

# Introduction to the ITER Control System

## Система автоматизации токамака ИТЭР



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IO/DG/COO/SCOD/CSD/CDC  
ITER Organization

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

# ITER Objectives

- 1) Produce 500 MW of fusion power for pulses of 400s (Q=10)**
- 2) Demonstrate the integrated operation of technologies for a fusion power plant**
- 3) Achieve “burning” D-T plasma (in which the reaction is sustained through internal heating)**
- 4) Test tritium breeding**
- 5) Demonstrate the safety characteristics of a fusion device**

# ITER Timeline

- 2005 Decision to site the project in France
- 2006 Signature of the ITER Agreement
- 2007 Formal creation of the ITER Organization
- 2007-2009 Land clearing and levelling
- 2010-2014 Ground support structure and seismic foundations for the Tokamak
- 2012 Nuclear licensing milestone: ITER becomes a Basic Nuclear Installation under French law
  
- 2014-2021 Construction of the Tokamak Building (access for assembly activities in 2019)
- 2010-2021 Construction of the ITER plant and auxiliary buildings for First Plasma
- 2008-2021 Manufacturing of principal First Plasma components
- 2015-2021 Largest components are transported along the ITER Itinerary
  
- 2018-2025 Assembly phase I
- 2024-2025 Integrated commissioning phase (commissioning by system starts several years earlier)
- **Dec 2025 First Plasma**
- **2035 Deuterium-Tritium Operation begins**

# ITER Work Site

September 2017

# Control System Architecture

## Plant Operation Network (PON)

General purpose command, status, archive,... (Gbps Ethernet)

## Synchronous Databus Network (SDN)

Distributed feedback control (10 Gbps Ethernet, cut-through UDP/IP multi-cast)

## Time Communication Network (TCN)

Absolute time synchronization (Ethernet IEEE 1588 2008, timing boards)

## Data Archiving Network (DAN)

High volume data archiving (10-40 Gbps Ethernet)

## Central Interlock Network (CIN)

Industrial Ethernet, Hardwired

## Central Safety Networks (CSN)

Industrial Ethernet, Hardwired

# 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

# 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 $\mu$ s
Maximum jitter sensor to actuator (SDN)	50 $\mu$ s 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

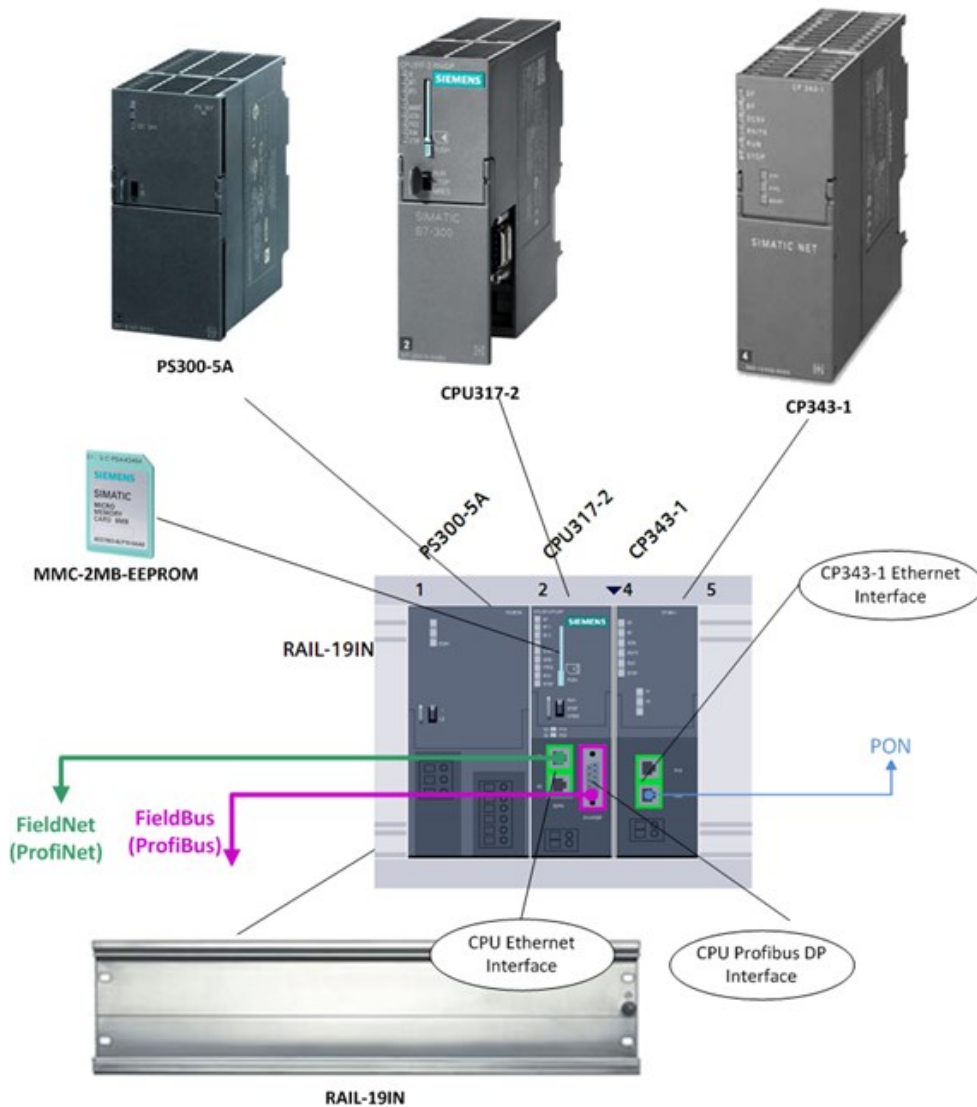
# Plant System I&C Technology

## Hardware





# Slow Controllers (PLC)



- Siemens PLCs of families 300, 400, 1500
- ProfiNet / ProfiBus as standard communication links
- I/O modules defined in the catalog
- Programming with STEP 7 environment
- To be used for industrial plant systems with  $>10$  ms control response time

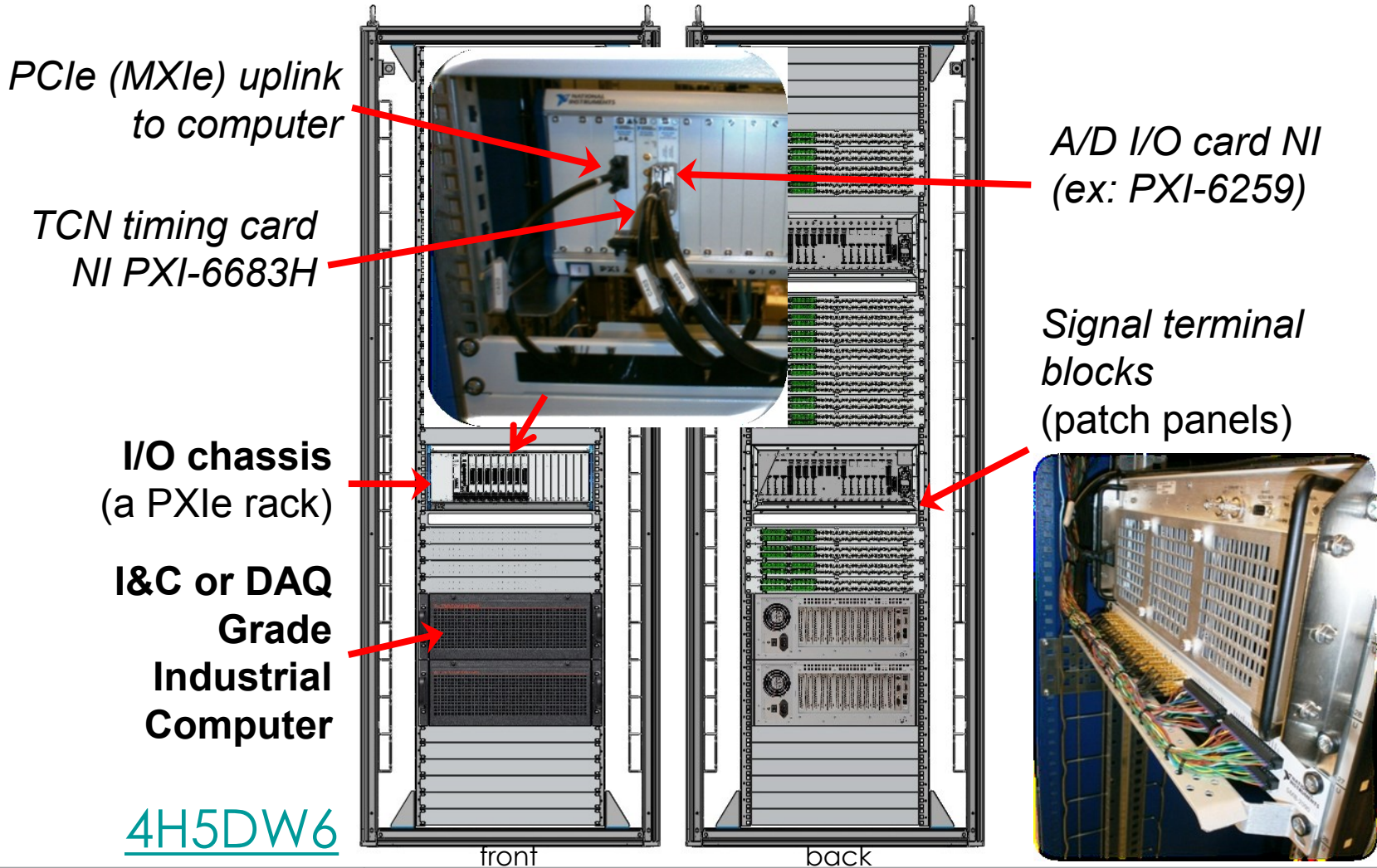
# Fast Controllers

## When to use a **Fast Controller**?

- ❑ Fast Controller is a computer...
  - ❑ that can drive I/O interfaces and/or SDN/DAN interfaces
  - ❑ that can satisfy performance requirements (beyond PLC)
  - ❑ that is connected to TCN for an accurate system time
- ❑ Used for:
  - ❑ Data acquisition with accurate time stamping
  - ❑ Actuation with precise timing
  - ❑ Real-time exchange of data with other systems
  - ❑ Local control loops in real-time
- ❑ Rule-of-thumb:
  - ❑ Synchronized control
  - ❑ Control loop period less than ~10 ms
- ❑ Fast Controllers use standardized Hardware and Software to provide a tested platform that can fulfill all these use-cases

# Fast Controllers

## What constitutes a **Fast Controller**?



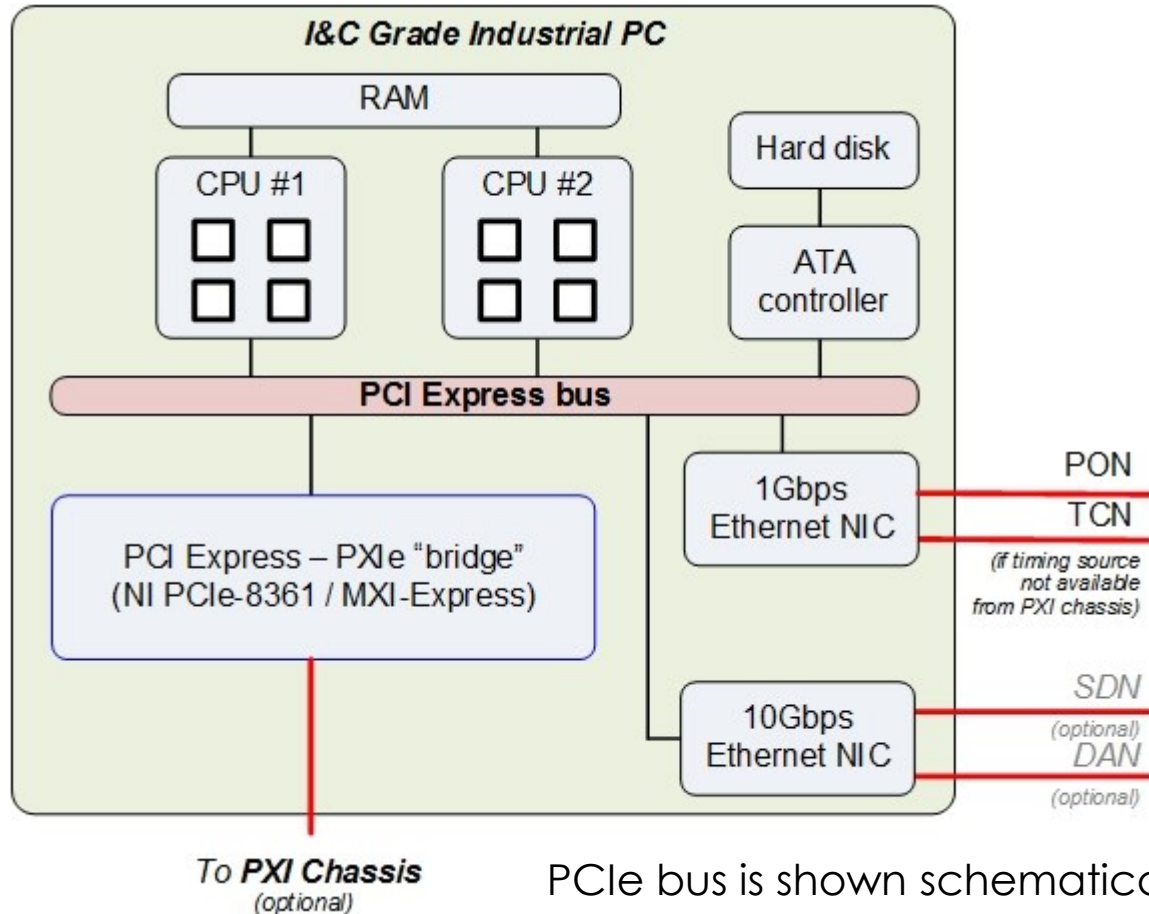
# Fast Controllers

## The I&C Grade Industrial Computer

- ❑ Compliant to **PICMG 1.3** specification
- ❑ Rack height: **4U**
- ❑ **PCI Express** bus
- ❑ CPU: **2x Quad Core Xeon E5-2418L (2.0GHz)**
- ❑ HDD: **2x 2.5" SATA III SSD 3SE-P series 64G, SLC type, RAID-1**
- ❑ RAM: **4x Mini DIMM-DDR3 2GB, 1600MHz**
- ❑ **1Gbps** network interface for **PON**
- ❑ **1Gbps** network interface for **TCN** (only if not interfaced through timing board on PXI chassis)
- ❑ Optionally, **10Gbps** network interfaces for **SDN** and **DAN**

# Fast Controllers

## The I&C Grade Industrial Computer



PCIe bus is shown schematically. For detailed topology, refer to manufacturer's specification (Trenton BPX6610 PICMG1.3 Backplane [IDM D NEAD4Q](#)).

# Fast Controllers

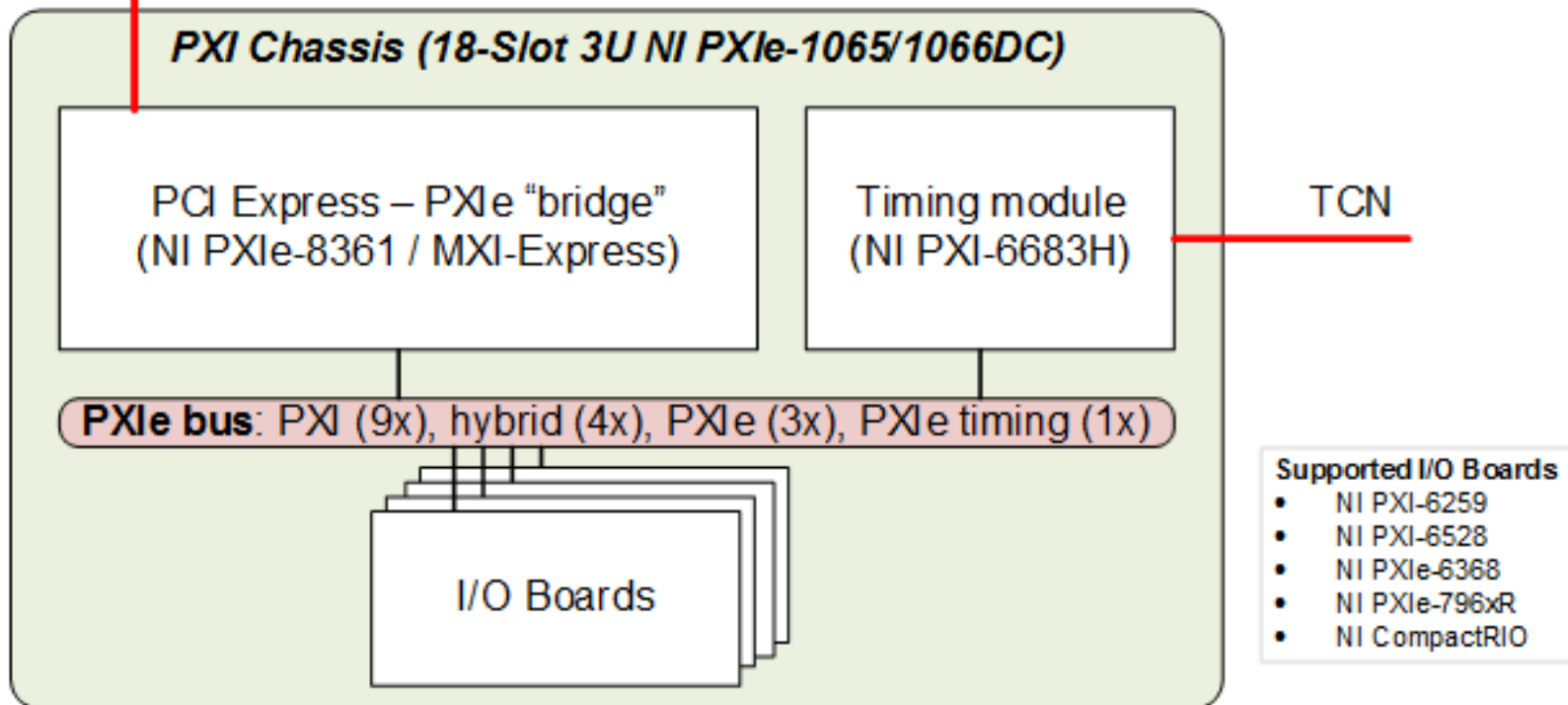
## The I/O Chassis

- ❑ PXIe-1065
  - ❑ **PXIe bus**
  - ❑ Rack height: **4U**
  - ❑ 18 3U slots (**9 PXI, 4 hybrid, 3 PXIe, 1 PXI-e timing**)
- ❑ PXIe-1066DC
  - ❑ Same as PXIe-1065, except:
  - ❑ Rack height: **5U**
  - ❑ **High-availability** (redundant power supplies and fans)
  - ❑ Requires high voltage DC power supplies
- ❑ NI 9159 (**CompactRIO**)
  - ❑ 14 **cRIO** I/O modules
  - ❑ **LX110 FPGA**

# Fast Controllers

## The PXI I/O Chassis

To I&C Grade Industrial PC





# Software Support for Plant System I&C

- Slow controllers: Siemens S7 PLCs
  - s7plcAsyn driver
  - Full list of supported hardware: “Siemens S7 PLC catalogue” (IDM [333J63](#))
- Fast controllers: PXI-6259, PXI-6528 and PXI-6683H
  - N.I. **PXI-6683H** : **Synchronization and timing** (IEEE1588-2008 / TCN)
  - N.I. **PXI-6259**: **multi-function data acquisition**
    - 16b analog input channels (16/32)
    - 16b analog output channels (4)
    - 16b digital input/output channels (48)
  - N.I. **PXI-6528** : **Digital I/O**
    - 24 optically isolated input channels
    - 24 solid-state relay output channels
  - N.I. PXIe-6368 (**X-series boards**)
    - 16b 2MS/s analog input channels (16)
    - 16b 3.3 MS/s analog output channels (4)
  - N.I. PXIe **FlexRIO** and **CompactRIO**: Flexible I/O with **FPGA**.
  - Full list of supported hardware: “**ITER Catalogue of I&C Products Fast Controller**” (IDM [345X28](#)) .



# Plant System I&C Technology

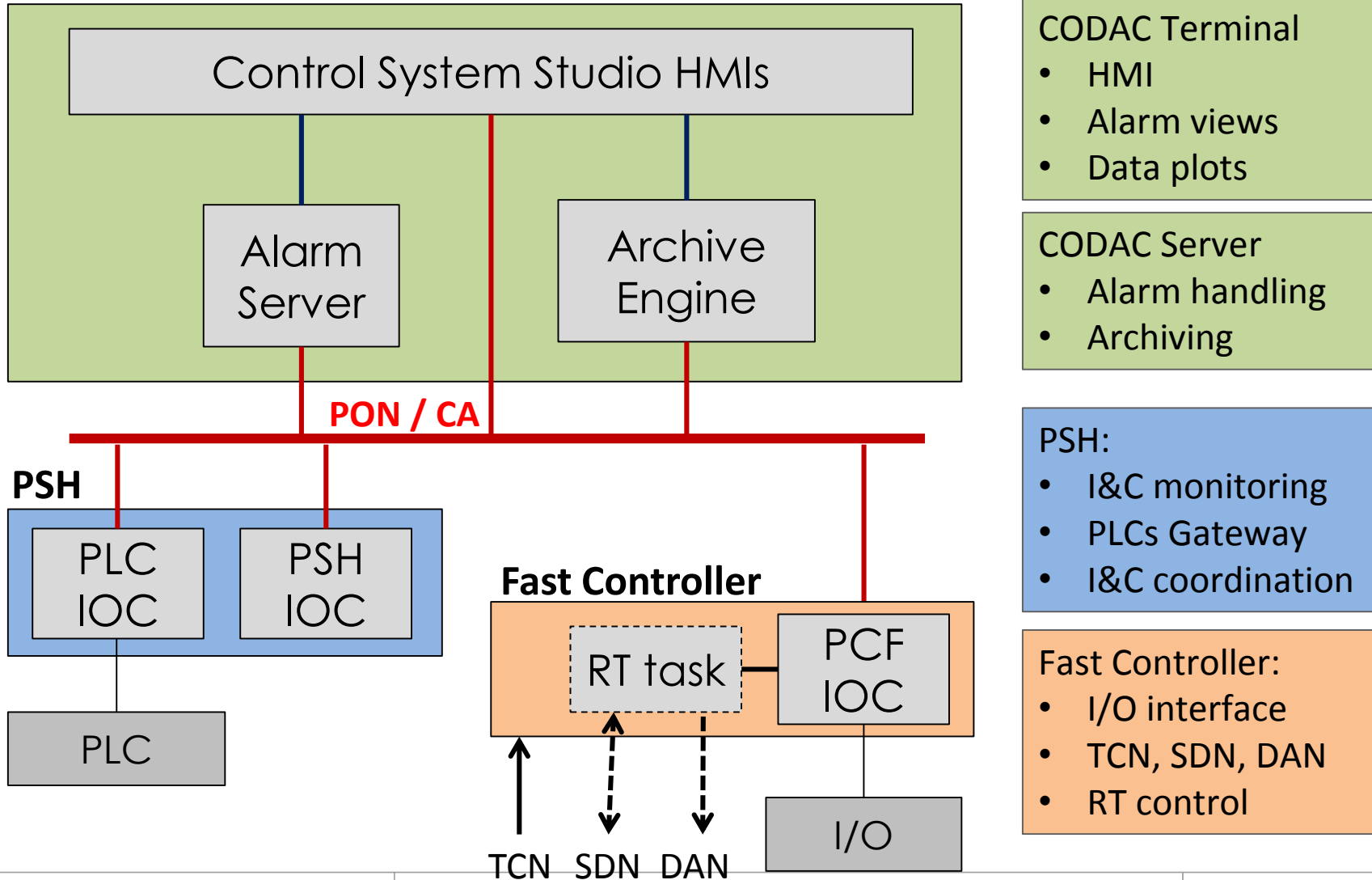
**Software**

# CODAC Core System

- The **CODAC Core System** is the CODAC software distribution for:
  - CODAC servers
  - CODAC terminals
  - **Mini-CODAC**
  - **Plant System Host**
  - **Plant System Fast Controllers**
- The distribution includes the **Operating System**
- It is the **software infrastructure** for all standard I&C computers with the exception of PLC
- 2 variants for each distribution:
  - **Development**, with development tools (SDD, Maven...)
  - **Operation**, without any development tool

# CODAC Core System Architecture

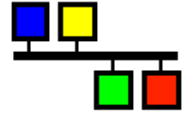
## Mini-CODAC



# Operating System

## Red Hat Enterprise Linux (RHEL)

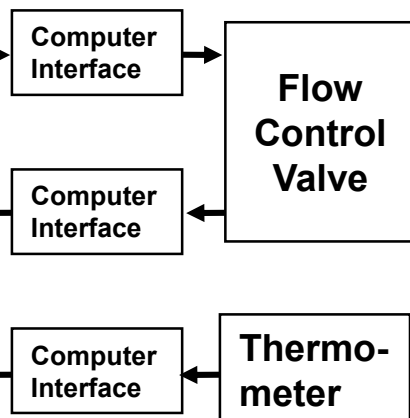
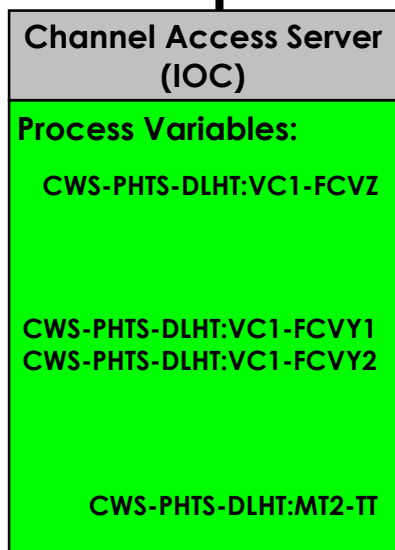
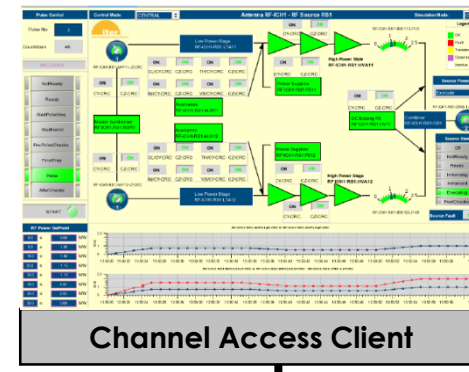
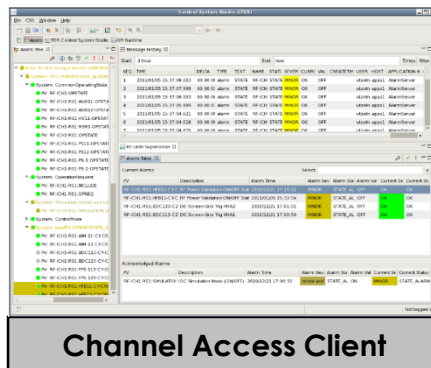
- The selected operating system is **Red Hat Enterprise Linux** for the x86-64 architecture (**RHEL x86\_64**)
  - Linux (open software)
  - With commercial support (RHEL)
  - For all computers (servers, PSH, fast controllers, terminals...)
- The version of the operating system will be upgraded at regular intervals throughout the lifetime of ITER (obsolescence mitigation).
  - RHEL 6.x (6.1, 6.3, 6.5) “now” (2012-2017)
    - Current is 6.5 (from CCS 5.x) which includes PTP support for PTP compliant hardware in fast controllers.
    - Support from supplier until 2020
  - RHEL 7 will be deployed starting 2018 (for CCS 6.x)
- RHEL MRG-R option used for real-time systems



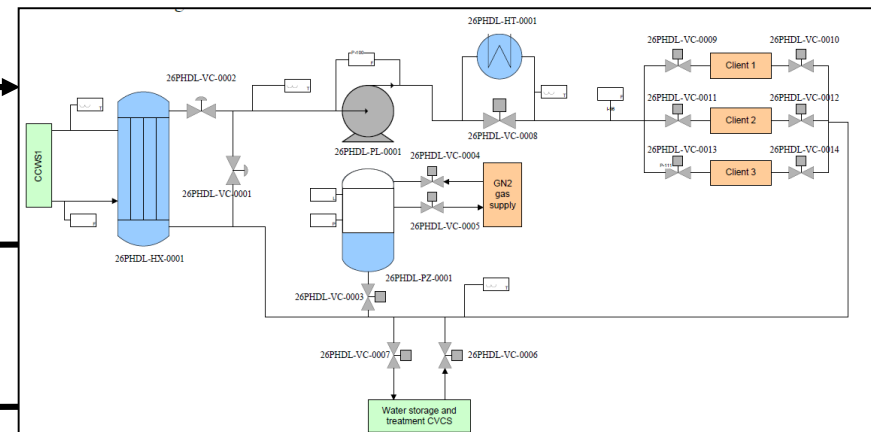
## EPICS

- The infrastructure layer is implemented with **EPICS** (Experimental Physics and Industrial Control System)
- EPICS is
  - an **open-source** control system toolkit
  - used in hundreds of large and small **experimental physics projects world-wide**: light sources, high energy physics, fusion (KSTAR, NSTX), telescopes
  - maintained and further developed by a world-wide **community of users** (including ITER)
- The same infrastructure for the CODAC servers and for the plant system controllers to ensure a **uniform standard interface**.

# Control System Architecture with EPICS



## Cooling water plant system



# Control System Studio

## CS-Studio is based on Eclipse

- CS-Studio is an **Eclipse-based** Integrated Environment:
  - Based on **plugin** technology and therefore easily extensible
  - Generic features like menus, preferences, help...
  - Multi-platform support (portable **JAVA** code)
- **Development** environment
  - Operator interface design, State Machine code, EPICS database edition, debugging tools

**Operator Interface** to different control systems

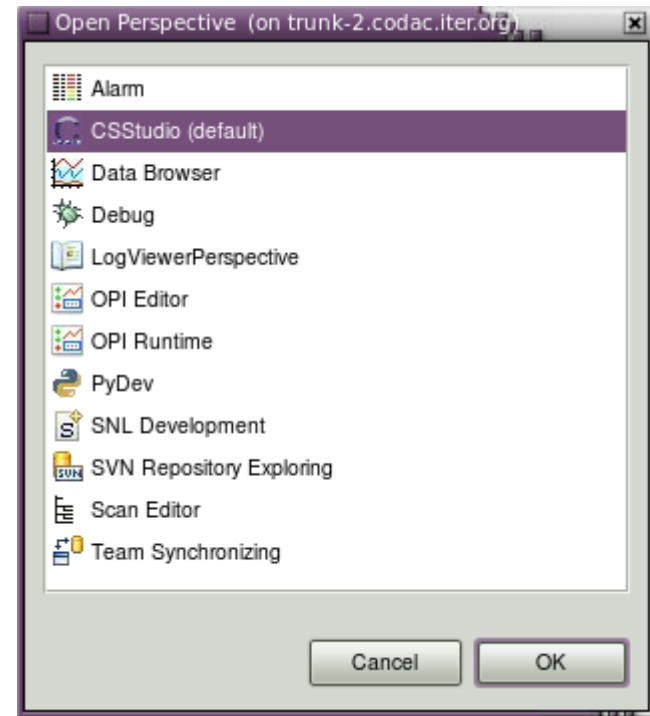
- Mini-CODAC operator interface
  - Monitoring screen, Alarm Handling, Data Trend Display





# Control System Studio

- CS-Studio is a common platform
  - Different perspectives for different tasks
    - Development
      - OPI Editor
      - Scan Editor
      - SNL Development
      - PyDev & Debug
      - SVN Repository
      - Team Synchronisation
    - Runtime
      - OPI Runtime
      - Alarm
      - Data Browser
      - Log Viewer Perspective



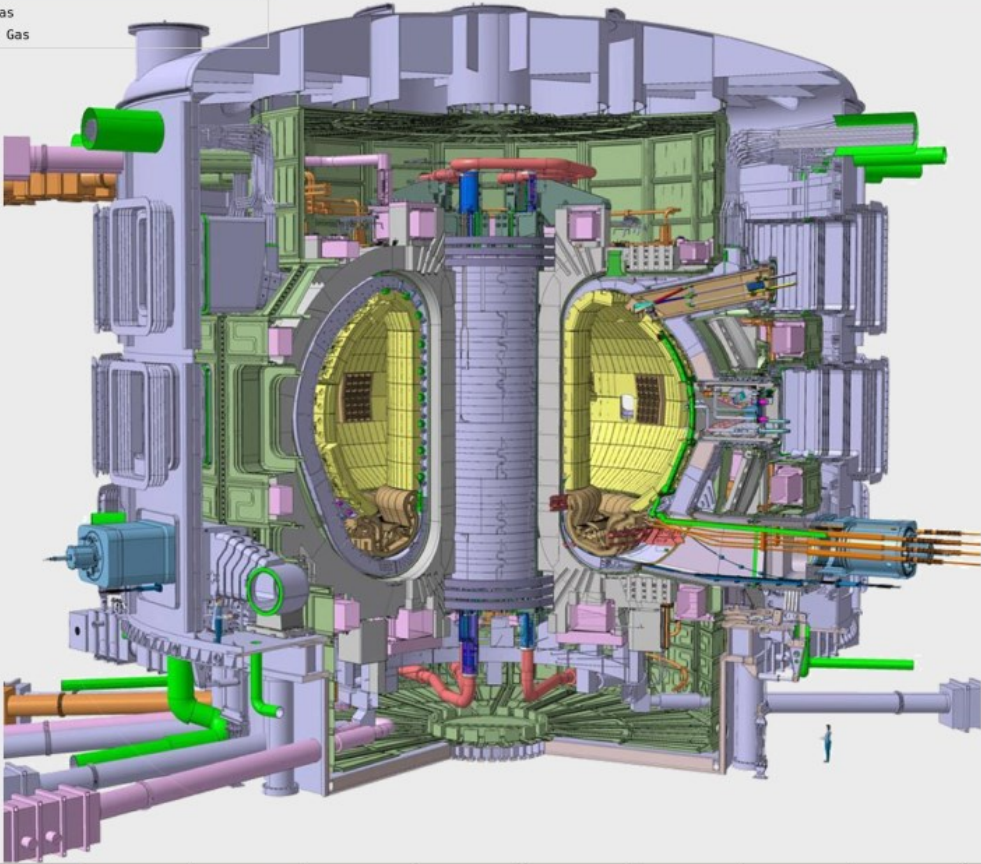
# CS-Studio for Operator Screens

ITER TOKAMAK MACHINE OVERVIEW

Pulse ID 1289  
SUP ###

ITER TOKAMAK MACHINE OVERVIEW

2016/02/04 15:30:56



CAS     CSS  
 CODAC     CIS  
 Compressed Air     Helium Gas  
 Demineralized Water     Nitrogen Gas

Description	Alarm Time
B91 STEP - Case 2.48	18:31:07
Fault of DM1-W 020DHT0	18:31:07

Legend

Invalid alarm state	3.14	
Major alarm state	3.14	
Minor alarm state	3.14	
On - running state	3.14	
Off - stopped state	3.14	
Flow		
No Flow		

BUIL	CRST	CRYO	CTRL	CWS	D1	D2	EC	FUEL	IC	MAG
NB	PFCS	RAD	RH	SAFE	TRIT	UTIL	VAC	VV	111	222

ITER HOME

# Example HMI (Reactive Power Compensation - CN delivery)

**Status bar**  
**Alarm pane**  
**Control pane**  
**Navigation pane**  
**Mimic**

UTIL-RPC UTIL-RPC-RPC1 Pulse ID 1289 SUP ### UTIL-RPC-RPC1 2016/10/10 10:51:51 iter

400kV Busbar  
 Ua Ia  
 Ub Ib  
 Uc Ic

66kV Busbar  
 Uab Ia  
 Ubc Ib  
 Uca Ic

Fence State  
 TRV Fence  
 TCR Fence  
 F357 Fence  
 FBDN Fence

Pulse State OFF  
 aab  
 abc  
 aca

Iab Ia  
 Ibc Ib  
 Ica Ic

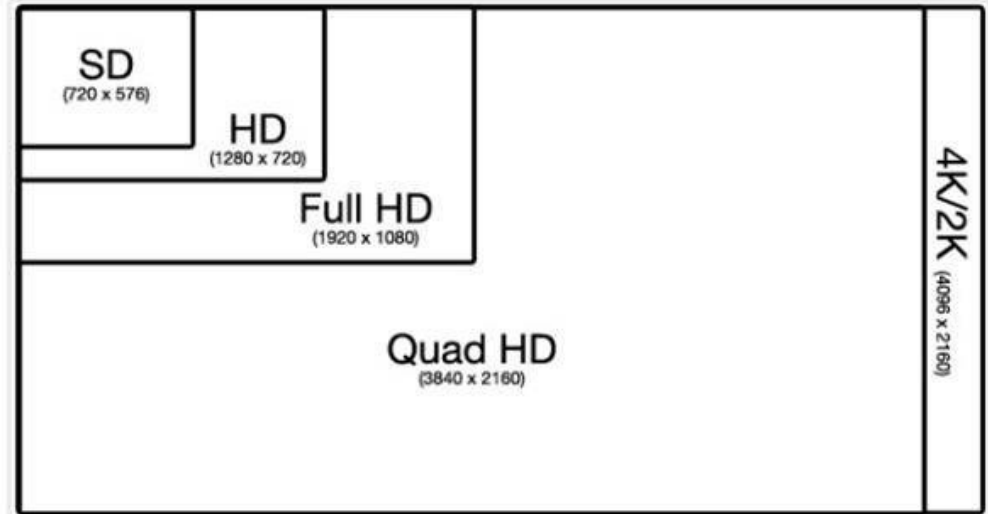
1st LFC TRIP 09:50:55  
 LIC DEVICE TRIP 09:50:55  
 LIC DEVICE FAULT 09:50:55  
 LIC DEVICE ALARM 09:50:55  
 UPS FAULT 09:50:55  
 THYRISTOR FAULT 09:50:55  
 TCR LOOP OVER CURRENT 09:50:55  
 SYNCHRONIZATION VOLTAGE 09:50:55  
 PULSE UNIT FAULT 09:50:55  
 PULSE LOST FAULT 09:50:55  
 66kV OVER VOLTAGE 09:50:55  
 LIC BRANCH OVER CURRENT 09:50:55  
 PARAMETER LOAD FAULT 09:50:55  
 CUBICLE FAULT 09:50:55  
 LIC UNDER VOLTAGE TRIP 09:50:55  
 BOARD FAULT 09:50:55  
 OUTSIDE SIGNAL TRIP 09:50:55  
 LIC OVER CURRENT TRIP 09:50:55  
 SWITCH FAULT 09:50:55  
 LIC CAPACITY BANK FAULT 09:50:55

PULSE  
 Status Controls Help  
 Operation Mode  
 Current State  
 Step Operation Enable OFF  
 Operation Command  
 Operate Command  
 Start Pulse OFF  
 Stop Pulse OFF

HOME UTIL RPC RPC1 LFC HM WAVEFORMS CWS CONF PSOS

# OPI Size and Naming Convention

- 4k size
  - OPI size: 3830 x 2080
  - Mimic: 3226 x 1760
  - Each area has a fixed size



*Four resolutions compared: standard definition, full high definition, Quad HD and 4K/2K.*

- By convention, the OPI file name is based on the CBS structure:
  - ITER-**{CBS1}**[-**{CBS2}**[-**CBS3**]].opi
  - Example: ITER-UTIL-S15.opi
- The mimic shall be provided as a separate OPI:
  - ITER-**{CBS1}**[-**{CBS2}**[-**CBS3**]]\_Mimic.opi
  - Example: ITER-UTIL-S15\_Mimic.opi

# Colours and Styles Standardization

- IO Background colour for the mimics, IO Foreground colour for the text and line, IO Alarm colours, IO On/Off colours

Color Demonstration
Pulse ID 1289
CSS
CODAC
CIS

**COLORS DEMONSTRATION SCREEN**

2016/02/05 11:17:36

Compressed Air	Helium Gas
Demineralized Water	Nitrogen Gas

The operator interface shall use no more than 6 colors (in addition to black and white) at one time. Alarm color coding shall not be used for other purpose.

Function	Identification	Color name	RGB	Sample
Background	Mimic background	IO Background Light grey	235, 235, 235	
Text	Text foreground	IO Foreground Black	0, 0, 0	
Alarms	Invalid alarm state	IO Invalid Level Alarm Yellow	255, 255, 255	215.15
Alarms	High alarm state	IO High Level Alarm Red	250, 12, 14	215.15
Alarms	Minor alarm state	IO Medium Level Alarm Yellow	255, 255, 0	215.15
Component states	1 - On	IO PV ON Blue	0, 0, 255	
		IO Running Symbol Fill Dark grey		
Component states	0 - Off	IO PV OFF Brown	149, 125, 71	
		IO Stopped Symbol Fill White		
Electrical lines Pipelines	Energised	IO Energised Busbar	95, 95, 95	
	Not energised	IO De energised Busbar	178, 178, 178	
	Flow	IO Flow Pipeline	95, 95, 95	
	No flow	IO No Flow Pipeline	178, 178, 178	

#	Description	Alarm Time
0	MBBI Absent wrong stati	11:17:26
0	BI shall never be OFF	11:17:25
0	AI1 Analog value 93.00	11:17:25
0	COMPONENT2 invalid st	11:02:10
0	BO shall never be inva	10:51:46
0	COMPONENT0 CLOSED inva	10:51:31
0	COMPONENT3 STOPPING in	10:51:31

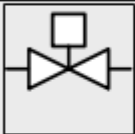
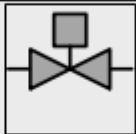
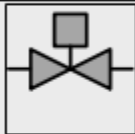
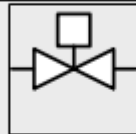
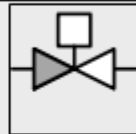
**Legend**

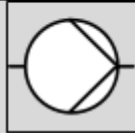
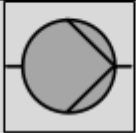
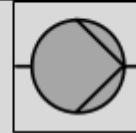
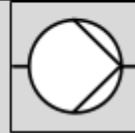
Invalid alarm state	3.14	
Major alarm state	3.14	
Minor alarm state	3.14	
On - running state	3.14	
Off - stopped state	3.14	
Flow		
No Flow		

iter HOME
General
Colors

# Industrial Symbol Library

- Examples:

0 - CLOSED	1 - OPEN	2 - OPENING (flash)	3 - CLOSING (flash)	4 - HALF-OPEN
				
Symbol – Black Symbol fill – White	Symbol – Black Symbol fill – Dark grey	Symbol – Black Symbol fill – Dark grey (as per the position the component is moving to) Flash rate of symbol: 2Hz until movement is complete	Symbol – Black Symbol fill – White as per the position the component is changing to Flash rate of symbol: 2Hz until movement is complete	Symbol – Black Symbol fill – left side dark grey and right side white.

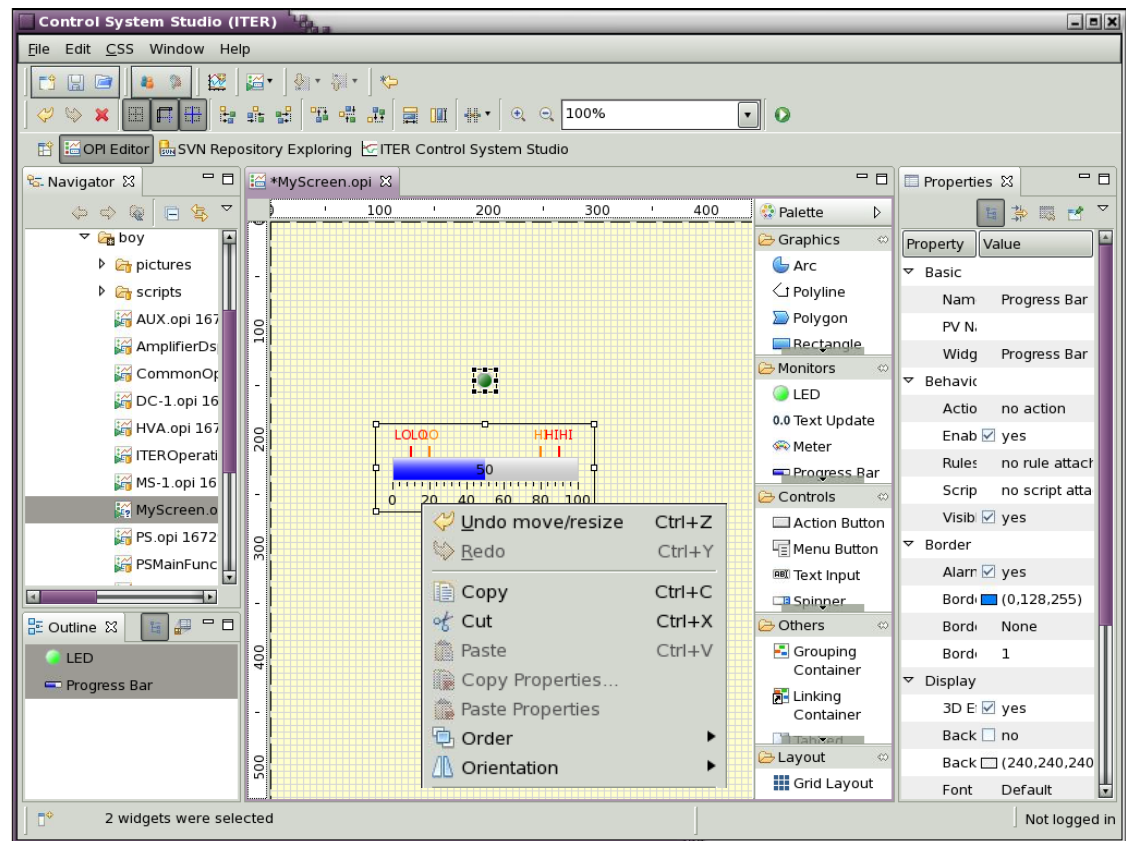
0 - STOPPED	1 - RUNNING	2 - STARTING	3 - STOPPING
			
Symbol – Black Symbol fill – White	Symbol – Black Symbol fill – Dark grey	Symbol – Black Symbol fill – Dark grey (as per the position the component is moving to) Flash rate of symbol: 2Hz until movement is complete	Symbol – Black Symbol fill – White as per the position the component is changing to Flash rate of symbol: 2Hz until movement is complete

# Interactive OPI Editor



- File -> New -> BOY -> OPI File

- Select one or multiple widgets
- Move
- Resize
- Copy
- Paste
- Clone
- Delete
- Undo/Redo
- Align Multiple Widgets
- Snap to grid or other widgets by geometry
- Guide
- Zoom In/Out
- Change Order
- Change Orientation
- Group

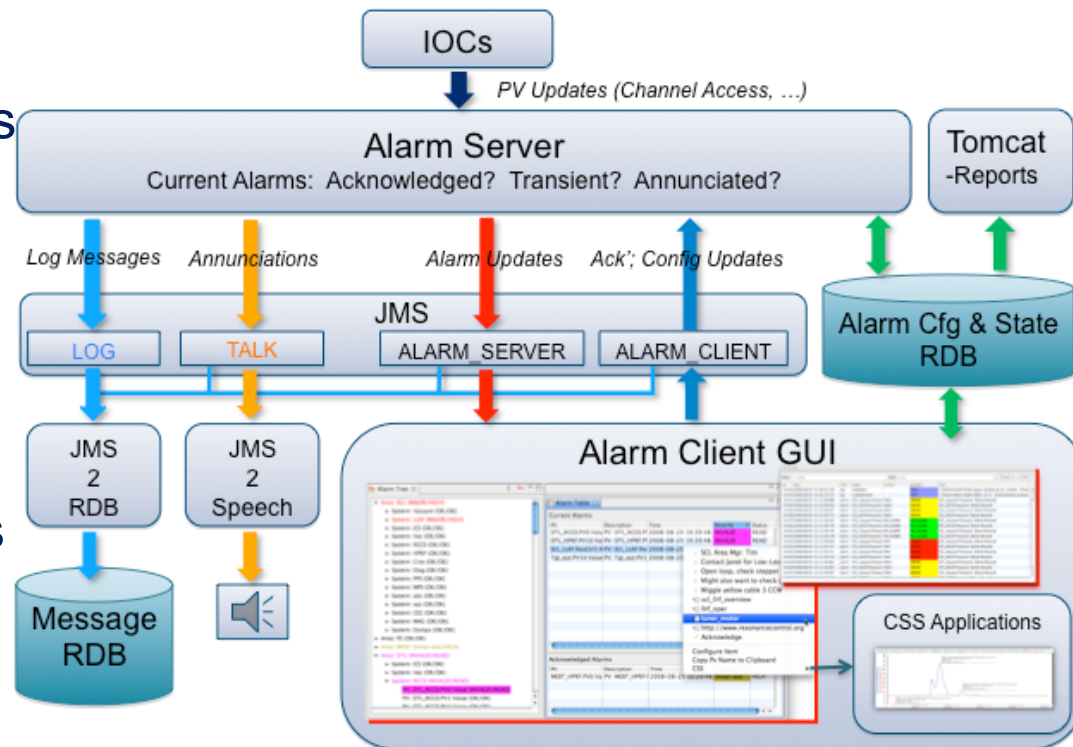


# CS-Studio for Alarm Handling

## What is BEAST?

- **Best Ever Alarm System Toolkit (BEAST)** - is distributed alarm system consisting of:

- Alarm Server that monitors alarm triggers in the control system
- Relational Database for configuration and logging
- CSS user interface for viewing current alarms as a table or hierarchical tree





# Alarm Perspective Layout

Global view

Current Alarms View

Alarm Tree View

The screenshot displays the CS-Studio OPI Editor interface. The main window shows a 3D cutaway view of a tokamak reactor. On the left, there is an 'Alarm Area Panel' with a grid of colored buttons (green and red) representing different alarm systems. Below it is an 'Alarm Tree' showing a hierarchical structure of alarm systems and their components. At the bottom, an 'Alarm Table' lists current and acknowledged alarms with details such as date, time, message, action, and ID.

**Alarm Area Panel:**

UTIL-S15-AG07	UTIL-S15-AG91
UTIL-S15-AG92	UTIL-S15-AG93
UTIL-S15-AG94	UTIL-S15-BG07
UTIL-S15-BG91	UTIL-S15-BG92
UTIL-S15-BG93	UTIL-S15-BG94

**Alarm Tree:**

- Area: UTIL-S15 (MAJOR/STATE\_ALARM)
  - System: UTIL-S15-AG07
    - PV: UTIL-S15-AG07:BUSBAR1
    - PV: UTIL-S15-AG07:HMC10-YT1
    - PV: UTIL-S15-AG07:HMC11-YT1
    - PV: UTIL-S15-AG07:HMC9-YT1
    - PV: UTIL-S15-AG07:MUT9-TT1
    - PV: UTIL-S15-AG07:MUT9-TT2
    - PV: UTIL-S15-AG07:MUT9-TT3
    - PV: UTIL-S15-AG07:MUT9-TT4
  - System: UTIL-S15-AG91 (MAJOR/STATE\_ALARM)
    - PV: UTIL-S15-AG91:BUSBAR1
    - PV: UTIL-S15-AG91:HMC19-YT1 (MAJOR/STATE\_ALARM, MAJOR/S)
    - PV: UTIL-S15-AG91:HMC2-YT1
    - PV: UTIL-S15-AG91:HMC22-YT1
    - PV: UTIL-S15-AG91:HMC25-YT1
    - PV: UTIL-S15-AG91:HMC28-YT1
    - PV: UTIL-S15-AG91:HMC3-YT1
    - PV: UTIL-S15-AG91:HMC6-YT1
    - PV: UTIL-S15-AG91:MUT1-ET4
    - PV: UTIL-S15-AG91:MUT1-ET5
    - PV: UTIL-S15-AG91:MUT1-ET6

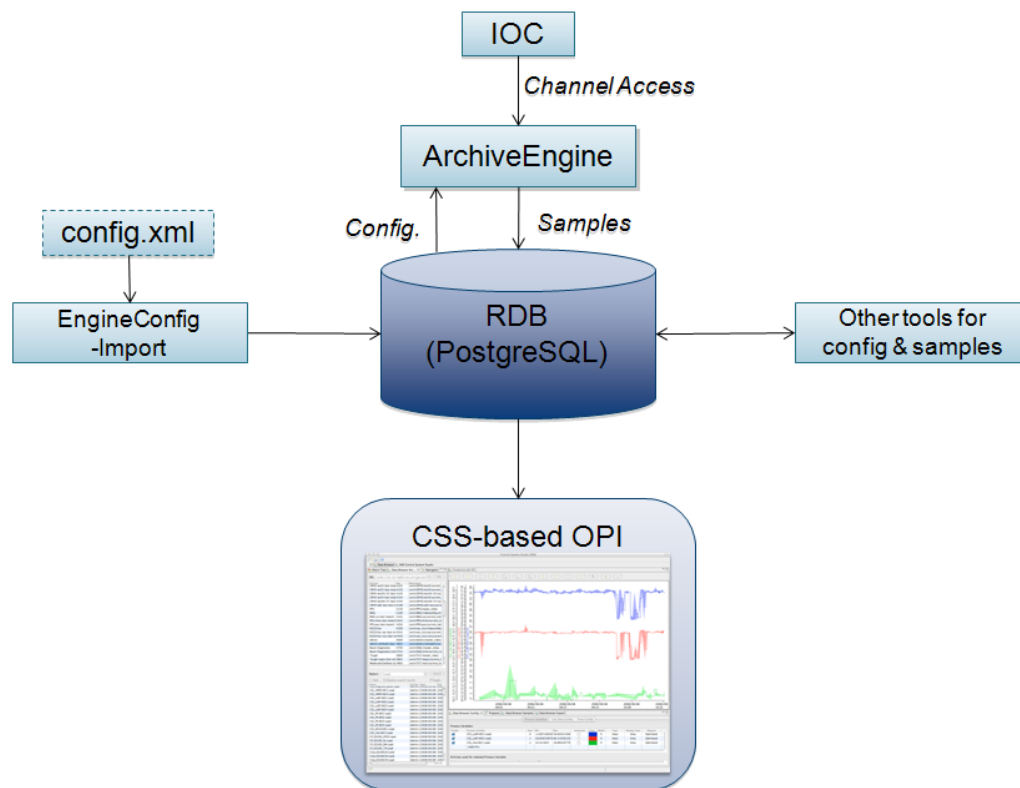
**Alarm Table [UTIL]:**

Date and Time	Alarm Message	Alarm Action	Alarm ID
2016/02/06 10:	15KV/400V Transfo output Frequency	Purpose of alarm : Frequency variation on LV busbar of B40. Alarm response action: Check incoming Frequency. Failure Consequence: Over frequency will cause overspeed of motor and underfrequency will Operator response time: Before permissible period of withstanding of frequency variation	B40 LV busbar Frequency out of lim
2016/01/31 18:	B91 STEP - Case 2-48 - Defect	Purpose of alarm : B91 Substation STEP feeder trouble. Alarm response action: Check Fault condition for STEP feeder. Failure Consequence: Low Voltage Supply Interruption to feeder. Operator response time: Before permissible period of power loss to feeder.	B91 Substation STEP feeder trouble
2016/01/31 18:	Fault of DML-W 020DHT01	Purpose of alarm : DHT01 is in Fault condition Alarm response action: Check fault conditions Failure Consequence: High Voltage Supply Interruption Operator response time: Before permissible period between fault and Interruption of HV sur	20DHT01 Circuit Fault detected

# CS-Studio for Engineering Data Archive

## What is BEAUTY?

- **Best Ever Archive Utility, Yet (BEAUTY)** - is an EPICS Channel Archiver set of tools
  - Archive Engine takes samples from IOCs via Channel Access
  - And stores them on a Relational Database with their original time stamp, alarm status/severity, PV value and metadata (unit, limits...)
  - CSS user interface for accessing to historic data samples in that storage



# Browsing the Archive

Data Browser Perspective

Search View

Toolbar

Plot area

Properties View

The screenshot displays the ITER Control System Studio interface. On the left, the 'Data Browser' shows a search for 'RF\*' in a PostgreSQL database, listing various plasma parameters. The main area features a multi-axis plot showing the time evolution of several RF current signals. A text box in the plot area indicates the end of plasma. At the bottom, a 'Properties View' table lists the selected traces with their respective colors and scan parameters.

Show	Item (PV, Formula)	Display Name	Color	Scan Peri	Buffer Siz	Width	Axis	Trace Type	Request
<input checked="" type="checkbox"/>	RF-ICH1-RS1:AHF11-JZ-CRC	RF-ICH1-RS1:AHF11-JZ-CRC	Blue	0.0	5000	2	RF-ICH1-f Area	Optimiz	
<input checked="" type="checkbox"/>	RF-ICH1-RS1:AHF12-JZ-CRC	RF-ICH1-RS1:AHF12-JZ-CRC	Red	0.0	5000	2	RF-ICH1-f Area	Optimiz	
<input checked="" type="checkbox"/>	RF-ICH1-RS1:BDC113-JT-CRC	RF-ICH1-RS1:BDC113-JT-CRC	Green	0.0	5000	2	RF-ICH1-f Area	Optimiz	

# Plant System I&C Technology

## Network Interfaces

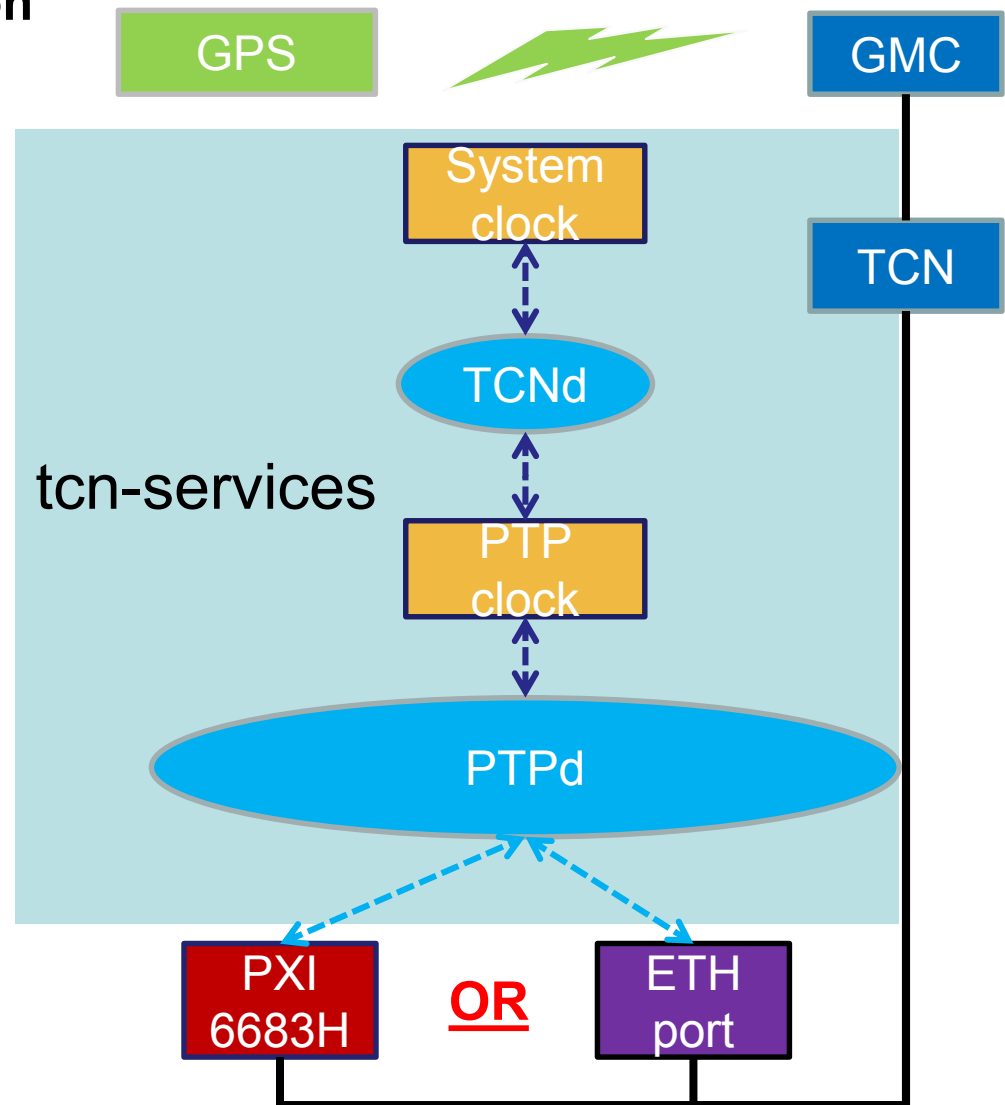
# Plant Operation Network (PON)

- PON software interface is EPICS Channel Access
- EPICS variables are used for:
  1. interfacing the signals connected to the controller's I/O modules.
    - by mapping variables to the signals connected to I/O modules
    - by using templates associated to the I/O modules
  2. implementing the application logic using the EPICS database functions
  3. Interfacing the status and configuration of controller
- PON is also used to transmit NTP time synchronization

# Time Communication Network (TCN)

## Fast Controller Synchronization

- ❑ IEEE 1588-2008 protocol
- ❑ Grand Master Clock (GMC) is synchronized with GPS
- ❑ Controllers requiring precision timing are connected to TCN via a dedicated interface
- ❑ PTPd daemon maintains accuracy of hardware clocks
- ❑ TCNd synchronizes operating system time
- ❑ ITER time is UTC (different from local time)



# Synchronization Accuracy

- ❑ What timing accuracy is achievable with the fast controller?
  - ❑ Synchronous software function (triggered on ITER time): **<10  $\mu$ s**
    - ❑ Software functions are scheduled to be called on the same absolute time in various fast controllers.
  - ❑ Asynchronous software function (triggered on SDN event): **<50  $\mu$ s**
    - ❑ Condition or data available in one fast controller triggers activation of a software function in another; latency is function of size of message.
  - ❑ Synchronous hardware function (triggered on ITER time): **<50 ns RMS**
    - ❑ Hardware triggers or clocks are activated on the same absolute time in various fast controllers.

# Synchronous Databus Network (SDN)

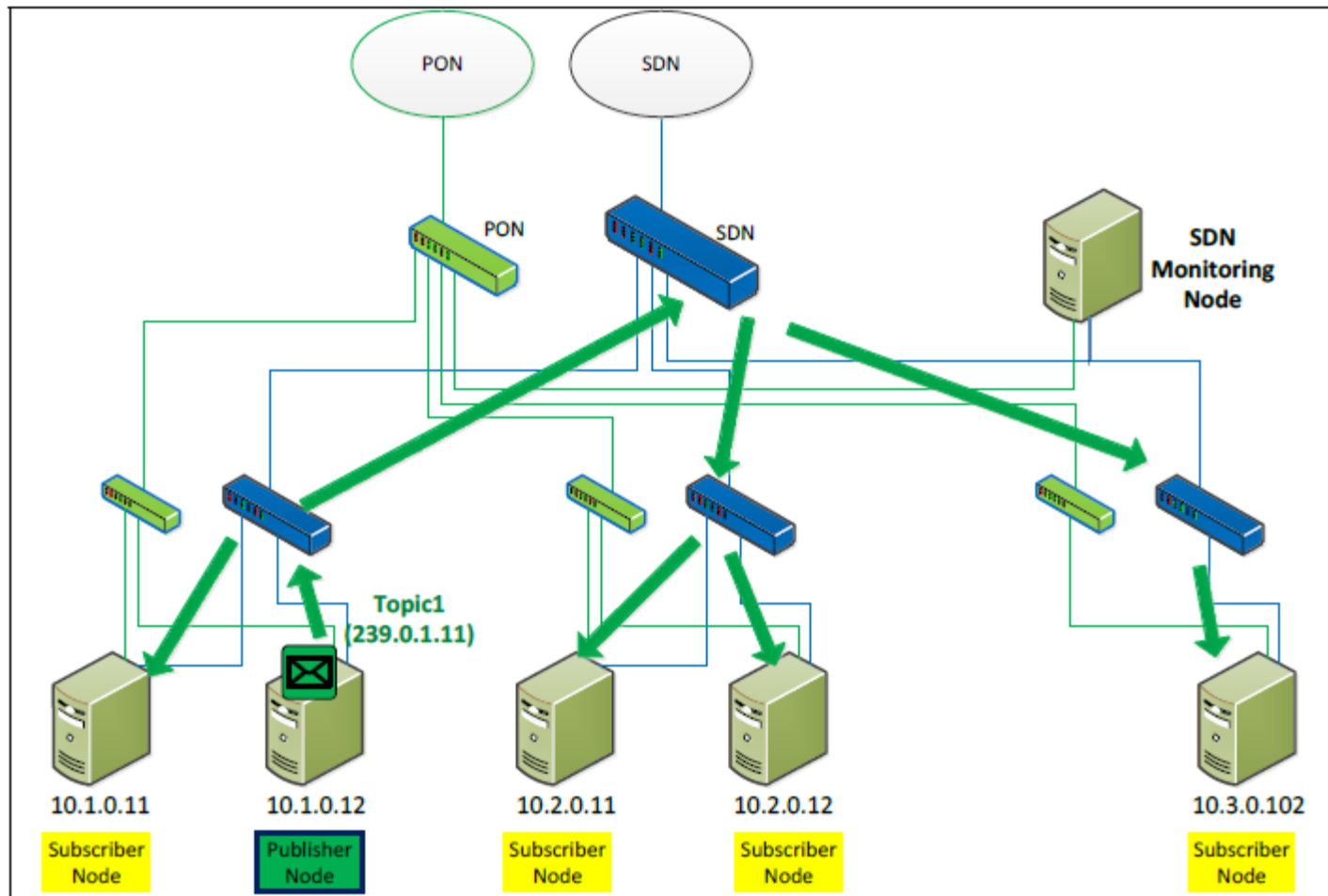
## How to communicate **deterministically** between two **different** Fast Controllers?

- ❑ Fast controllers may interface SDN (**Synchronous Databus Network**)
- ❑ **Topic-based** publish/subscribe communication pattern (using **UDP/IPv4 multicast**)
  - ❑ SDN **Data** (default) is **unacknowledged** by subscriber
  - ❑ SDN **Events** are **acknowledged** by subscriber
- ❑ **10GbE cut-through switches**
  - ❑ Datagrams sent based on destination MAC, no buffering in the switch
    - ❑ Switch forwarding latency is constant and typically below 1-2  $\mu$ s
    - ❑ Multicast messages are replicated by the switch, latency is constant regardless on the number of destination nodes
- ❑ 10GbE COTS network accelerators, kernel bypass technologies are deployed on the fast controllers
- ❑ **Application-to-application latency deterministically below 50  $\mu$ s**



# SDN Communication

SDN topics are associated with multicast IP addresses



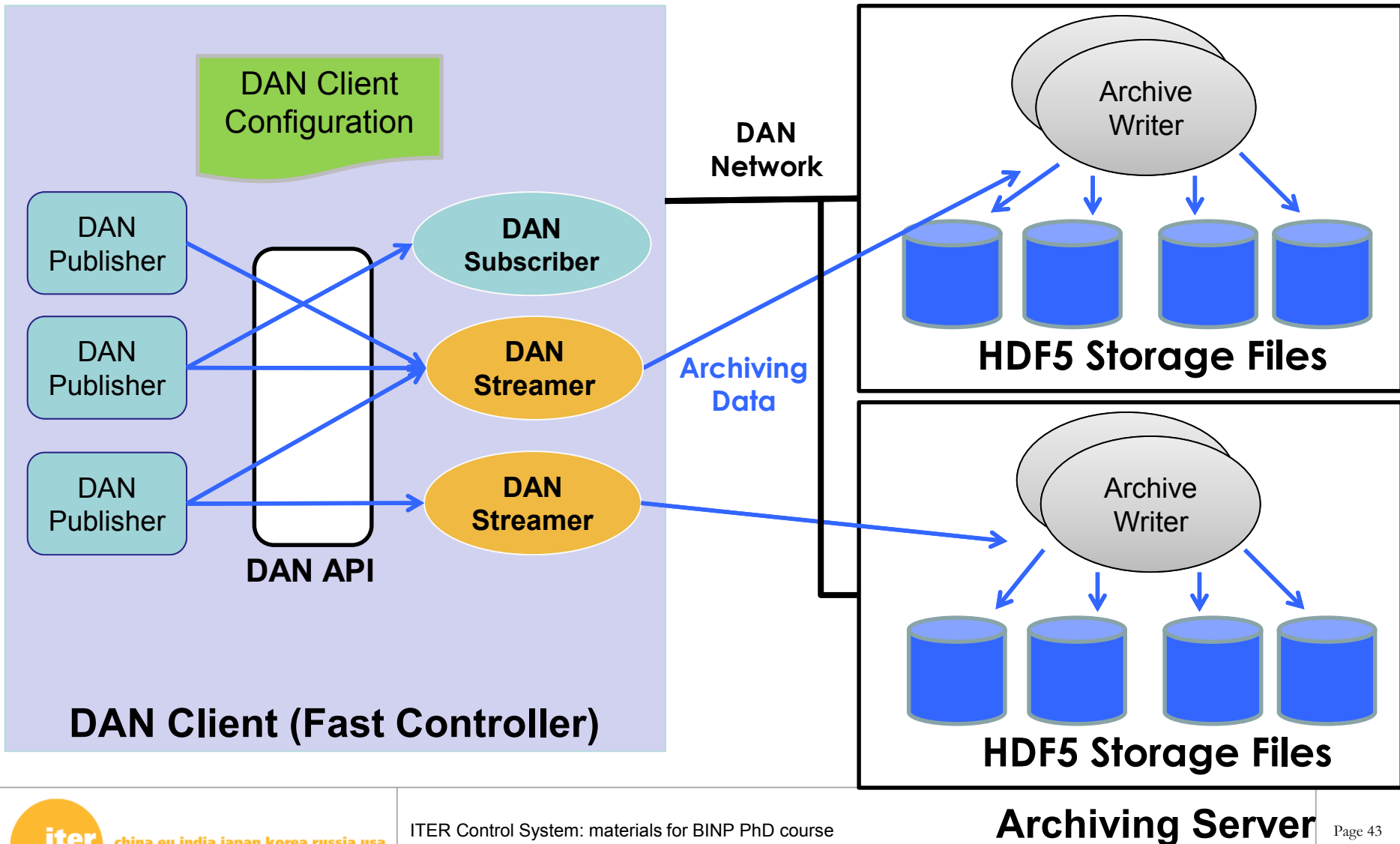
# Data Archiving Network (DAN)

## How to **archive large amounts of data** produced by Fast Controllers?

- ❑ Fast controllers may interface DAN (**Data Archiving Network**)
- ❑ Designed to evacuate high data rates reliably for archiving
- ❑ Adaptable data rates: from a few MB/s up to 1 GB/s
- ❑ TCP based for reliability (package reception acknowledged)
- ❑ Local Publisher/Subscriber mechanism on PCF:
  - ❑ DAN Publishers on the PCF announce (publish) when new data is available from a particular DAN source in the DAQ Buffer, and its memory reference
  - ❑ DAN Subscribers on the same PCF get notifications from Publishers and are able to access data in DAQ Buffer
- ❑ DAN Sources, Publishers and Subscribers are defined in configuration file

# Data Archiving Network (DAN)

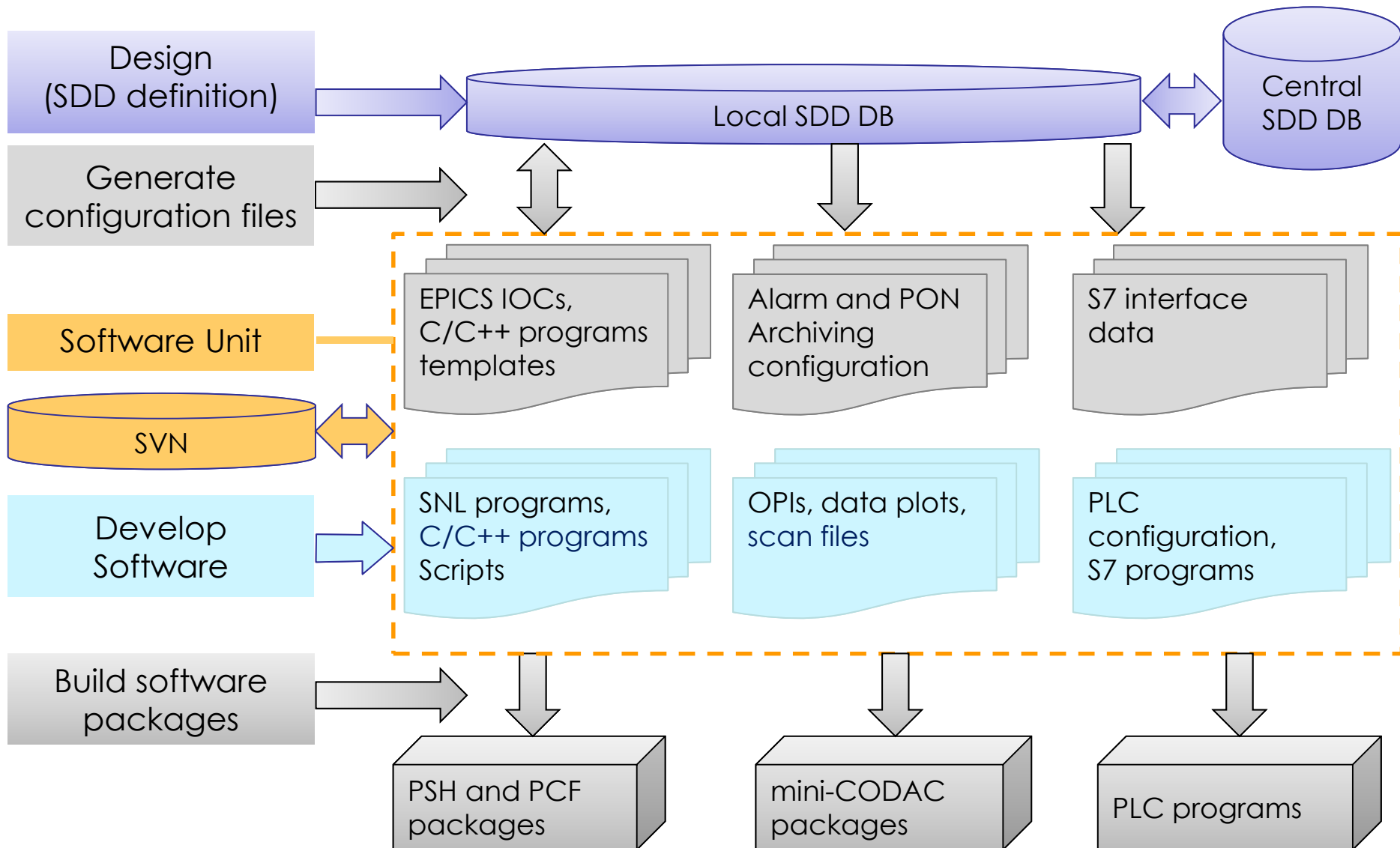
## DAN Chain Diagram



# Plant System I&C Technology

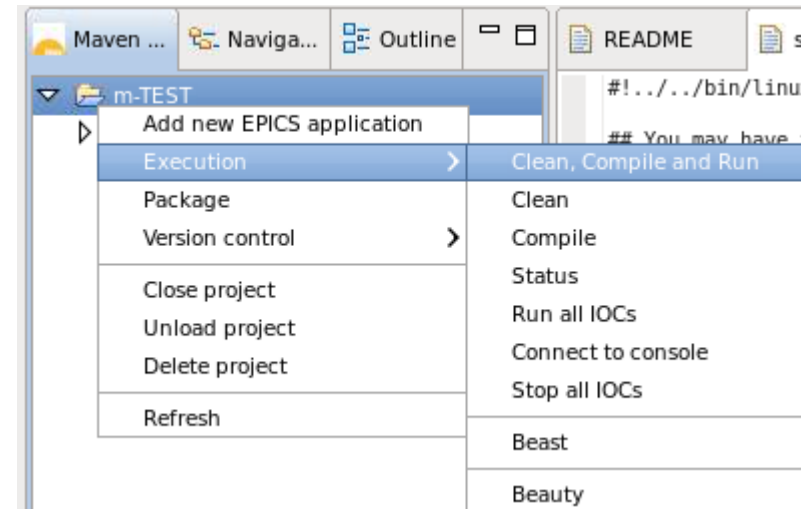
## Development Workflow

# Development Workflow



# I&C Project / Software Unit

- For each **I&C project**:
  - One definition in SDD
  - One software unit
  - The software packages for installation on each target computer.
  - One SVN<sup>(\*)</sup> unit
- For any software unit, standard commands, implemented with Apache Maven, are provided to
  - **Compile** all EPICS applications and C/C++ programs
  - **Run / Stop** EPICS IOCs and C/C++ programs
  - **Package** the files for deployment
  - **Install** packages



(\*) SVN is the software revision control system used by IO

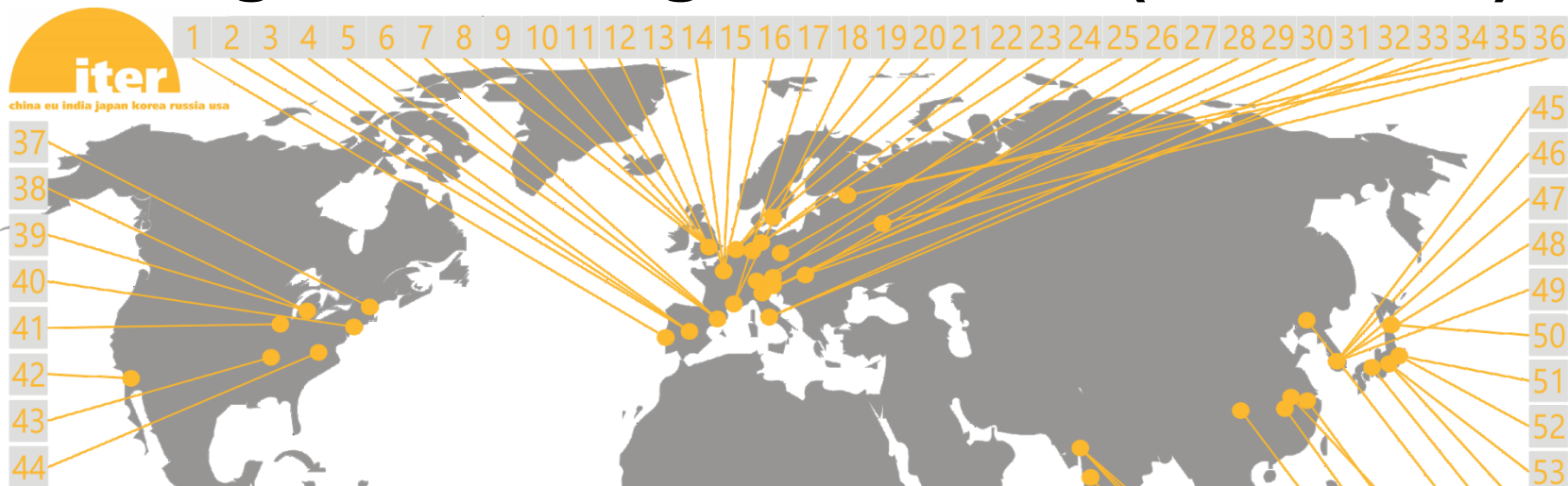
# CODAC Core System Releases

Base	2013		2014		2015		2016		2017	2018	2019	2020	2021
RHEL 6.3 EPICS 3.14 MRG-R 2.1	4.0	4.1	4.2	4.3	Support								
RHEL 6.5 EPICS 3.15 MRG-R 2.5					5.0	5.1	5.2	5.3	5.4	Support			
<i>RHEL 7.3</i> <i>EPICS 3.16 (7)</i> <i>MRG-R (TBD)</i>										6.0	6.1	6.2	6.3

Version	Date
<b>1.0.0</b>	<b>15-Feb-2010</b>
1.1.0	28-Jun-2010
<b>2.0.0</b>	<b>15-Feb-2011</b>
2.0.1	06-May-2011
2.1.0	23-Jul-2011
<b>3.0.0</b>	<b>15-Feb-2012</b>
3.1.0	22-June-2012
<b>4.0.0</b>	<b>15-Feb-2013</b>
4.1.0	04-Jul-2013
4.2.0	14-Feb-2014
4.3.0	07-Jul-2014
4.3.1	30-Mar-2015
<b>5.0.0</b>	<b>20-Feb-2015</b>
5.1.0	17-Jul-2015
5.2.0	17-Feb-2016
5.3.0	01-Jul-2016
5.4.0	20-Feb-2017

- Two Versions a year until 2016
- One version a year from 2017 until 2021
- New OS base & major branch on 2018

# Registered Organizations (Feb 2017)



1. IPFN-IST: Lisboa, Portugal
2. CIEMAT: Madrid, Spain
3. UPM: Madrid, Spain
4. GMV: Madrid, Spain
5. Procon: Badalona, Spain
6. F4E: Barcelona, Spain
7. GTD: Barcelona, Spain
8. CCFE: Abingdon, UK
9. Tessella: Abingdon, UK
10. Oxford Technologies: Abingdon, UK
11. Arcadis: London, UK
12. Assystem: Preston, UK
13. CEA Saclay: Saclay, France
14. NI France: Nanterre, France
15. ECRIN: Paris, France
16. EADS: Paris, France
17. ITER IO: Cadarache, France
18. CEA Cadarache: Cadarache, France
19. Intermodalics: Leuven, Belgium
20. ITER-NL: Eindhoven, Netherlands
21. ESS: Lund, Sweden
22. NAT: Bonn, Germany

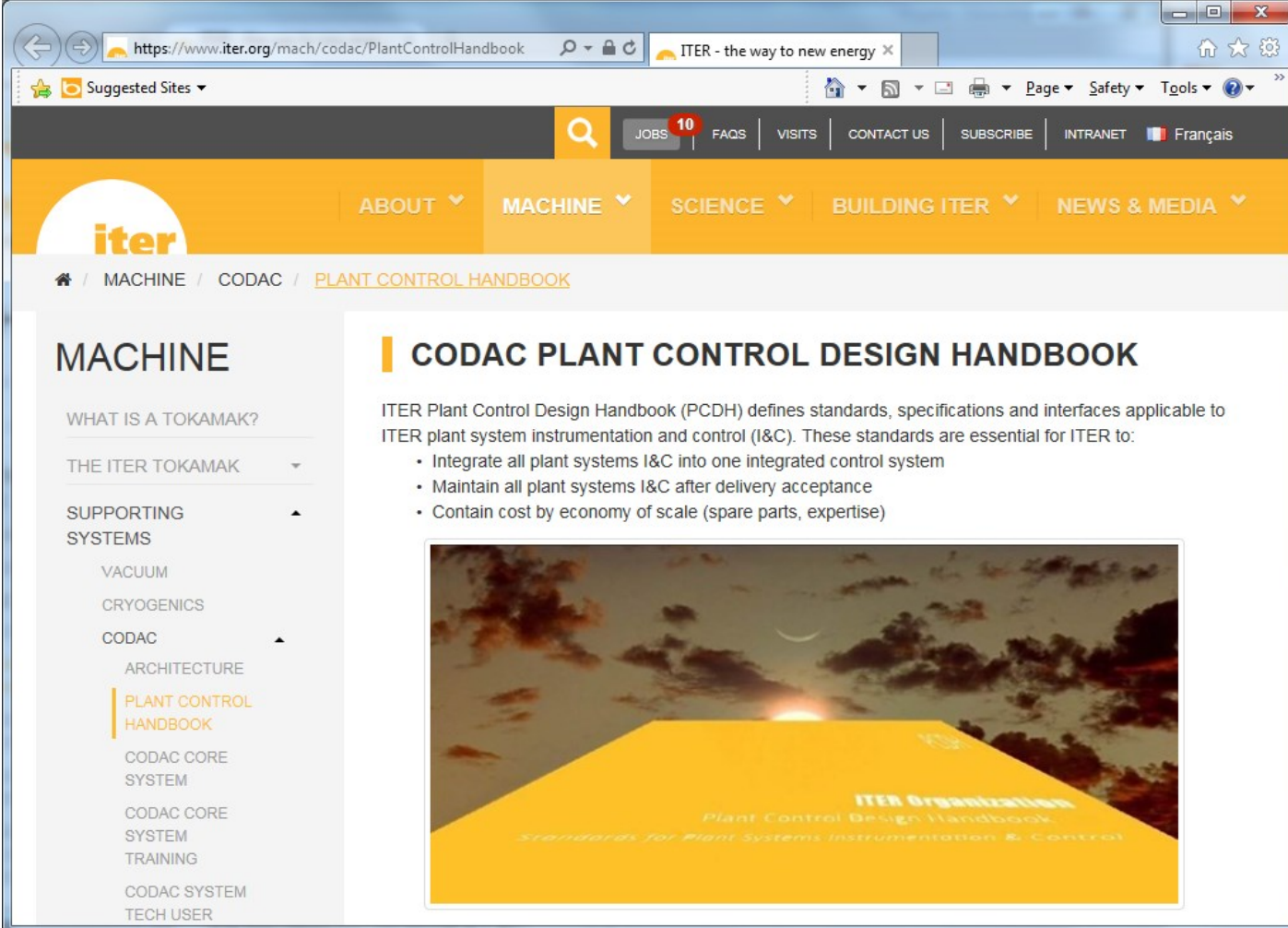
23. EICSYS: Hamburg, Germany
24. MP-IPP: Garching, Germany
25. DMCS-TUL: Lodz, Poland
26. Wigner RCP: Budapest, Hungary
27. Alceli: Meisterschwanden, Switzerland
28. INFN-LNL: Legnaro, Italy
29. Consorzio RFX: Padova, Italy
30. ENEA Brasimone: Brasimone, Italy
31. ENEA Frascati: Frascati, Italy
32. Vitrociset: Rome, Italy
33. Cosylab: Ljubljana, Slovenia
34. NIIFFA: Saint Petersburg, Russia
35. IOFFE-RF: Saint Petersburg, Russia
36. ITER-Russia: Moscow, Russia
37. MIT: Cambridge, USA
38. Carcassi LLC: Ann Arbor, USA
39. FRIB: East Lansing, USA
40. PPPL: Princeton, USA
41. HDF Group: Champaign, USA
42. General Atomics: San Diego, USA
43. ITER-US: Oak Ridge, USA
44. nHance: Lynchburg, USA

45. MOBIS: Seoul, Korea
46. Dawonsys: Siheung, Korea
47. NFRI: Daejeon, Korea
48. KSTAR: Daejeon, Korea
49. KAERI: Daejeon, Korea
50. IFMIF: Obuchi, Japan
51. JAEA: Tokaimura, Japan
52. A-Tech: Tokaimura, Japan
53. Toshiba: Yokohama, Japan
54. NIFS: Toki, Japan
55. MHI: Kobe, Japan
56. RXPE: Anshan, China
57. IPP: Hefei, China
58. ITER-China: Suzhou, China
59. HUST: Wuhan, China
60. SWIP: Chengdu, China
61. ITER-India: Gandhinagar, India
62. IPR: Gandhinagar, India
63. OSPL: Ahmedabad, India
64. TCS: Pune, India



# Plant Control Design Handbook

Technical details available at the ITER site (30 documents):  
<http://www.iter.org/mach/codac/PlantControlHandbook>



The screenshot shows a web browser window displaying the ITER website. The address bar shows the URL <https://www.iter.org/mach/codac/PlantControlHandbook>. The page features a navigation menu with options like JOBS (10), FAQs, VISITS, CONTACT US, SUBSCRIBE, INTRANET, and Français. The main content area is titled "CODAC PLANT CONTROL DESIGN HANDBOOK" and includes a description of the handbook's purpose and a list of key objectives:

- Integrate all plant systems I&C into one integrated control system
- Maintain all plant systems I&C after delivery acceptance
- Contain cost by economy of scale (spare parts, expertise)

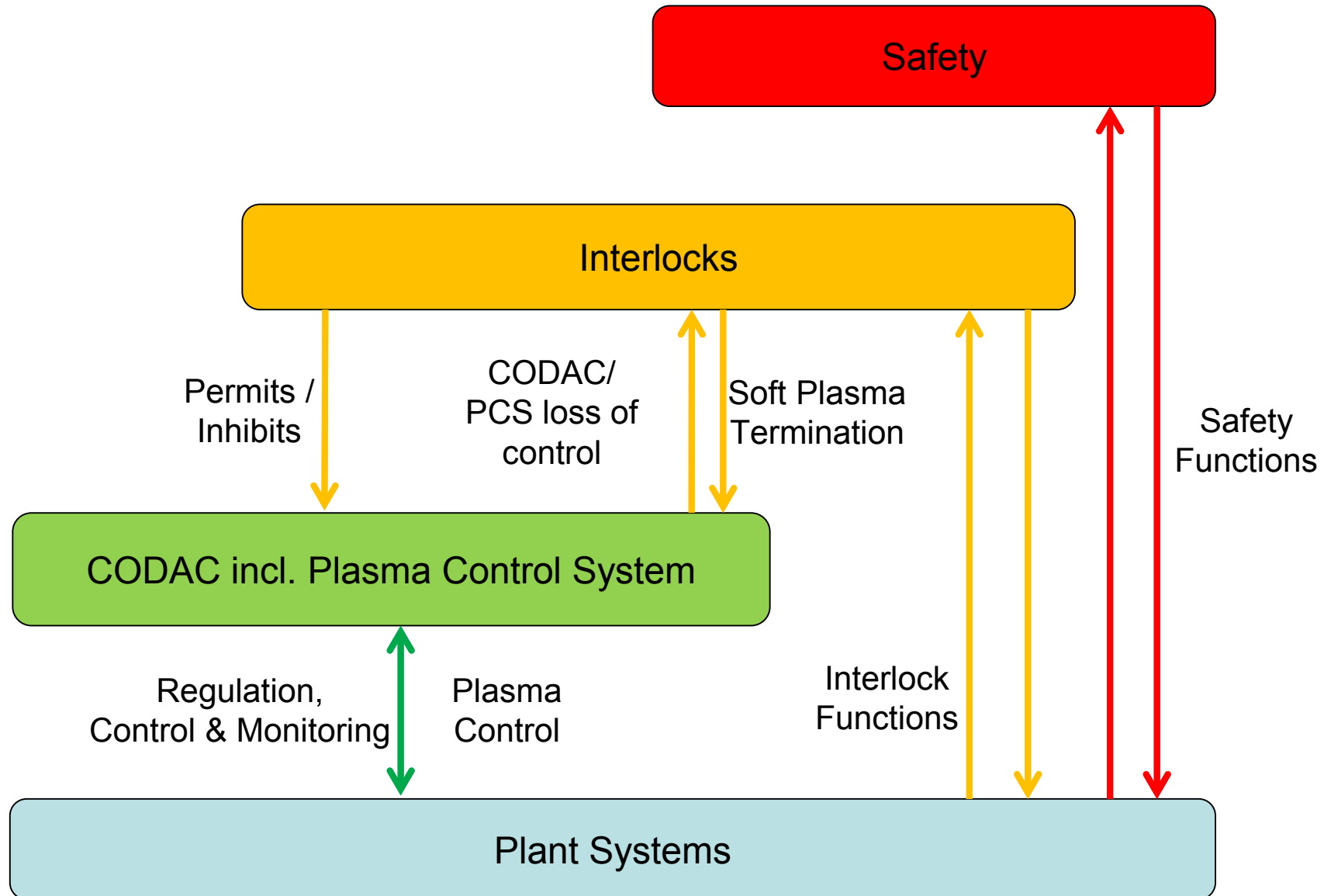
Below the text is a large image of the handbook cover, which features a sunset over a field and the text "ITER Organization Plant Control Design Handbook Standards for Plant Systems Instrumentation & Control".

On the left side of the page, there is a sidebar menu under the heading "MACHINE". The menu items are:

- WHAT IS A TOKAMAK?
- THE ITER TOKAMAK
- SUPPORTING SYSTEMS
  - VACUUM
  - CRYOGENICS
  - CODAC
    - ARCHITECTURE
    - PLANT CONTROL HANDBOOK
    - CODAC CORE SYSTEM
    - CODAC CORE SYSTEM TRAINING
    - CODAC SYSTEM TECH USER

# Central I&C Systems Design

# Defence in Depth



# CODAC Operation Applications

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

## 1. Preparation

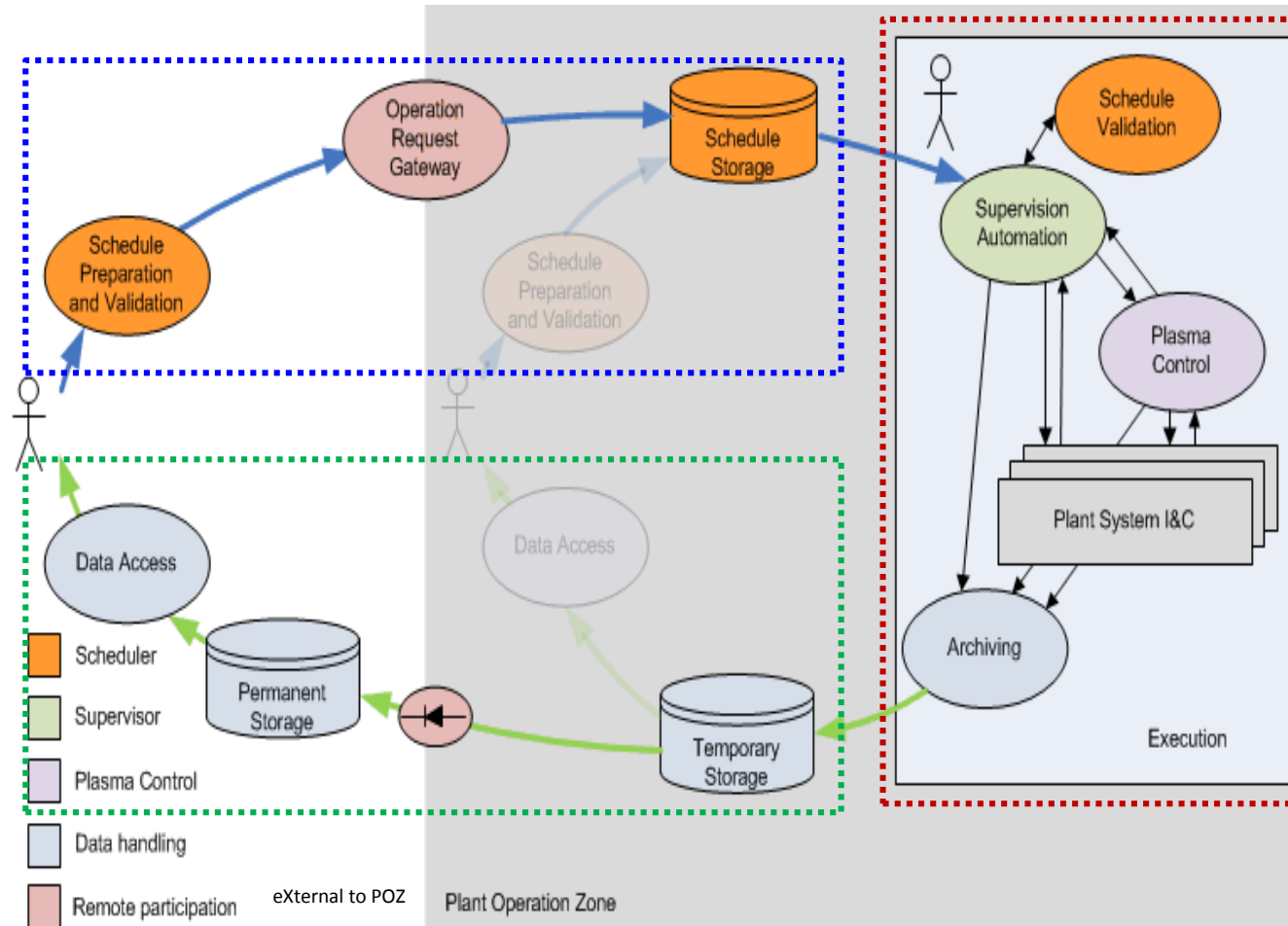
Scheduling (PSPS)  
Gateway (ORG)

## 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
- **Operation Request Gateway (ORG)**
  - Support remote participation by securely controlling and screening interaction with the outside world
- **Supervision and Automation (SUP)**
  - Provides the infrastructure to execute a pulse schedule prepared by PSPS and to support automated operation and continuous monitoring
- **Plasma Control System (PCS)**
  - Performs the distributed real-time control and monitoring during the pulse
- **Data Handling**
  - Provides the system to write, store, retrieve and visualize all data produced during ITER commissioning and operation.
- **Data Access**
  - Provides a unified access to all data produced by ITER and API's for selected preferred user processing and visualization software (e.g. Matlab, MDSplus,...)

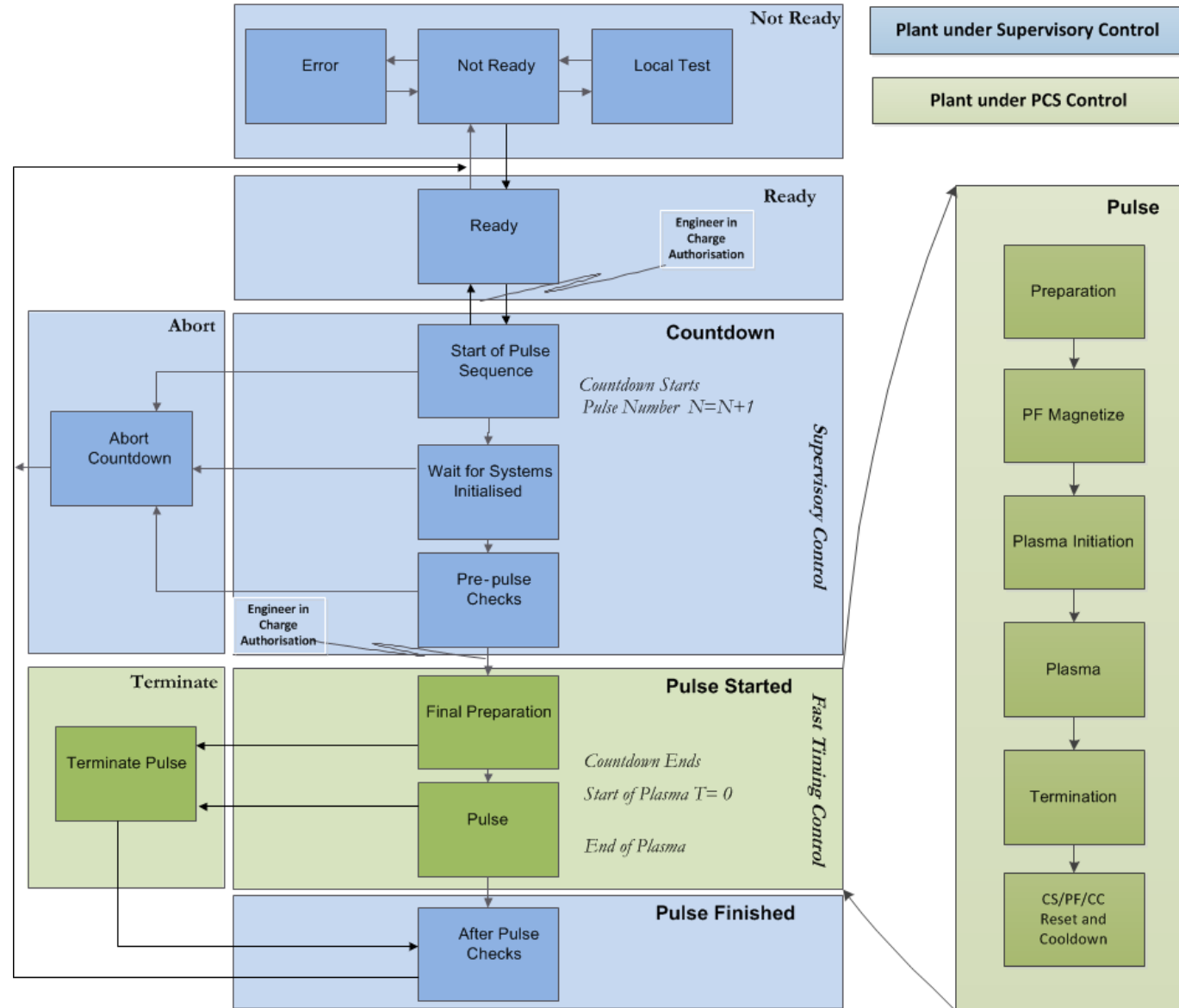
# Supervision and Plasma Control System

## ○ CODAC Supervisor (SUP)

- Normally controls operations
- Performs pre-pulse checks and countdown to pulse
- Passes control to the PCS

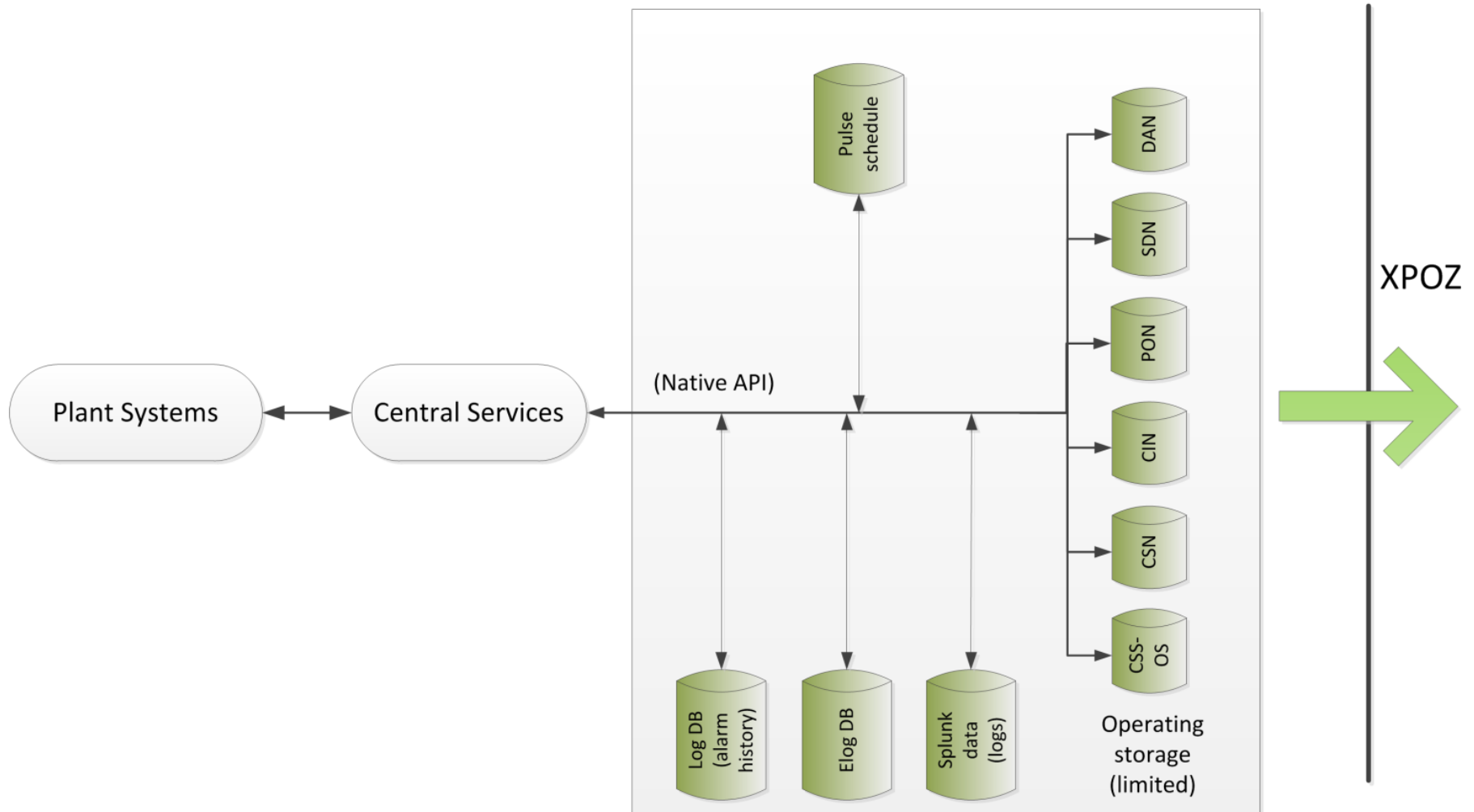
## ○ PCS controls pulse operation

- Performs final pre-pulse checks
- Begins pulse energizing CS/PF
- Performs plasma initiation, rampup, flatop, rampdown
- After plasma termination, controls CS/PF currents to zero
- Returns control to SUP



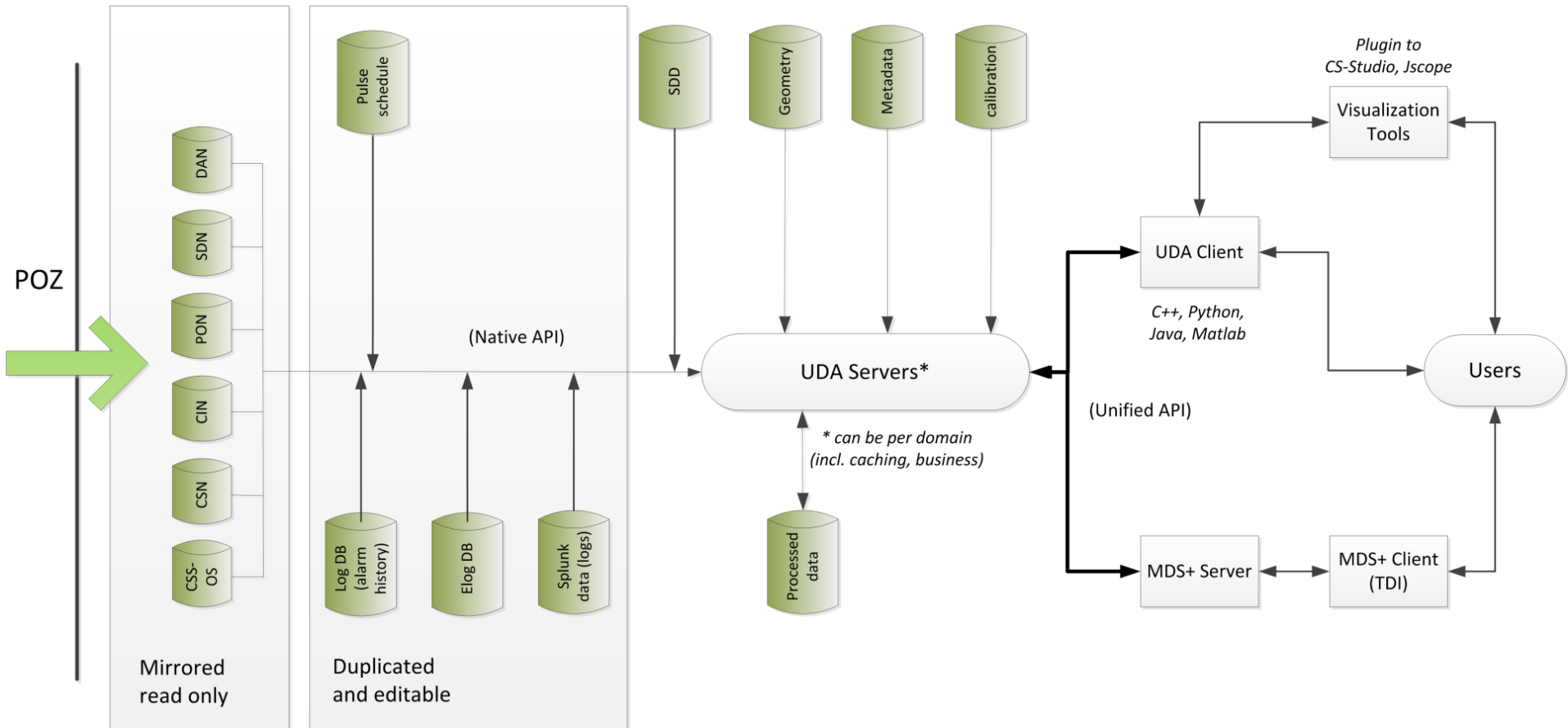
# Data Handling (POZ)

## Data Access Workflow – POZ (“small POZ”)



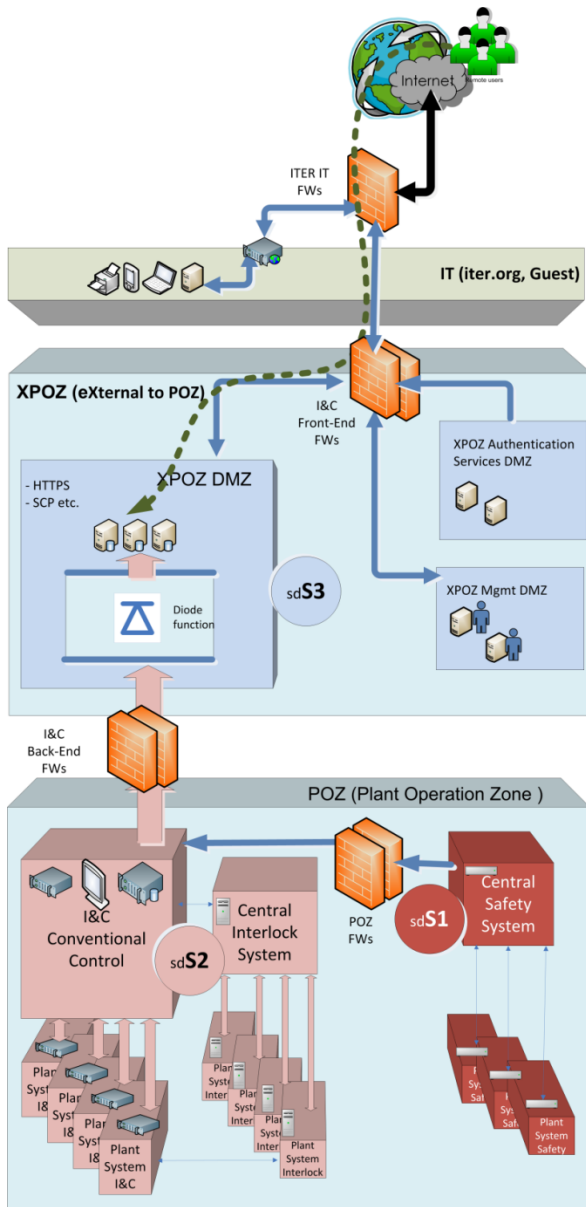
# Data Handling and Access (XPOZ)

Data Access Workflow - XPOZ





# Cyber Security Aspects



## IEC 62645 Ed1

### Nuclear power plants I&C system requirements for security

- **S3** – XPOZ EXT– off-line data access, remote participation and other activity requiring access to the produced data but not participating to the operation.
- **S3** – XPOZ INT– User authentication, System and Network management and hosting the Plant System I&C during the assembly phase.
- **S2** – POZ – ITER I&C, Interlocks and Safety Systems (OS, PIC/SIC-2B, PIC/SIC-2C, SR SCS-N).
- **S1** – POZ – Safety Systems (PIC/SIC-1).

At network level, systems ensuring communication shall enforce the security of the interconnected systems. In case of a communication between two zones having different security degrees, the communication must be initiated and managed by the zone having the higher security degree.



**Thank you for your attention!**