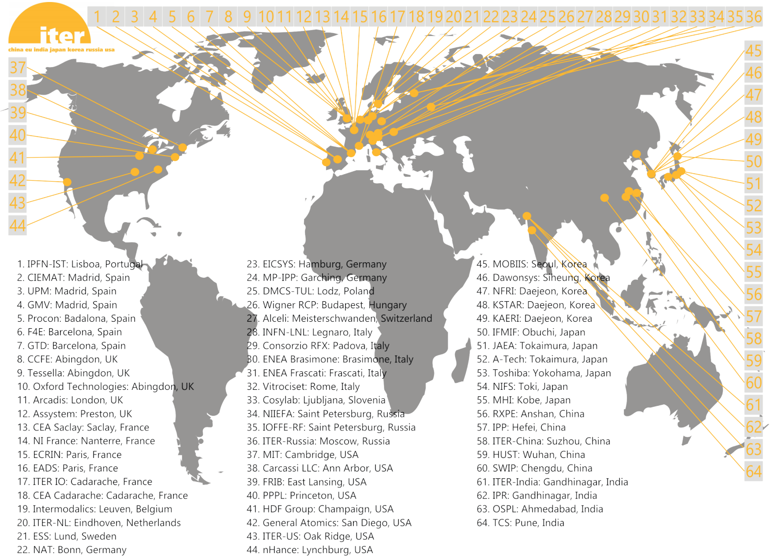
- An industrial network switch to set-up the local network
- A cubicle monitoring system
- The interfaces boards to connect the fast controllers to High Performance Networks (TCN/SDN/DAN)

Standardization – Distribution Status

- **I&C Integration Kits Deliveries**
  - 102 kits (out of 171) shipped since 2013
- **CODAC Core System (CCS) Distribution:**
  - RedHat satellite since 2012 has distributed RPMs to 64 registered institutions

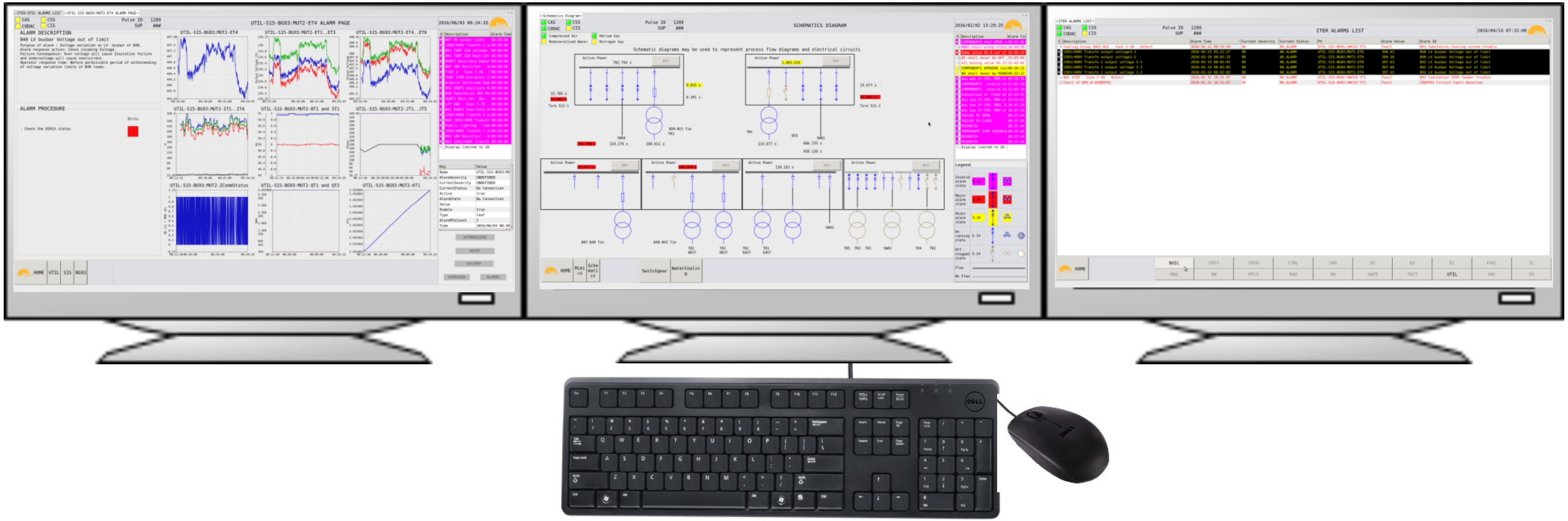
CN	11
EU	22
IN	6
IO	13
JA	7
KO	11
RF	18
US	15





Standardization – HMI Style Guide and Toolkit

- Plant System operator VDU workstation: 3 VDU (terminals)
  - Ultra HD resolution as a minimum
    3840 x 2160 (4K) at 60Hz
  - 24 inches
  - Aspect ratio of 16:9



CODAC Operation Applications

CODAC Operation Applications are ITER dedicated software packages deployed on dedicated central servers

1. Preparation

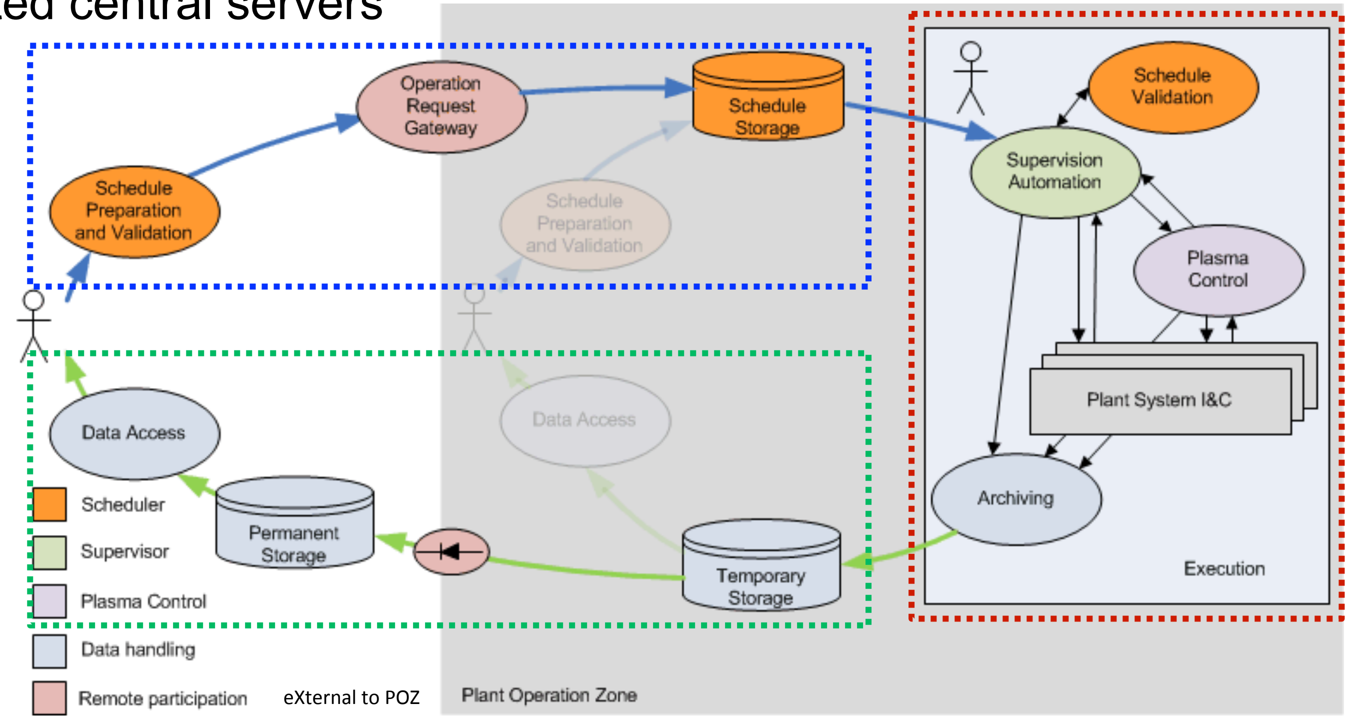
Scheduling (PSPS)
Gateway (ORG)

2. Execution

Control (PCS)
Supervision (SUP)

3. Analysis

Data handling
Data access



CODAC Operation Applications

- **Pulse Schedule Preparation System (PSPS)**
  - Scheduler for schedule preparation and validation
  - Initial existing version allows editing, managing, saving and exporting configuration objects

- **Operation Request Gateway (ORG)**
  - Support remote participation by securely controlling and screening interaction with the outside world
  - Initial existing version allows unidirectional mirroring of data from POZ to XPOS and configuration requests transmission from XPOZ to POZ

CODAC Operation Applications

- **Supervision and Automation (SUP)**
  - Provides the infrastructure to execute a pulse schedule prepared by PSPS and to support automated operation and continuous monitoring
  - Initial existing version implements Plasma Operation State (POS) sequence and Common Operational State (COS) aggregation and partitioning function

- **Plasma Control System (PCS)**
  - Performs the distributed real-time control and monitoring during the pulse
  - Final design of underlying real-time infrastructure framework completed. Preliminary design of physics algorithms completed.

CODAC Operation Applications

- **Data Handling**
  - Provides the system to write, store, retrieve and visualize all data produced during ITER commissioning and operation.
  - First implementation to store fast data in HDF-5 format and interface to EPICS data archiving available

- **Data Access**
  - Provides a unified access to all data produced by ITER and APIs for selected preferred user processing and visualization software (e.g. Matlab, MDSplus,…)
  - First implementation of Unified Data Access API available

Upgrade to EPICS 7

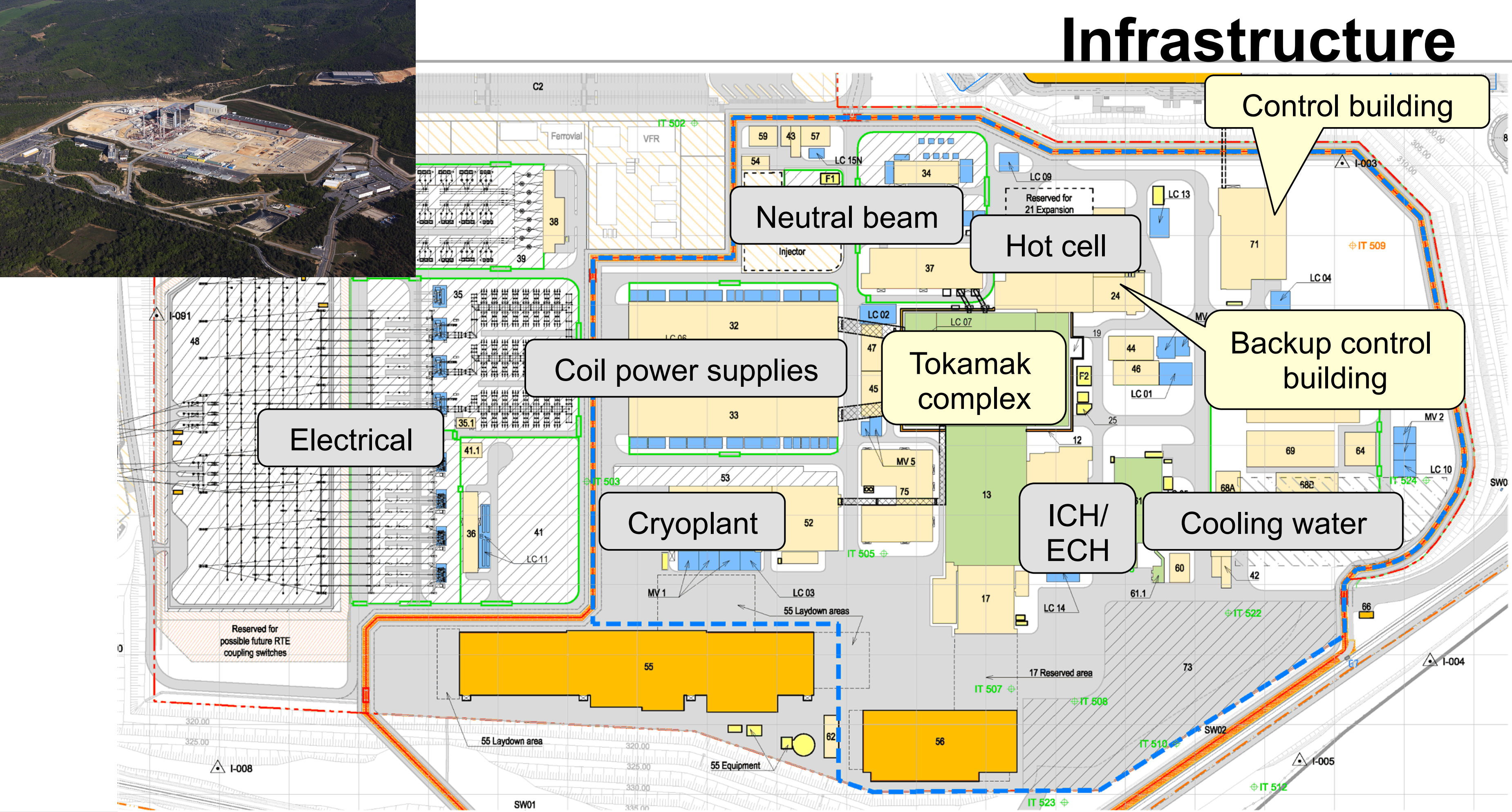
EPICS 7 introduces a network protocol that supports structured data

- SUP (Supervision and Automation) will benefit from being able to consistently read/write configuration for a complete system
- PCS (Plasma Control System) will benefit from consistent control and monitoring of real-time nodes
- HMI will benefit from efficient image transfer across the network

- The early plant systems' I&C will be based on current EPICS V3 – EPICS 7 provides multiple interoperability options

(more details in seminar this afternoon: 3rd bldg, 7F, meeting room, 1.30pm)

Infrastructure

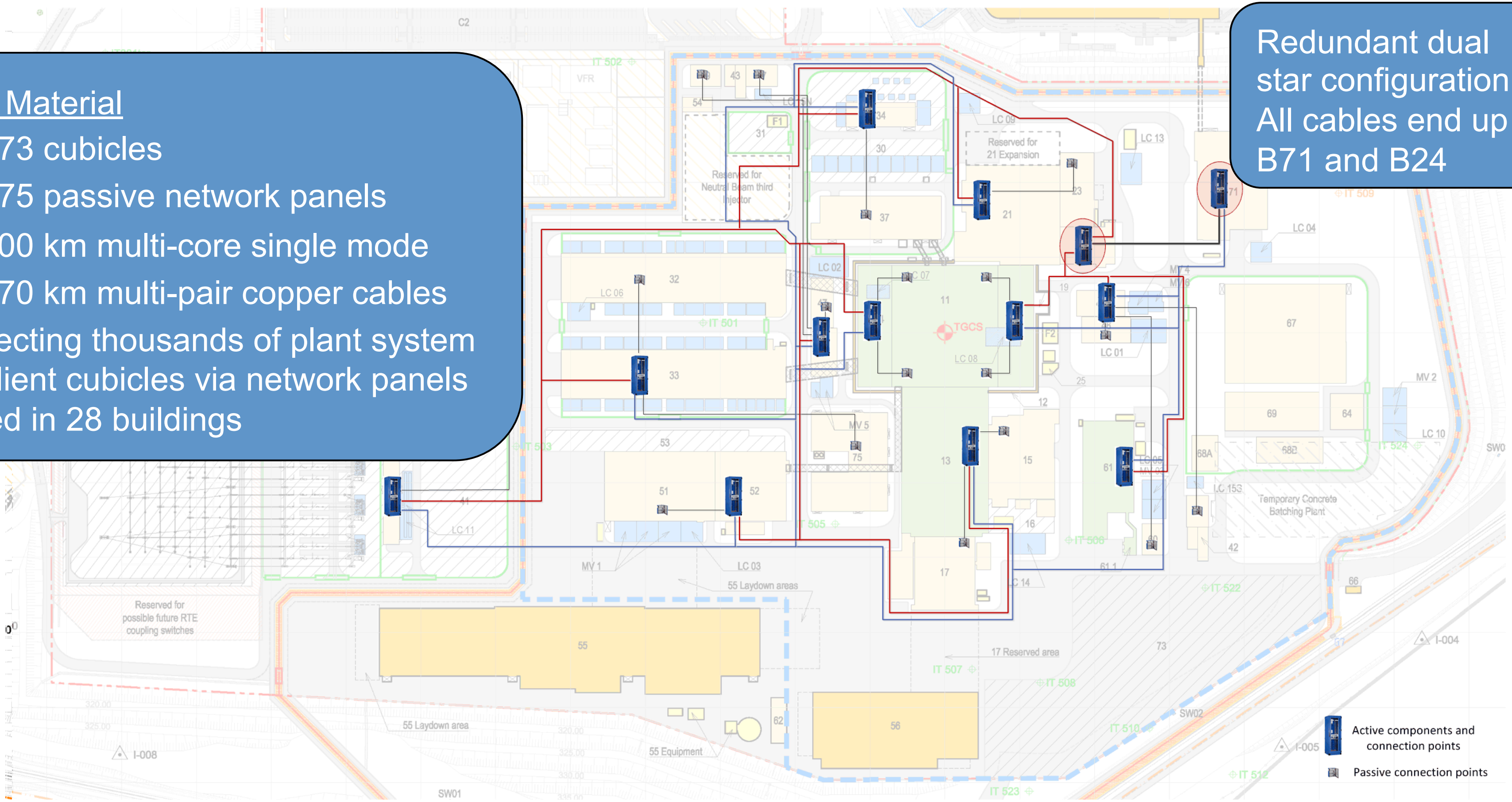


Bill of Material

- 173 cubicles
- 175 passive network panels
- 300 km multi-core single mode
- 170 km multi-pair copper cables

Connecting thousands of plant system I&C client cubicles via network panels located in 28 buildings

Redundant dual star configuration
All cables end up in B71 and B24



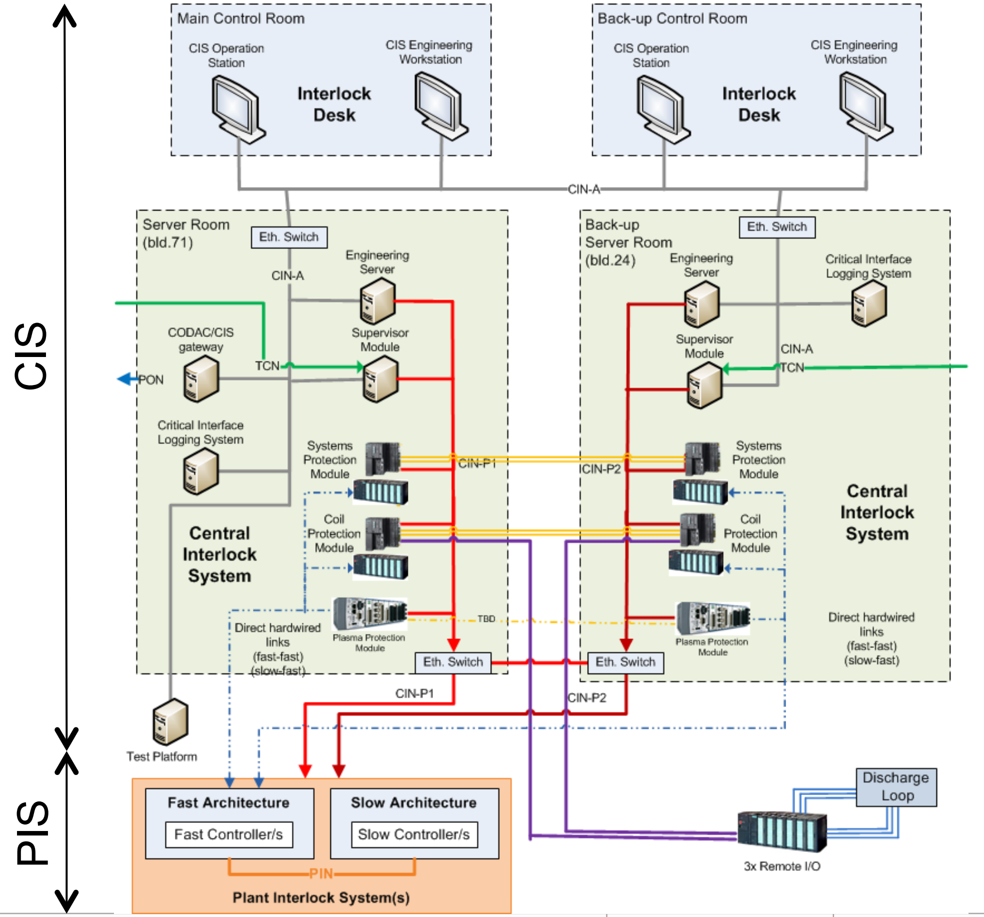
Machine Protection I&C

Architecture and Technologies

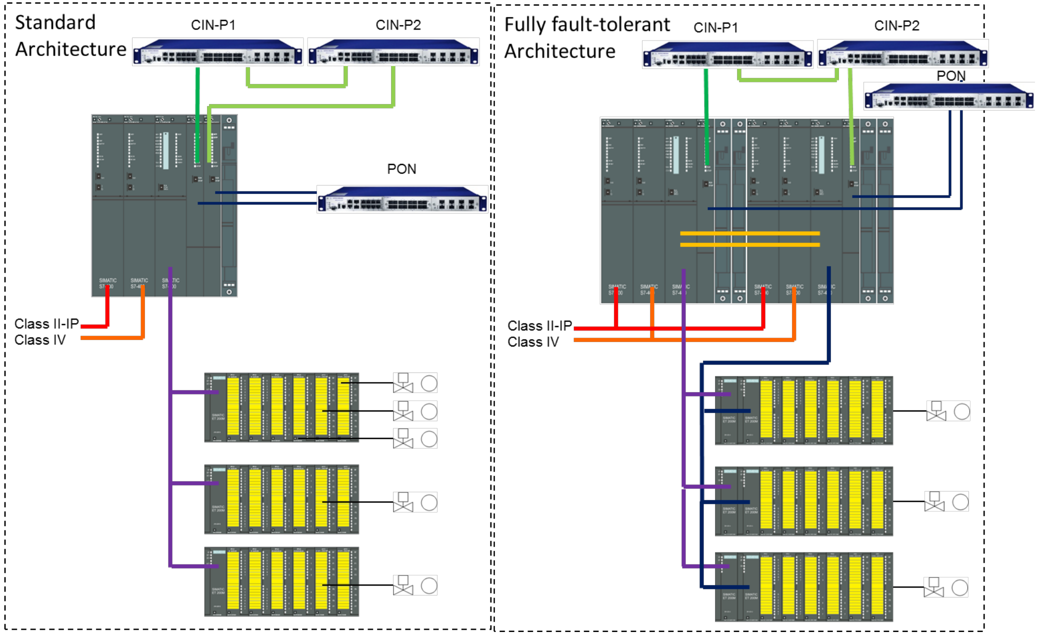
- Different requirements on time response and action complexity lead to three architectures.
    - Slow Interlock Architecture : slower than 0.3 sec
    - Fast Interlock Architecture : 100μs - 0.3 sec
    - Hardwired Loops : < 1μs

Final design completed

Manufacturing in progress



Machine Protection I&C – Slow Interlock



PLC based using

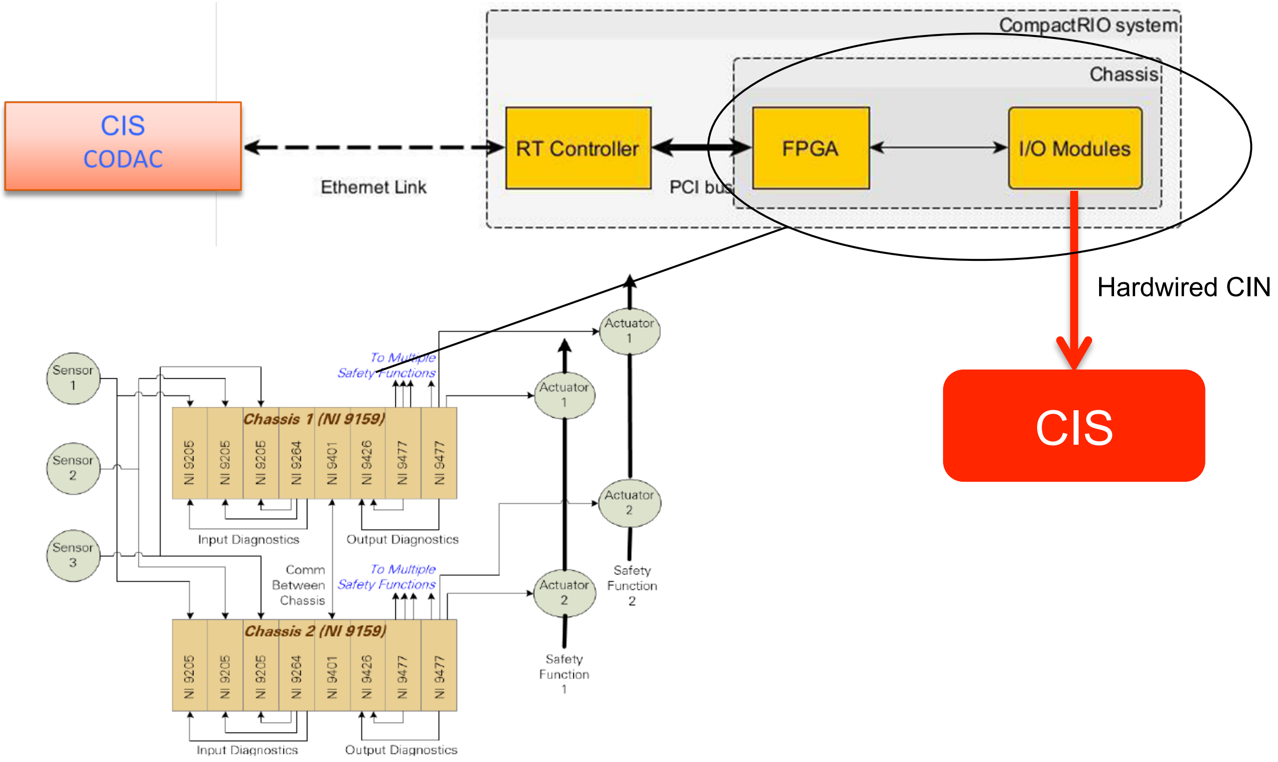
Siemens S7-400 F/FH

Example function:

Event: Loss of one LN2 plant

Action: Coil power permits removed, next pulse inhibited

Machine Protection I&C – Fast Interlock



FPGA based using

Customized NI compactRIO

Example function:

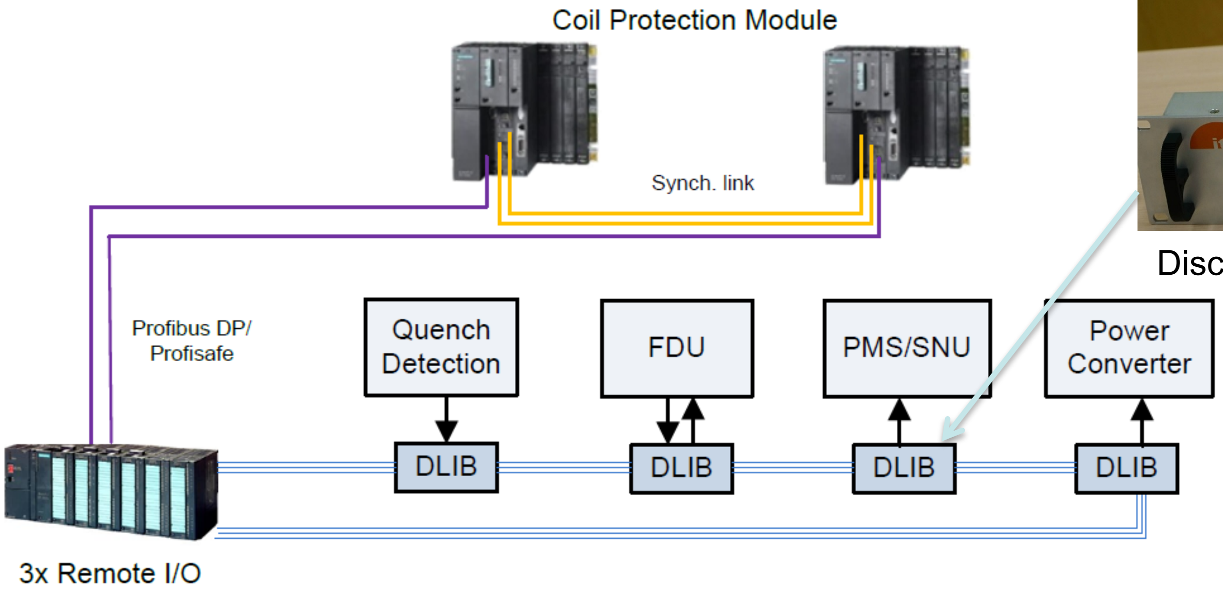
Event: Diagnostics detect Neutral Beam shine-through

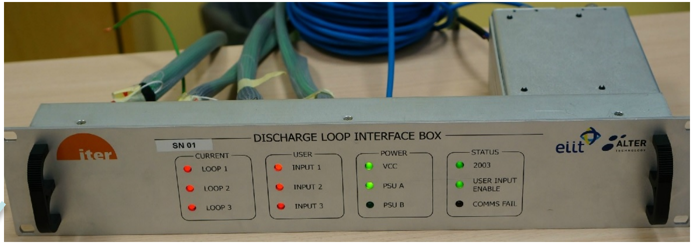
Action: Neutral Beam is stopped

Machine Protection I&C – Hardwired Loops

Current loops based on

Custom design (CERN derived)





Discharge Loop Interface Box (DLIB)

Example function:

Event: Magnet detects quench

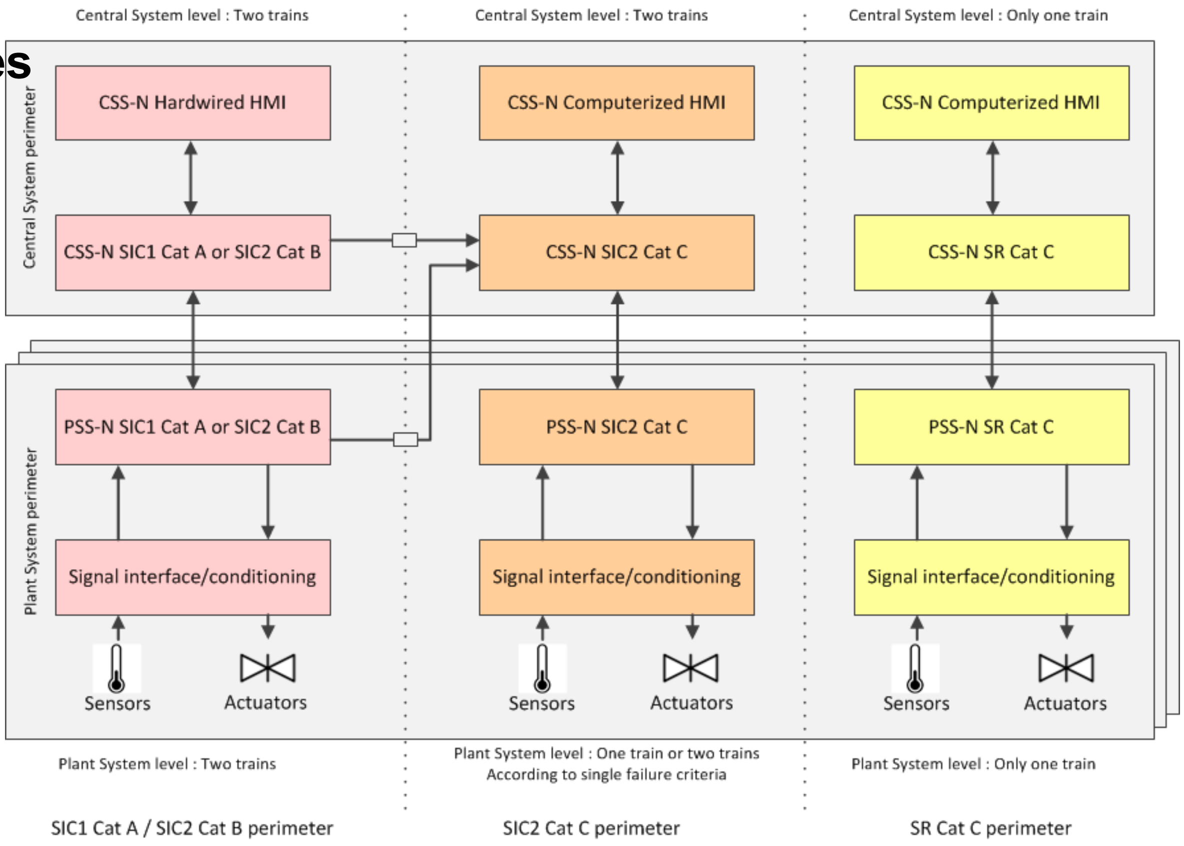
Action: Fast Discharge Unit is activated

Nuclear Safety I&C

Architecture and Technologies

- Safety functions are classified in four categories;
  - SIC 1 cat A and SIC 2 cat B Hardwired HIMA Planar 4
  - SIC 2 cat C and SR cat C Siemens S7-400 F/H
- Number of inputs/outputs estimated to 29.000
- Project Change Request transfers the scope of most PSS-N to Central Team

Final design in progress

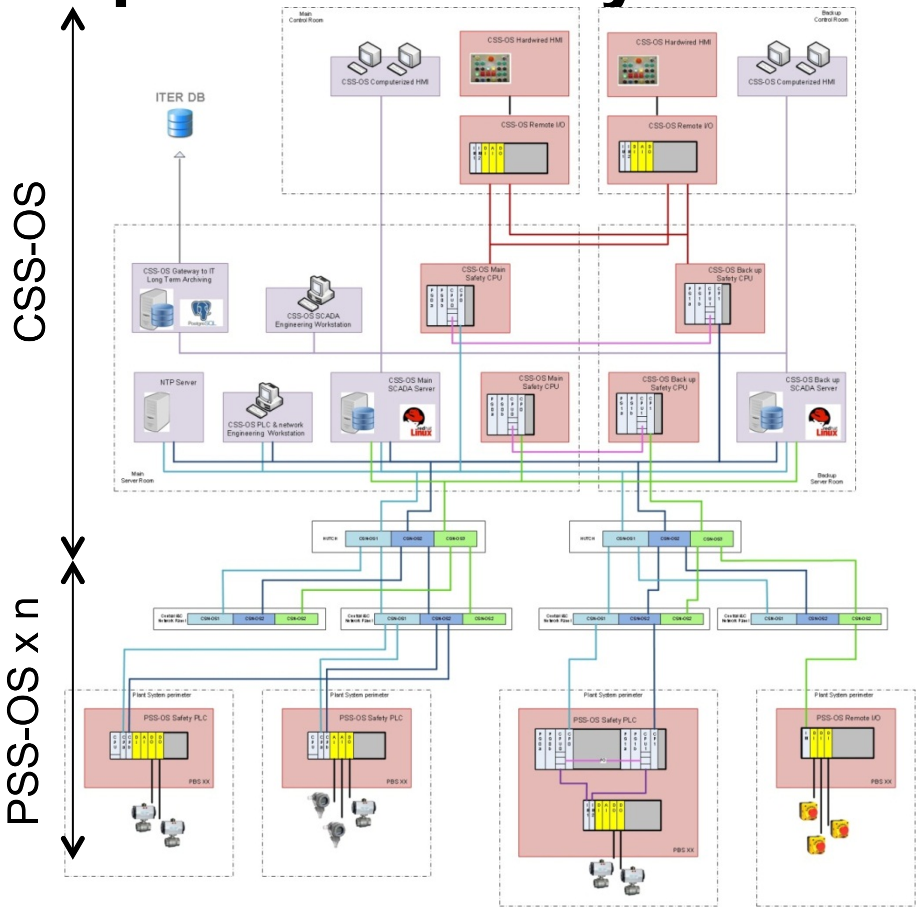


Occupational Safety I&C

Architecture and Technologies

- Safety functions are classified in three categories; SIL 1, 2 or 3
- S7-400 H and S7-300 F technologies

Final design suspended for lack of inputs and project schedule



ITER 2016 baseline approved by ITER Council in November 2016
Underpinned with detailed resource loading
Staged approach

First Plasma **(FP)** **Dec. 2025**

FP Finished and Start of Assembly II **Jun. 2026**

End of Assembly II **Jun. 2028**

Start of Pre-Fusion Power Operation-I **(SP)** **Dec. 2028**

End of Pre-Fusion Power Operation-I and Start of Assembly III **Jun. 2030**

End of Assembly III **Sep. 2031**

Pre-Fusion Power Operation-II **(TP)** **Jun. 2032**

End of Pre-Fusion Power Operation-II and Start of Pre-Nuclear Shutdown for Assembly IV **Mar. 2034**

End of Pre-Nuclear Shutdown for Assembly IV **Mar. 2035**

Fusion Power Operation **(DT)** **Dec. 2035**

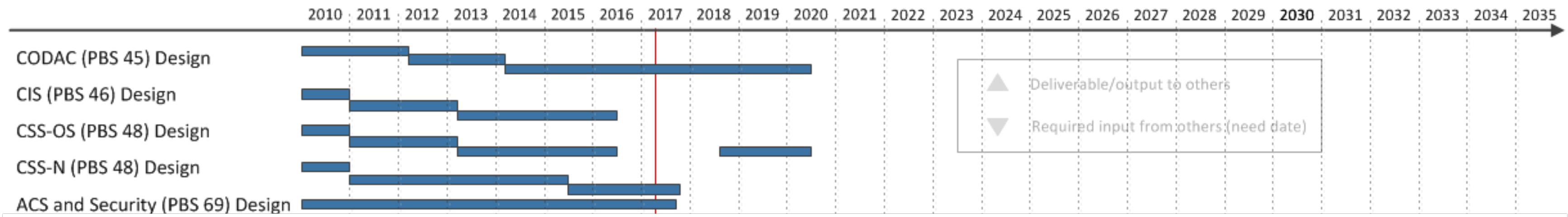
Engineering Operation (SC Magnets) (6 Months)	Assembly II (24 Months)	Integrated Comm. II (6 Months)	Pre-Fusion Power Operation-I (18 Months)	Assembly III (15 Months)	Integrated Comm. III (9 Months)	Pre-Fusion Power Operation-II (21 Months)	Assembly IV (12 Months)	Integrated Comm. IV (9 Months)

add 46
plant system I&C

add 29
plant system I&C

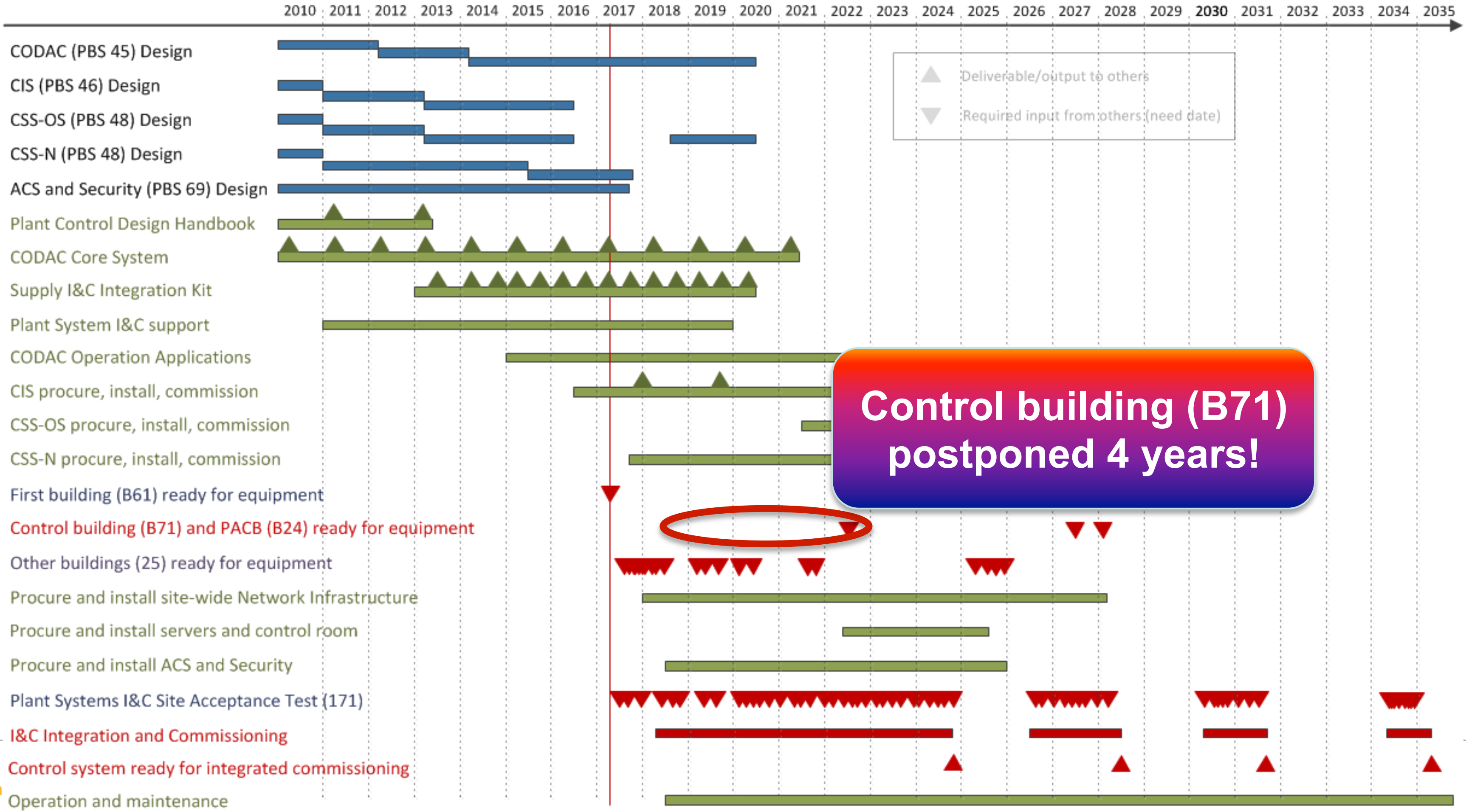
add 18
plant system I&C

Schedule



Design of central systems almost complete

Schedule



2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035
Deliverable/output to others
Required input from others (need date)
CODAC (PBS 45) Design
CIS (PBS 46) Design
CSS-OS (PBS 48) Design
CSS-N (PBS 48) Design
ACS and Security (PBS 69) Design
Plant Control Design Handbook
CODAC Core System
Supply I&C Integration Kit
Plant System I&C support
CODAC Operation Applications
CIS procure, install, commission
CSS-OS procure, install, commission
CSS-N procure, install, commission
First building (B61) ready for equipment
Control building (B71) and PACB (B24) ready for equipment
Other buildings (25) ready for equipment
Procure and install site-wide Network Infrastructure
Procure and install servers and control room
Procure and install ACS and Security
Plant Systems I&C Site Acceptance Test (171)
I&C Integration and Commissioning
Control system ready for integrated commissioning
Operation and maintenance
Control building (B71) postponed 4 years!

Mitigation: Temporary Control Rooms

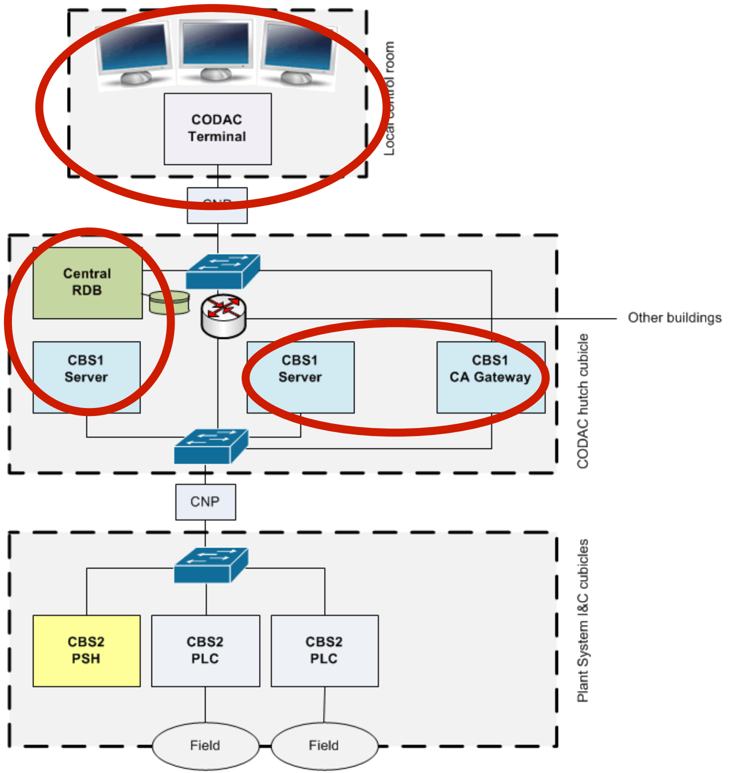
Requirements

- The central infrastructure and services must be available soon
- Human Machine Interfaces must be provided for plant system I&C integration
- Migration of all plant systems I&C control to B71 must be achieved within 18 months

Implementation

- Create temporary local autonomous “islands” in strategic buildings, providing central services and Human Machine Interfaces
- Connect islands with temporary cables to provide inter building connectivity
- Maximize emulation of final system to simplify migration to B71

Temporary Control Rooms



1. Install central servers in existing CODAC hutch cubicles

2. Standard HMI stations in suitable room

3. Add CIS and CSS when applicable (local test tools)

4. Cover all Plant Systems for First Plasma (before Control Building availability) by six Temporary Control Rooms

Conclusions

- ITER 2016 baseline schedule approved by Council
  - Resource loaded, using staged approach
- CODAC Core System stabilizing
  - Plant system design tool set in place
- CODAC Operation Applications under development
  - Integrating important EPICS developments
- Integration effort begins this year
  - Using local control rooms as control room building is delayed

Thank you