The Newly Constructed EPICS-Based Control System for KSTAR Tokamak Device

KSTAR
Korea Superconducting Tokamak Advanced Research

Mikyung Park

KSTAR Research Center

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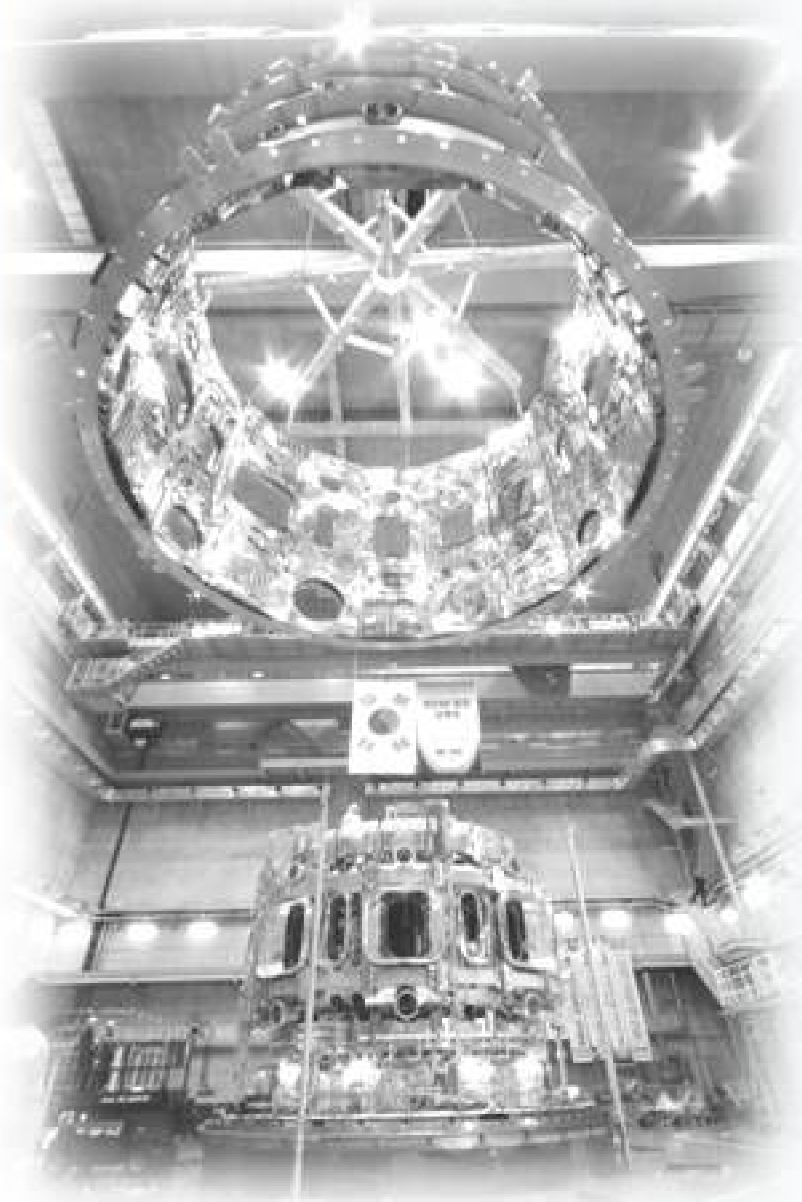
NFRI 국가핵융합연구소
National Fusion Research Institute

Outlines

- KSTAR Project
- Development of KSTAR Control System
  - Introduction of Entire Implementation
  - Plant Control & Diagnostic System
  - Real-time Feedback Control System
  - Machine Interlock
  - Data Visualization
- Conclusion –
  - Evaluation and Improvement Plan

1 KSTAR Project



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KSTAR Project ?

KSTAR

- **KSTAR** - Korea Superconducting Tokamak Advanced Research
- **Missions** -

  Development of a steady-state-capable advanced superconducting tokamak to establish the scientific and technological base for an attractive fusion reactor as a future energy source.

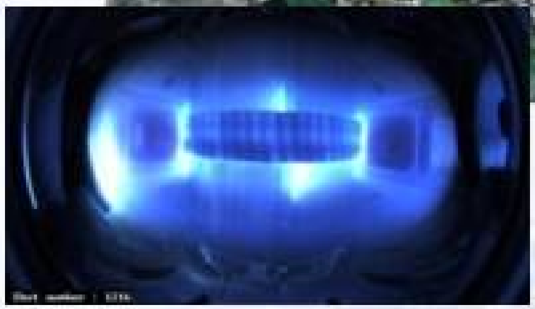
- **History-**

  1995 : Project launched

  1998 : Construction started

  2007 : Completion of Assembly

  2008 : Achievement of the 1st plasma



Major radius, R_0 / Minor radius, a	1.8 m / 0.5 m
Elongation, κ / Triangularity, δ	2.0 / 0.8
Plasma volume	17.8 m^3
Plasma surface area / cross section	56 m^2 / 1.6 m^2
Plasma shape	DN, SN
Plasma current, I_P	2.0 MA
Toroidal field, B_0	3.5 T
Pulse length	300 s
β_N	5.0
Plasma fuel	H, D-D
Superconductor	Nb_3Sn, NbTi
Auxiliary heating /CD	~ 28 MW
Cryogenic	9 kW @4.5K

KSTAR Bld.

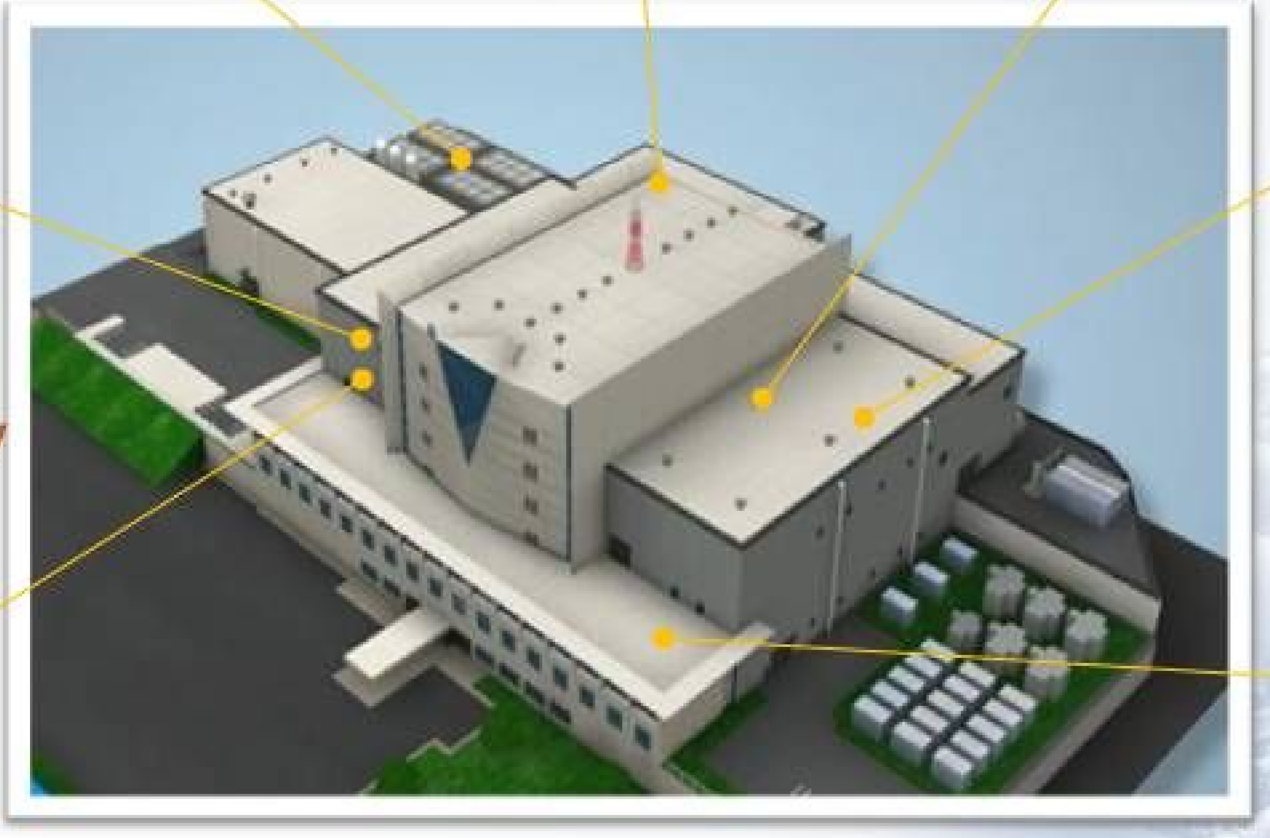
Tokamak & Ancillary Systems

KSTAR Tokamak

Cooling Water

Cryogenic Refrigerator

Magnet Power Supply

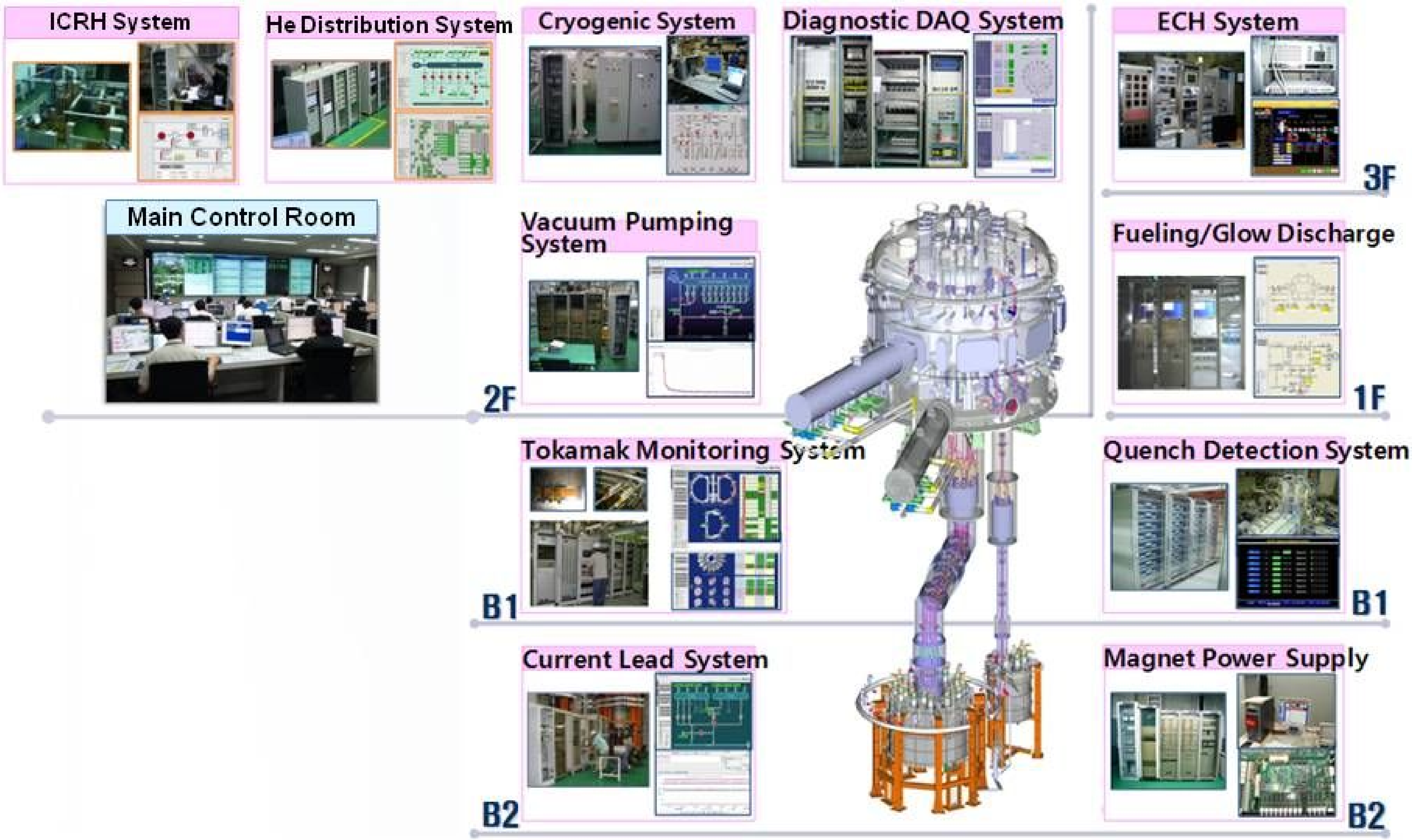


Diagnostics

Heating Devices

Control Room

2 Development of KSTAR Control System



Features

- **Missions**
  - Integrating all **Plant System I&Cs** for Tokamak Operation
  - Establishing the environment for **Real-time F/B Control** on plasma
  - Implementing **Machine Interlock & Protection**
  - Achievement of **Synchronized** Operation
  - Development of Schema for Sequential operation
- **Communication standard and software framework**
  EPICS (Experimental Physics and Industrial Control System)
- **Using every possible Open-source Tools for development**
- **Integration of Heterogeneous controllers**
  : VME, VXI, cPCI, PXI, PCI, PLC, and cFP
- **About 15,000 I/Os and 36,000 PVs (integrated in EPICS)**
- **About 800 experimental signal channels (managed by MDSplus)**
- **Using Five Different Optical Networks**
- **Adopting Two Databases : EPICS Channel Archiver, MDSplus**
- **Additional Databases for web_portal, signal DB (MSsql, Mysql)**

The control system just stands in the early stage, so it is growing !!

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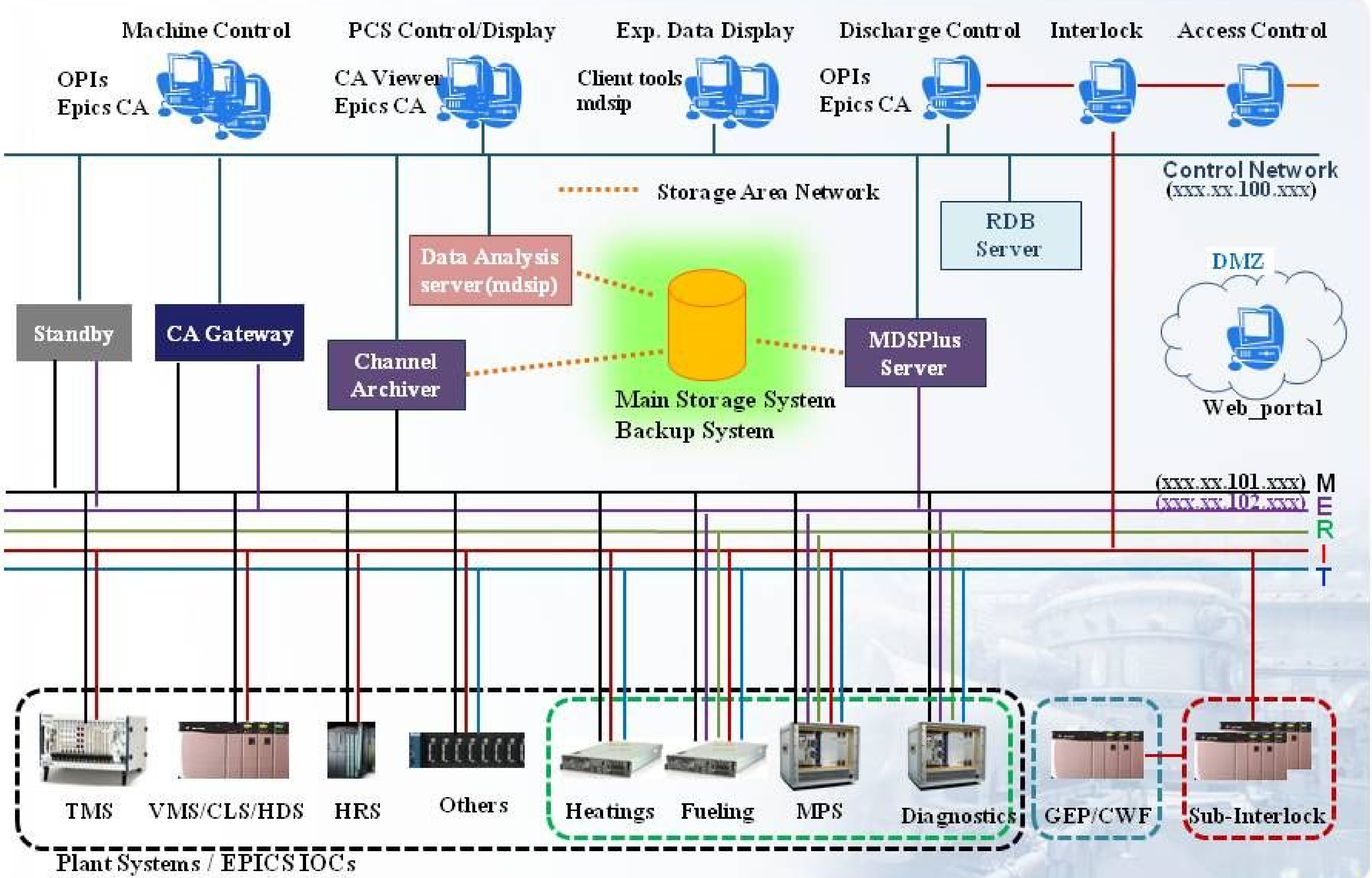
Features

Structure	2 Tier		•Control --- Interlock+Safety
	2 Layer		•Central --- Local
Middleware	EPICS		
Operating system	Linux		•Plant monitoring & control
	VxWorks		•Feedback control
H/W Platform	Slow control		•PLC, cFP
	Fast control		•VME, PXI, cPCI, PCI, VXI, (ATCA)
Interface (Networks)	Machine	EPICS CA	•Plant monitoring & control •Operational data transfer
	Experimental Data	MDSip	•Shot-based data storing
	Real-time	Shared-memory	•Real-time feedback control
	Interlock	(ControlNet)	•Machine interlock & protection
	Timing	Home-made protocol	•Timing & synchronized operation
OPI	Qt (open source)		•Home made
Data Managements	EPICS Channel Archiver		•Low rate continuous operational data
	MDSplus		•High rate shot-based experimental data

EPICS Libraries for KSTAR

System	Used libraries	Originator, modifier	Platform
Common	timestampRecordLib seqLib	SLAC, KSTAR PSI	
CCS, MPS	vmivme2534Lib vmivme5565RfmLib vxStatsLib kcm020	U. Hawaii, KSTAR KSTAR PSI KSTAR	VME/Vxworks
Timing	drvCLTU	KSTAR	PMC
PCS	pcsMessagesLib	KSTAR	PCI/Linux
VMS, CLS, HDS, ECH	etherIPLib pfeifferTPG262Lib SRSRGALib vgcGP307Lib pumpLib hepropLib	SNS KSTAR KSTAR KSTAR KSTAR KSTAR	AB PLC
HDS, HRS	S7plc hepropLib	SLS KSTAR	Siemens PLC
PXI	niPXISCXILib	KSTAR	PXI
PXI, Shutter	nicFP20x0Lib	KSTAR	cFP
ECH	PosfaPLC	KSTAR	PosfaPLC
VMS, CLS, HDS, ECH, ICRH	asynLib etherIPLib ESP300Lib icrfDM	APS SNS KSTAR KSTAR	Legacy I/O
Diagnostics	drvACQ196	KSTAR	cPCI/Linux
Diagnostics	drvModel6802	KSTAR	VME/Linux
All	autosave	APS	

Control System Architecture



Infrastructure



- **Main Control Room**
  - Operator's area : 24 operator's seats, Display wall containing 12 DLP cubes, 5 aux. displays
    E-stop buttons, access key-box, portable H.323, web-cam for web service, audio, ..
  - Equipment room : mainframes of OPI servers, CCS, Central timing, SIS, PSI, RMS, a node of PCS, ..
  - Meeting room : H.323, audio, project, etc….
  - Plan : enlargement of MCR, construction of remote OP room for KSTAR and ITER
- **Storage system**
  - Main storage : IBM DS 8100, 14TB
  - Disc Backup Storage : EMC6.5, temporary backup
  - Tape Backup Library : IBM TS3500, 110TB, permanent backup
- **Shared file system : GPFS v.3.2.1 (IBM)**
- **Network :** 2 backbones, 11 workgroup SW, multi-mode fiber-optic, star-topology
- **Servers** : Gateway, Data archiving, Data analysis, Computing, Relational DB, Web_portal, Standby, etc

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Plant Control System

System	Controller	Interface Host (OS)	Interlock Subsystem	Local Interlock Functions	Description
CCS	VME, Server	VxWorks	Sub-CCS/PSI	Yes	Supervisory control
PCS	cPCI, RT servers	Linux		Yes	RT F/B control on plasma, disconnect CA during RT mode
TF PS	VME, DSP	VxWorks	Sub-MPS	Yes	MPS for TF coil
PF1 PS	VME, DSP	VxWorks		Yes	MPS for PF coil 1
PF2 PS	VME, DSP	VxWorks		Yes	MPS for PF coil 2
PF3 PS	VME, DSP	VxWorks		Yes	MPS for PF coil 3
PF4 PS	VME, DSP	VxWorks		Yes	MPS for PF coil 4
PF5 PS	VME, DSP	VxWorks		Yes	MPS for PF coil 5
PF6 PS	VME, DSP	VxWorks		Yes	MPS for PF coil 6
PF7 PS	VME, DSP	VxWorks		Yes	MPS for PF coil 7
HRS	Siemens PLC	Linux	Sub-HRS	Yes	He refrigeration, limited integration
HDS HCS	Siemens PLC	Linux	Sub-HDS/VPS	Yes	He distribution –He control
HDS VPS	AB PLC	Linux		Yes	He distribution –vacuum pumping
VPS CRYO	AB PLC	Linux		Yes	Vacuum pumping-cryostat
VPS VV	AB PLC	Linux		Yes	Vacuum pumping-vacuum vessel
CLS HCS	AB PLC	Linux	Sub-CLS	Yes	Current lead-He control
CLS VPS	AB PLC	Linux		Yes	Current lead-vacuum pumping
TMS	NI PXI	Linux	Sub-TMS/QDS	Yes	Tokamak monitoring
QDS	VME	VxWorks		Yes	Quench detection
DLS	NI cFP, Server	Linux	Sub-DLS/Fuel	No	Control on diag. shutters and power
FUEL/GDC	AB PLC, Server	Linux		Yes	Fueling, Glow discharge
ICRH	DSP, Server	Linux	Sub-ICRH	Yes	Ion-cyclotron heating
ECH	AB PLC, Server	Linux	Sub-GEP/ECH	Yes	Electron-cyclotron heating
GEP	SCADA (Industrial)	No		Yes	Electric power plant, NO interface but only with interlock
CWF	DCS (Industrial)	No	Sub-CWF	Yes	Cooling water, NO interface but only with interlock
PSI	AB & Siemens PLC	No	Sub-CCS/PSI	Yes	Access control, NO interface but only with interlock
RMS	PC	No		Yes	Radiation monitoring, NO interface but only with interlock

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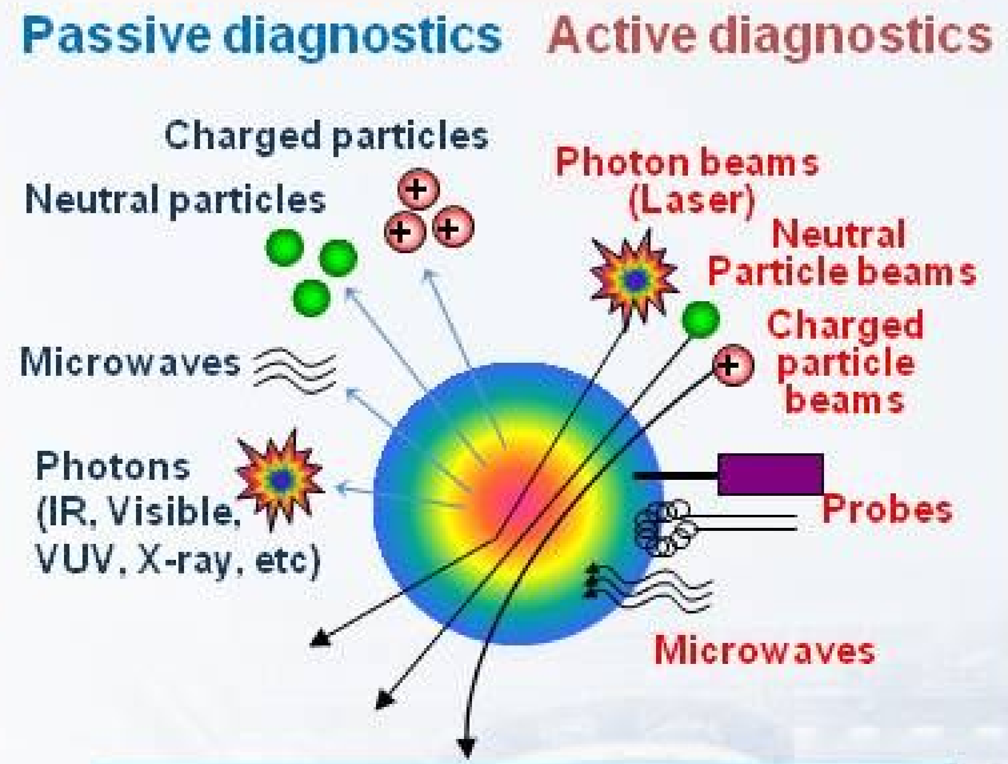
Diagnostic DAQ System

- 50 types of Diagnostics / 20 diagnostics installed (channels are increasing)
- MDSip / Experimental network : data stored to the MDSplus server/Central storage
- EPICS CA / Machine network : configuration, system status reporting, receiving of operation information
- Operated in synchronized manner using LTU (Local Timing Unit)

System	Channels(Final)	DAQ
Rogowski Coil	3	cPCI, max 200KHz
Flux/Voltage Loop	45	cPCI, max 200KHz
Magnetic Field Probe	244 (512)	cPCI, max 200KHz
Diamagnetic Loop	9	cPCI, max 200KHz
Saddle Loop	40	cPCI, max 200KHz
Vessel Current Monitor	3	cPCI, max 200KHz
Halo Current Monitor	15 (273)	cPCI, max 200KHz
Mirnov Coil	8 (72)	VXI, 1 ~ 10MHz
Fast Reciprocating Probe	5 (25)	cPCI, max 200KHz
Fixed Edge probe	6 (120)	cPCI, max 200KHz
MMW Interferometer	8	VME, max 200KHz
ECE Radiometer	40	VME, max 200KHz
Edge Reflectometer	4	PXI, max 200MHz
Resistive Bolometer	12	PXI, max 500KHz
X-ray Crystal Spectrometer	1	PCI, max 10KHz, Window
Visible Survey Spectrometer		PCI, max 100KHz, Window
Visible Filterscope		PCI, max 100KHz, Window
H_alpha Monitor	30	VME, max 200KHz
Soft X-ray Array	2	PXI, max 250KHz
Hard X-ray Array	80 (240)	PCI, 10MHz, Window
Visible/H_alpha TV	3	PCI, Window



Physics Parameters
• Plasma current • Loop voltage • Plasma shape & position • Temperature, density • Stored energy, impurities • Stability • confinement • Real-time measuring for feedback control

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Synchronized Operation Sequence

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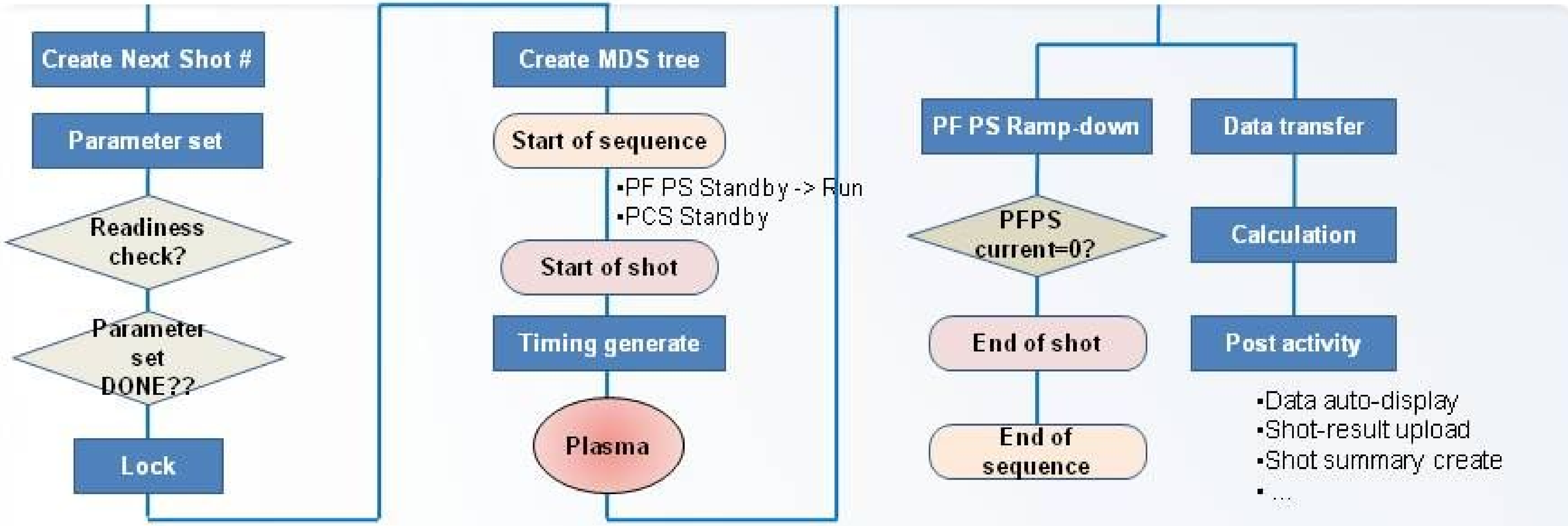
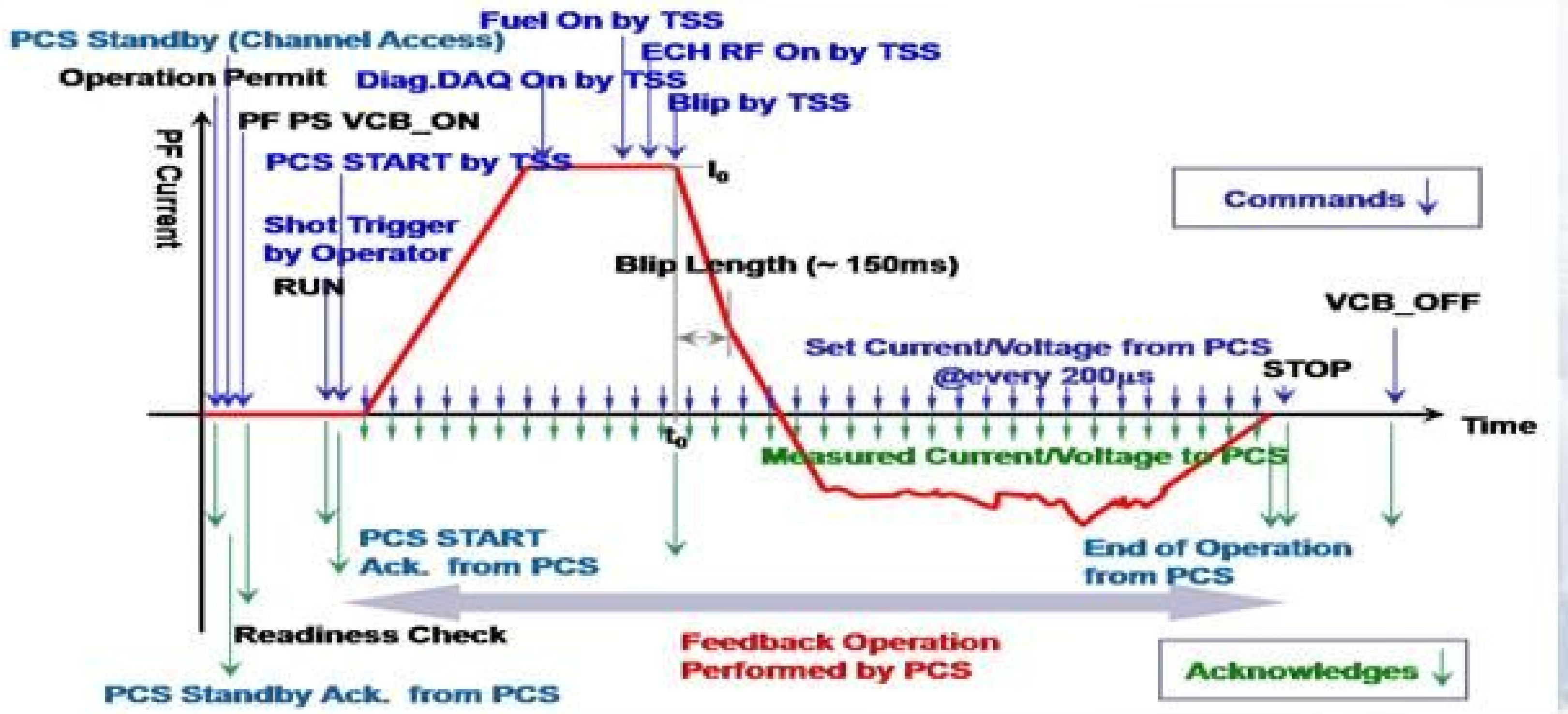
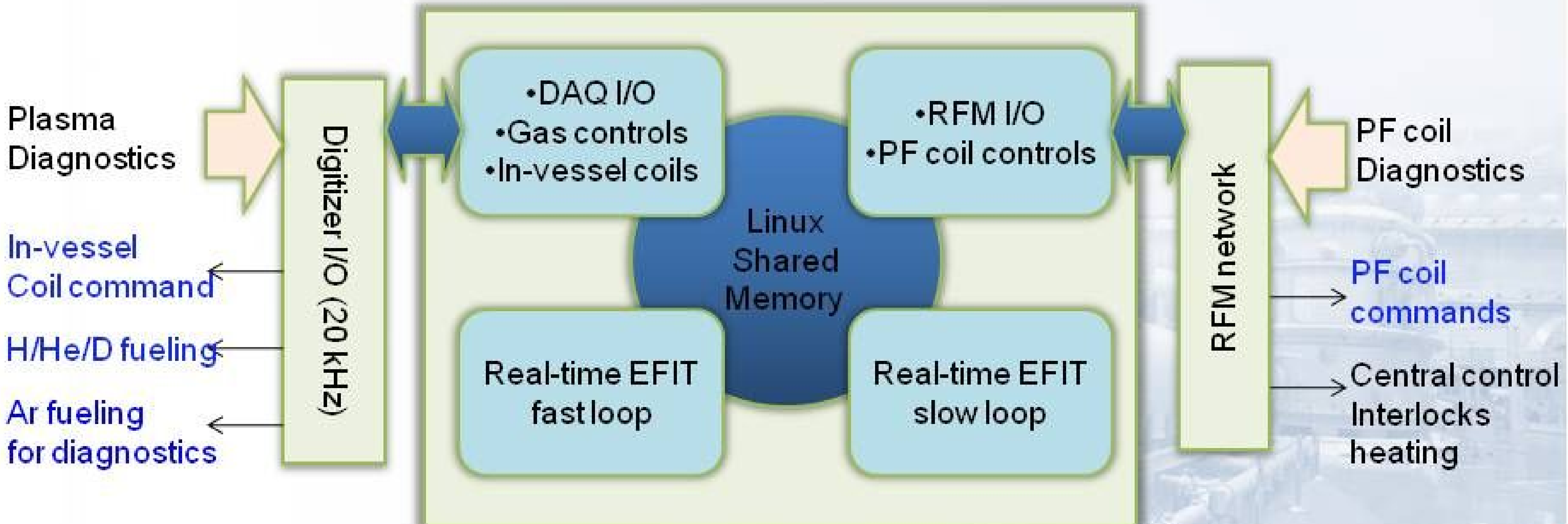




Real-time F/B Control on Plasma

- **Goal** : to generate plasmas by reloadable & reproducible actuator scenarios
  to maintain the plasma by active feedback
- Real-time feedback control on Ip and Rz, electron line density
- Multi-CPU system to deal with fast digital interface (~20 kHz) & future shape controls [RT-EFIT in 2010]
- **Sensors** :
  - Plasma diagnostics : 82->223 CH magnetic diagnostics, 1->4 CH mm-wave interferometer
  - Actuator diagnostics : digital PF coil measurements via reflective memory (RFM)
- **Actuators** : 7 sets of PF Power Supply, Deuterium gas puff, Diagnostic Argon valves
- Operation sequence & actuator limits are brought from EPICS CA
- Developed as a US-KSTAR collaboration



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Layout of Real-time F/B Control

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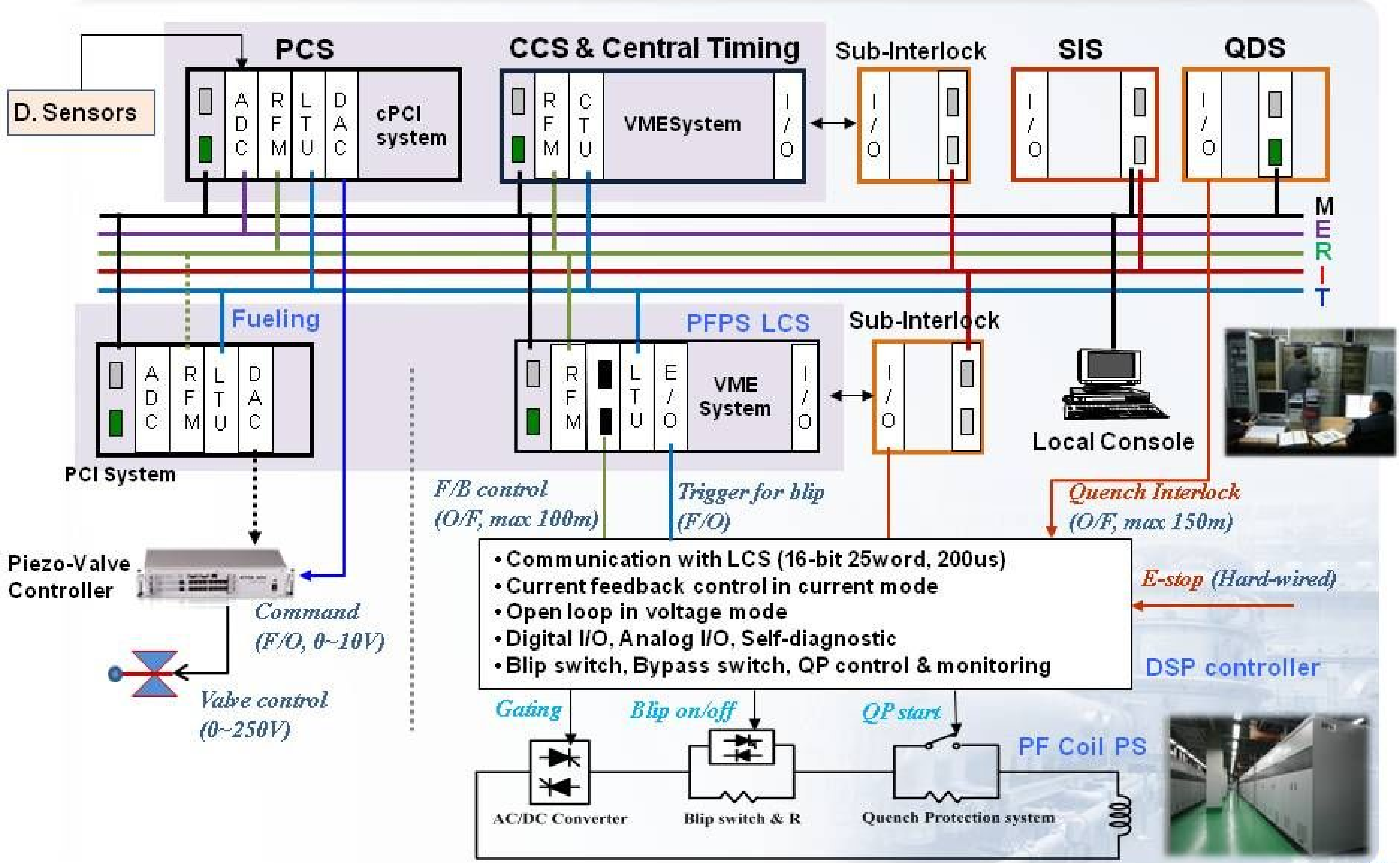

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Machine Interlock

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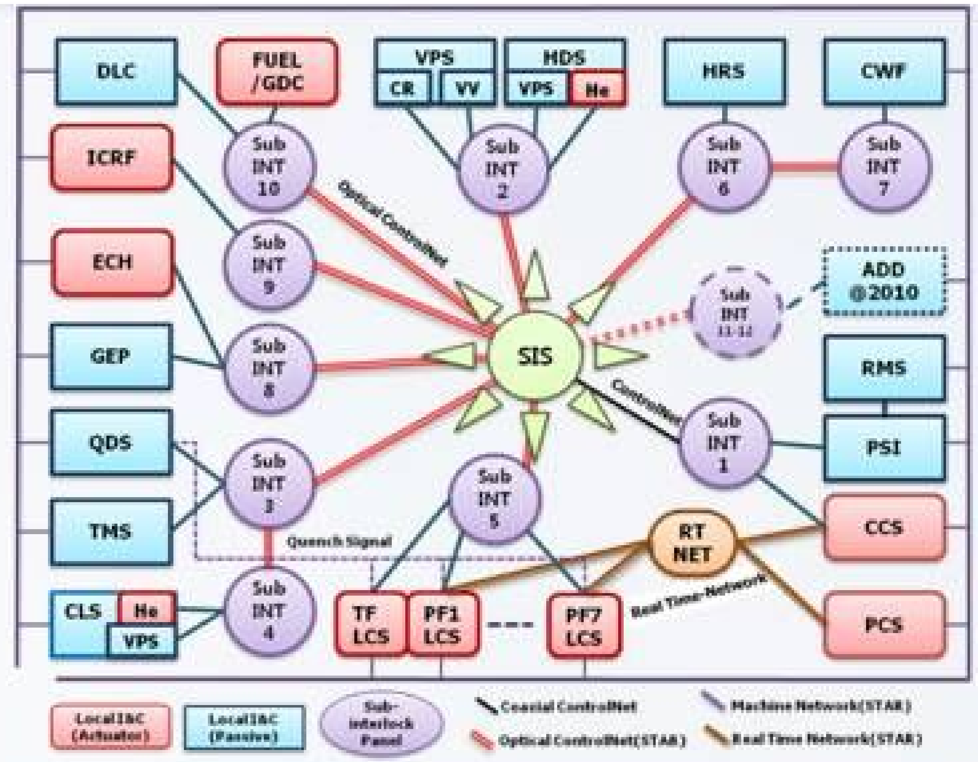
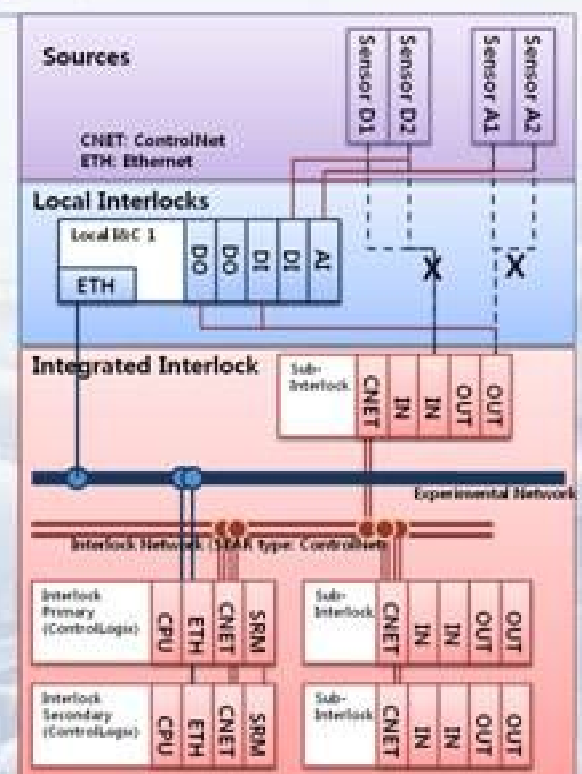
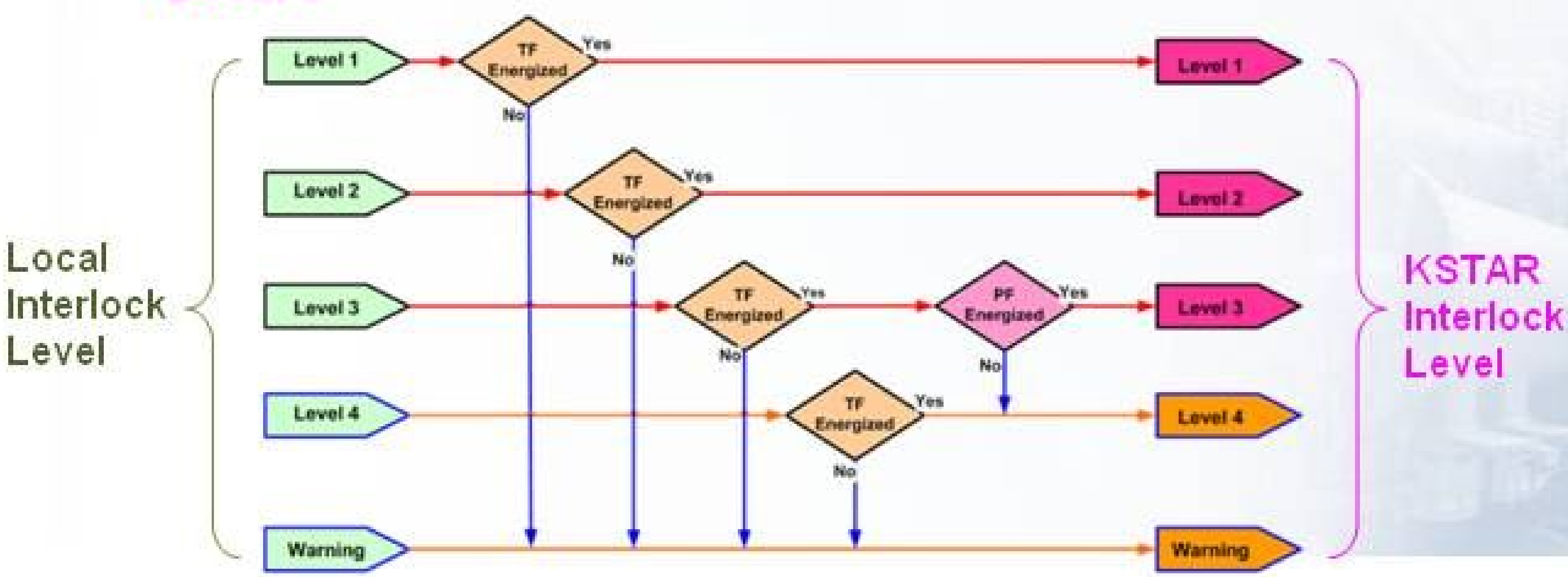
- **Structure**
  - 1 Supervisory Interlock (Fully redundant system)
  - 10 sub-interlock systems for 28 Local controllers
  - About 300 I/O points
- **Communication (ControlNet/duplicate)**
  - Media: Optical Fiber/ coaxial
  - Method: star + daisy chain
- **Assistant or Redundant Interlock**
  - Plasma Current Fault protection
  - Direct Quench signal for Magnet Power Supply
  - SMS (Short Message Service)
- **Four Interlock levels defined according to the severity**
  - **Level 1 : Fast discharge of TF current**
  - **Level 2 : Slow discharge of TF current**
  - **Level 3 : Experiment stop and fast discharge of PF current**
  - **Level 4 : Next shot inhibit**







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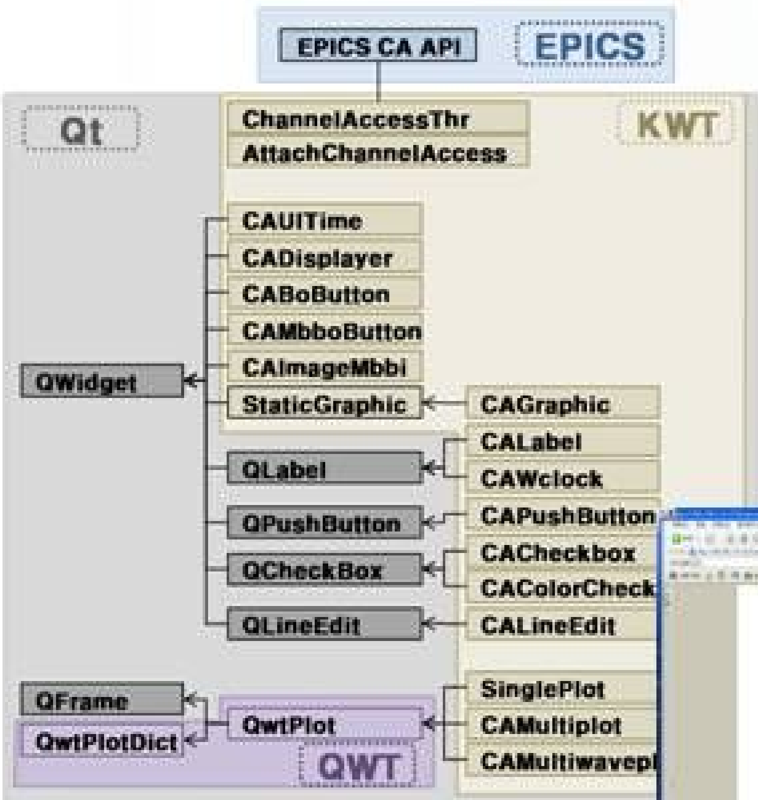
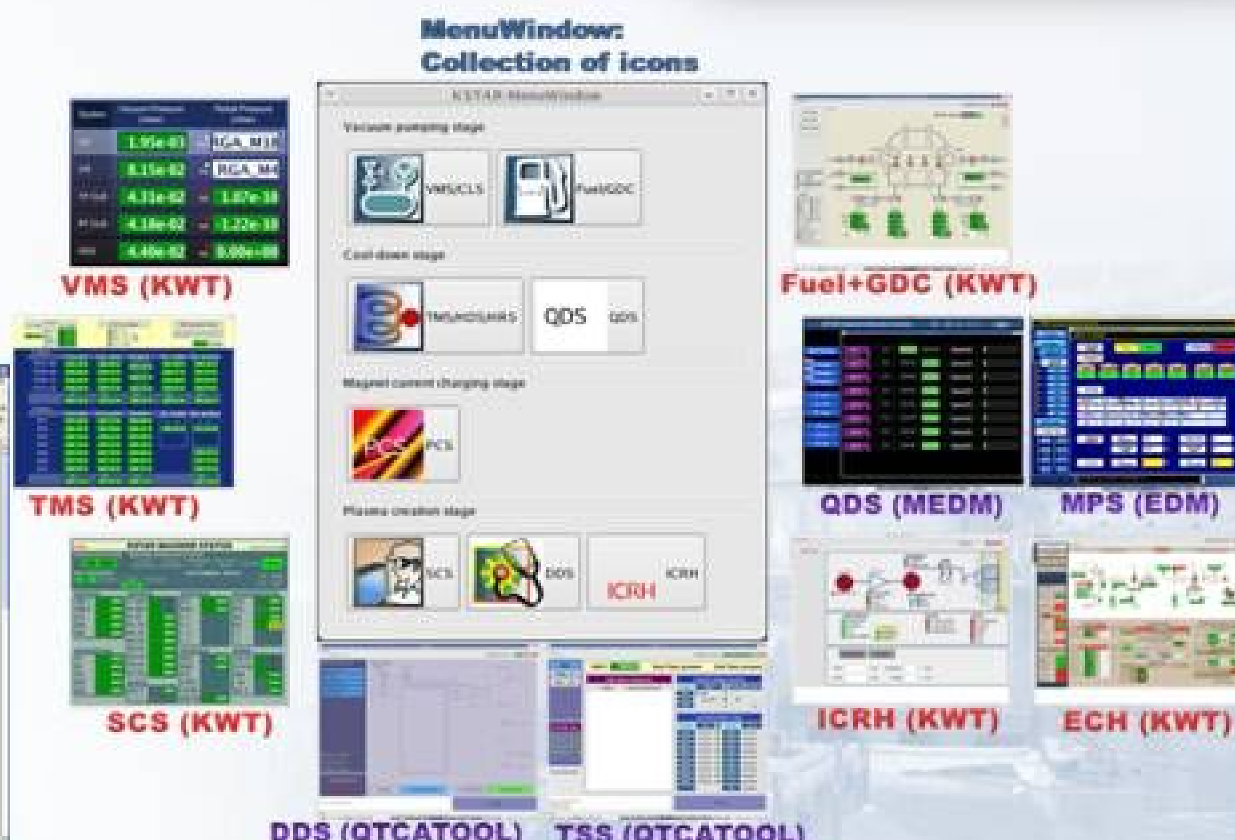
Data Visualization

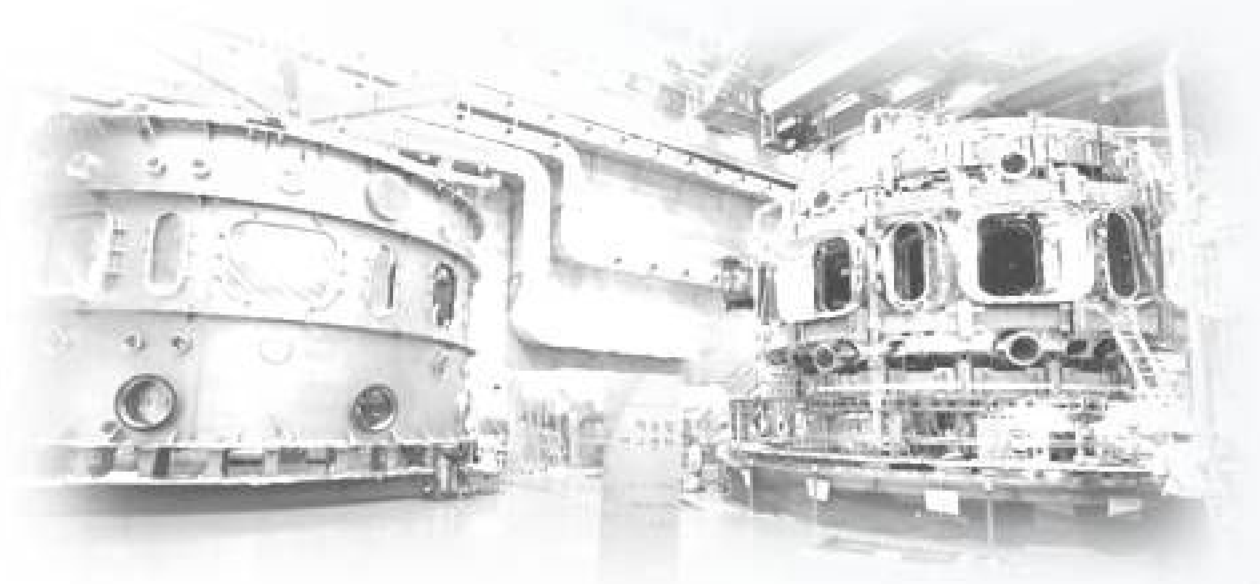
- Operator Interface
  - Developed panels : 154 first the 1st campaign
  - Development tool : Qt 4.3.1 Open source tool
- Data Visualization
  - Run-time Data Display : SinglePlot, MultiPlot
  - Experimental data display : jScope, Rtscope, Reviewplus, IDL/Matlab applications





3 Conclusions

- Evaluation of EPICS for Tokamak Control
- System Availability and Operational Parameters
- Improvement Plan



Evaluation of EPICS for Tokamak Control

- EPICS has proved its performance even in tokamak control system which has different operational requirements from particle Accelerator.
  - During the 1st plasma operation in KSTAR, the control system has successfully performed its missions of plant operation and discharge control.

- Wishes -
  - Bump-less restart
    To restart IOC during the machine operation may cause serious problems in some case.
  - Redundant IOC : difficult to build redundant system
  - Improvement in some applications such as "AutoSaveRestore"
  - Unsupported utilities
  - Etc.

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Availability & Operational Parameters

	2008	2009	2010
Experimental parameters			
• Peak TF field • Operation TF field • Flux • Ip • Plasma shape • Gas	• 1.5 T • 1.5 T • ~ 1 Wb • < 133 kA • Circular • H_2 (He for DC)	• 3.5 T • 1.5 T, 3.0 T • ~ 2 Wb • ~ 300 kA • Circular • H_2 (He for DC), D_2	• 3.5 T • 1.5 T, 2.0 T, 3.0 T • ~ 4 Wb • < 1 MA • Double null • H_2, D_2
Control			
Plasma control	• PF blip & start up • Ip, Rp , ne	• PF zero-crossing • Ip, Rp, ne	• IVC control • Ip, Rp, Zp, shape
Diagnostics			
Diagnostic systems	• MD/ MMWI/ ECE / Hα/ filterscope/ ViS . TV	• MD/ MMWI / ECE / Hα/ filterscope/ Vis. TV • PD / XCS / Soft X-ray / Reflect./ XCS (1 set) / Bolometer (resistive)	• MD / MMWI / ECE/ Hα/ filterscope/ Vis. TV • PD / XCS / Soft X-ray / Reflect. • TS/ Hard X-ray / Fast neutral / ECEI / IRTV/Fast Ion Loss Detector
Heating			
• ECH • ICRH • NBI • LHCD	• 0.5MW (84 GHz) • 0.03MW (30 MHz)	• 0.5MW (84 GHz) • 0.3MW (30 MHz)	• 0.5MW (84GHz) 0.5MW (110GHz) • 1 MW • 1 MW • 0.5 MW
In-Vessel System			
• In-vessel coil • PFC • Wall conditioning	 • Inboard limiter • Glow DC, RF DC	 • Inboard limiters • + boronization	• Vertical control • Divertor / limiters • Passive stabilizer • + PFC baking

Improvement Plan in Control System

1. Expansion of the Control System for Upcoming Plant Systems
   - Heating devices (NBI, LHCD, ECCD), In-vessel Components and Diagnostics
2. Improvement of Stability and Reliability
   - Still having some unstable action in CA gateway and Multiple IOCs
3. Management of Huge Data
   - For experimental data generated by many high-speed diagnostics
4. Establish the Remote Collaborative Environment
   - Plasma experiment performed by remote collaborators
   - KSTAR experiment data access outside laboratory
   - Remote operation room for ITER
5. Prepare for Longer Pulse Operation

Thank you for your Attention !

At the beginning of the KSTAR cool-down (April. 3, 2008)