Design Aspects of Personnel Safety and Interlock System for PAL-XFEL

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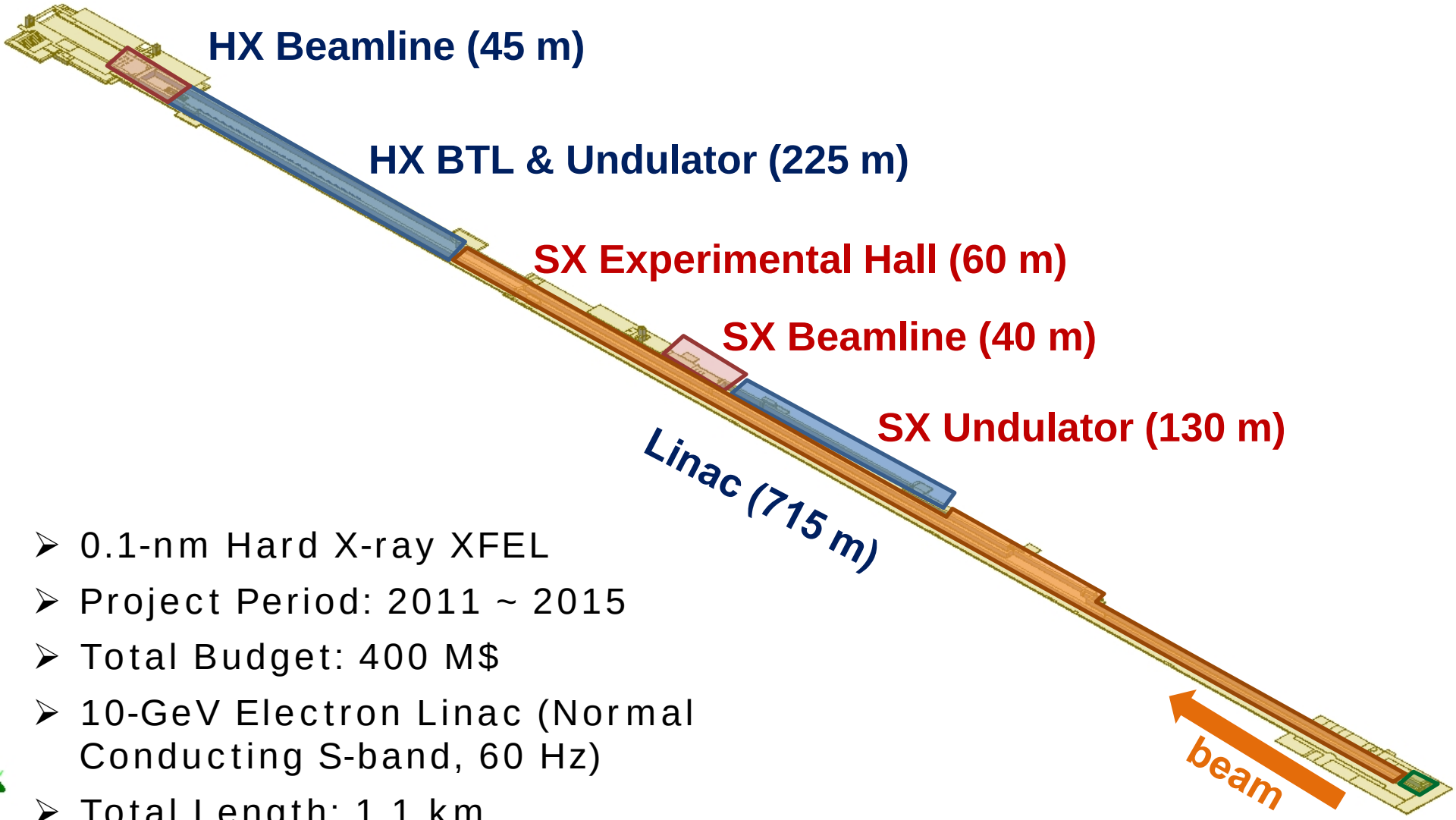
Outline

- **Introduction**
  - **Long long facility, PAL X-ray Free Electron Laser**
- **Design Considerations required for PSI System**
  - **PSI – Personnel Safety & Interlock**
- **How embodying in PSI System**
- **Radiation Monitoring System**
- **Summary**

Introduction

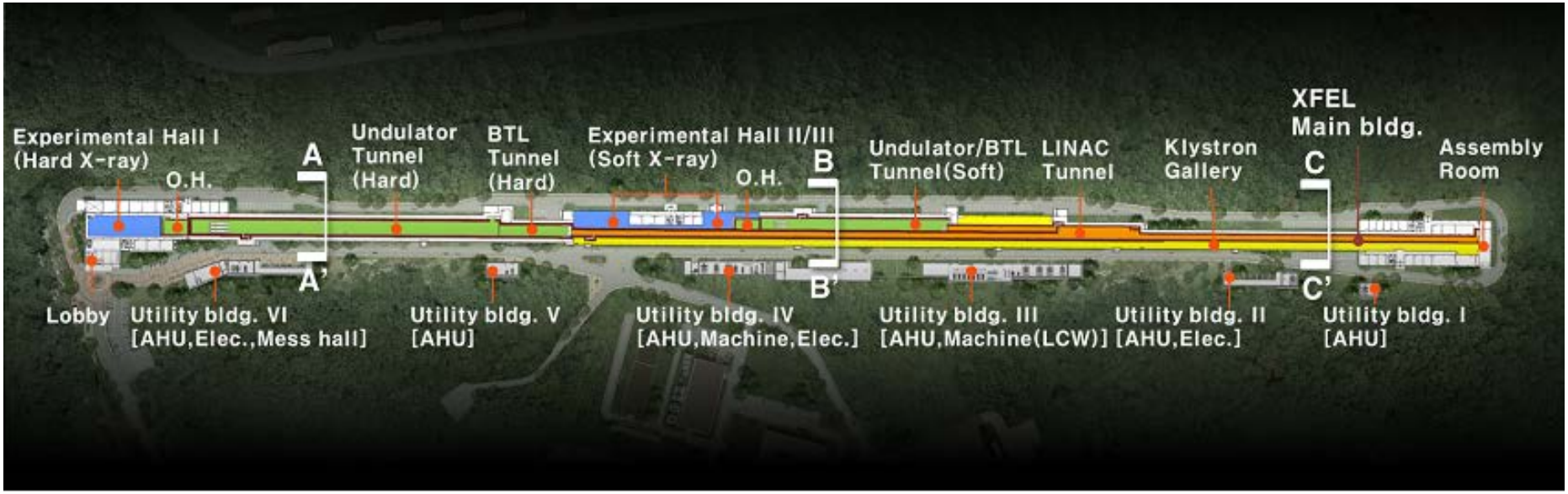
Pohang Light Source II + PAL X-ray Free Electron Laser

PAL X-ray Free Electron Laser & Building Layout

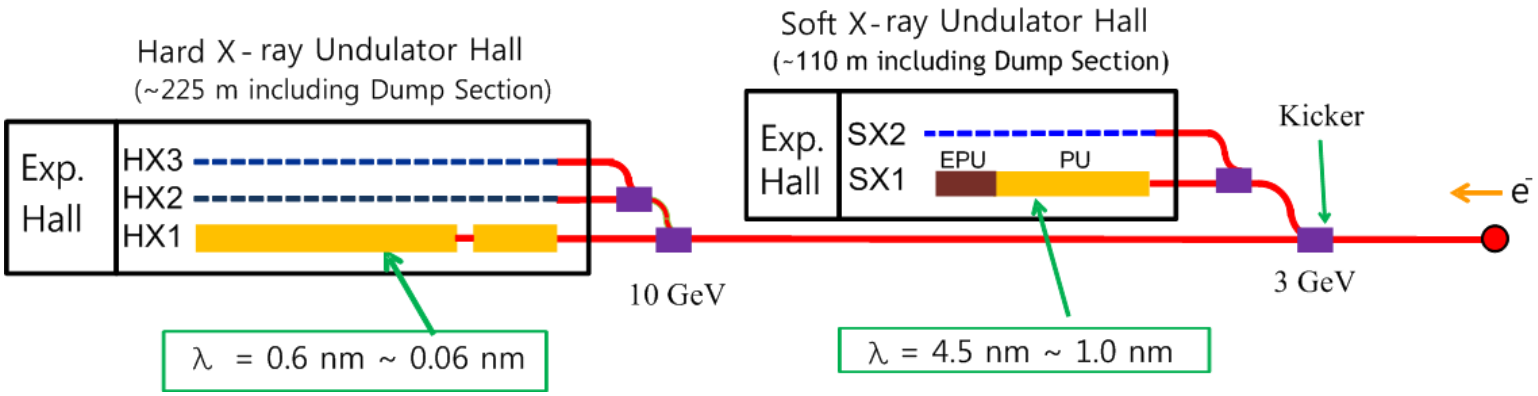


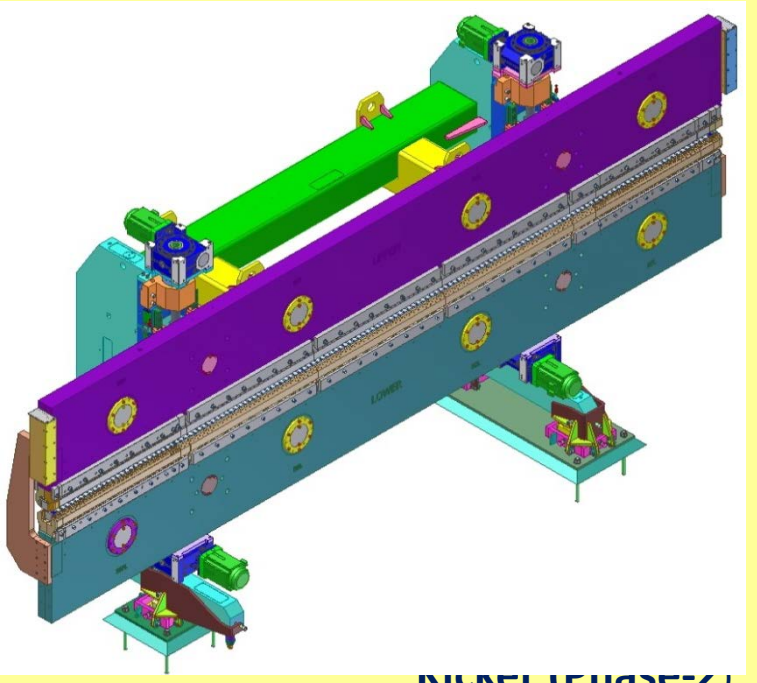
- 0.1-nm Hard X-ray XFEL
- Project Period: 2011 ~ 2015
- Total Budget: 400 M$
- 10-GeV Electron Linac (Normal Conducting S-band, 60 Hz)
- Total Length: 1.1 km

Layout and Building Structure



Undulator Lines





Kicker (Phase-2)

Undulator Line	HX1	SX1
Wavelength [nm]	0.06 ~ 0.6	1 ~ 4.5
Beam Energy [GeV]	4 ~ 10	3.15
Wavelength Tuning [nm]	0.6 ~ 0.1 (energy) 0.1 ~ 0.06 (Gap)	4.5 ~ 3 (Beam energy) 3 ~ 1 (Undulator gap)
Undulator Type	Planar variable gap, out-vacuum	Planar + APPLE II variable gap, out-vacuum
Undulator Period / Gap [mm]	26 / 8.3	35 / 8.3
Operation Mode	SASE (2016) Self-Seeding (2017)	SASE

Today at PALXFEL

Linac Tunnel

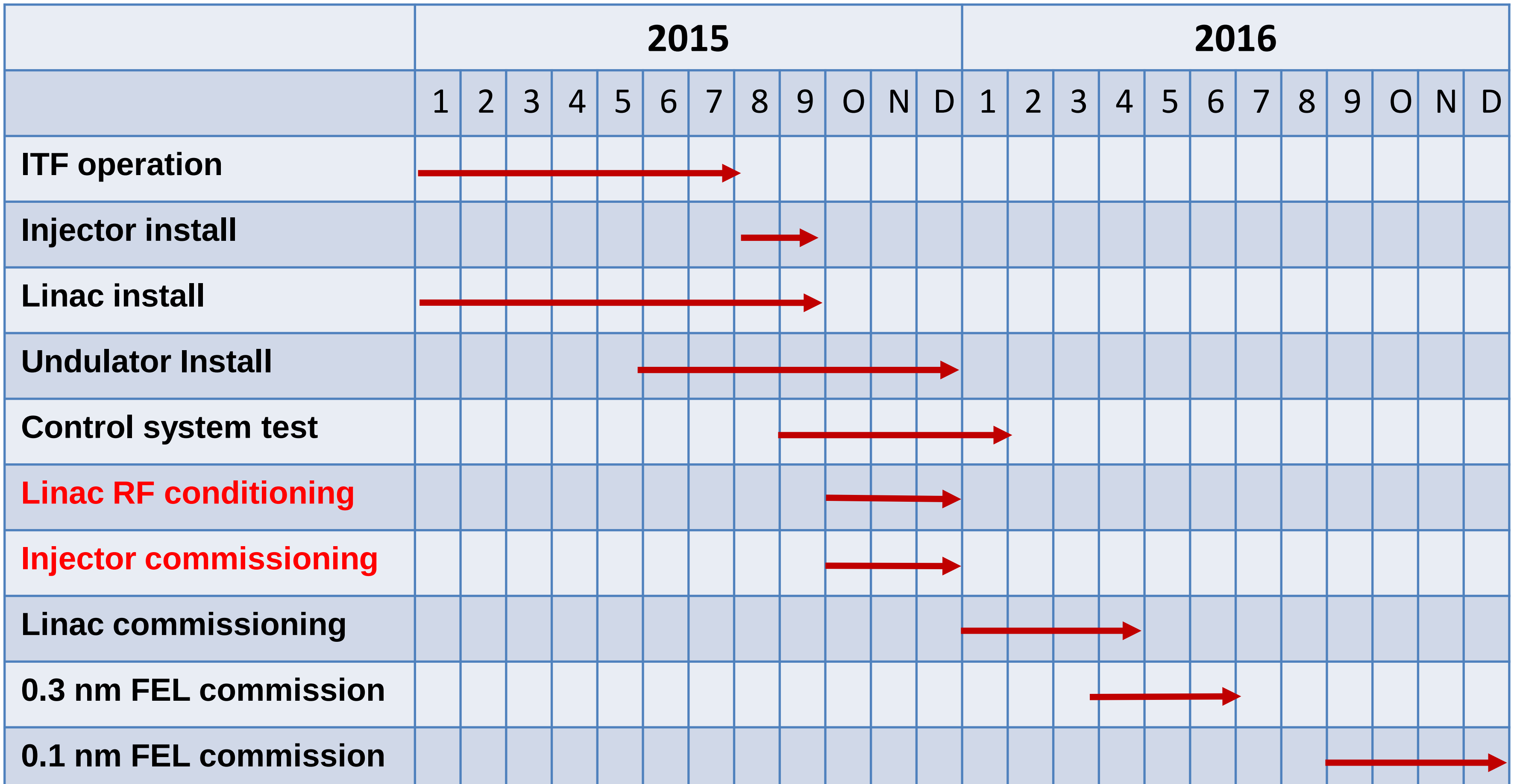
Klystron Gallery

Undulator & 250 m-long Hall

Experimental Hall

Install and FEL Commissioning

- Linac RF conditioning / Injector commissioning 2015. 10 ~ 2015. 12
- 1st FEL commissioning for 0.3 nm HX @10 Hz 2016. 01 ~ 2016. 06
- 2nd FEL commissioning for 0.1 nm HX @10 Hz 2016. 09 ~ 2016. 12



❖ HX undulator hall should be accessible during the Linac RF conditioning

Radiation Safety System at PAL

- **Developing Safety Policy**
- **Shielding Analysis including activity estimation**

Active

- **Personnel Safety & Interlock System**
- **Radiation Monitoring System for facility and environment**

- **To secure Personnel and environmental safety from PLS II and PALXFEL and small e accelerators**

Passive

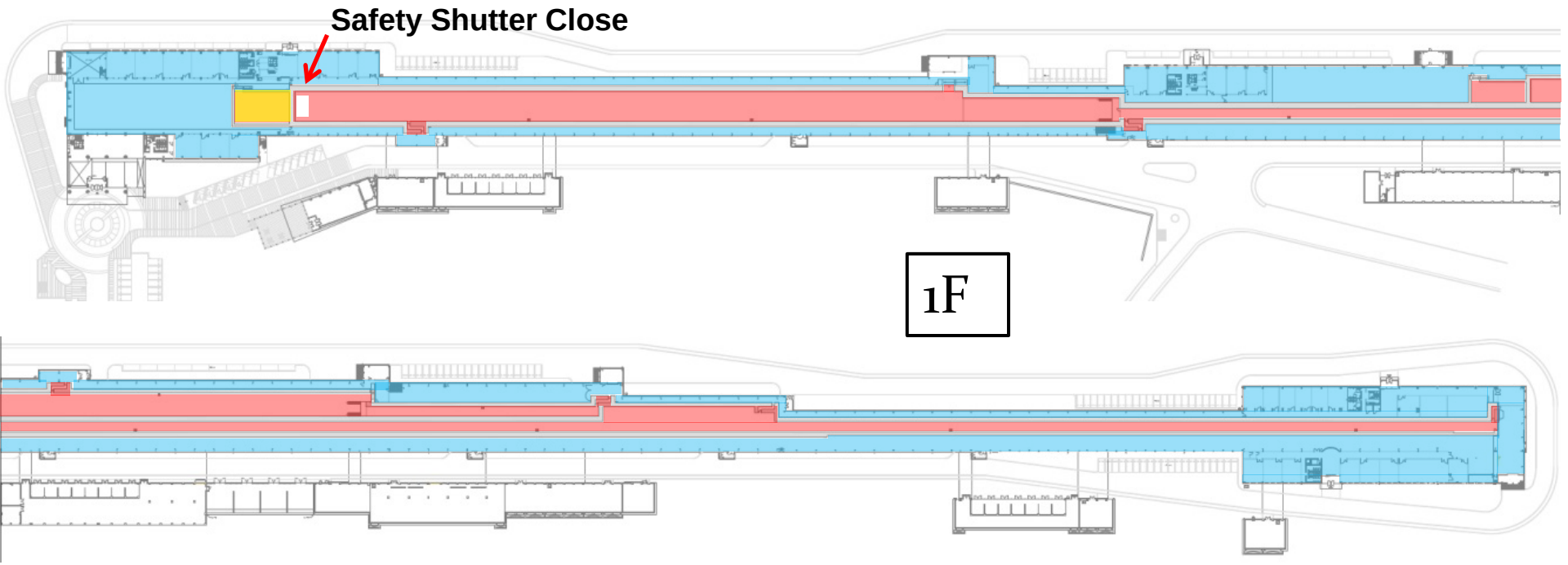
- **Personal Dosimetry with OSLN**

Area Classification of PAL-XFEL

High Radiation Area (Radiologically Controlled Area after the machine off)

Radiologically Controlled Area

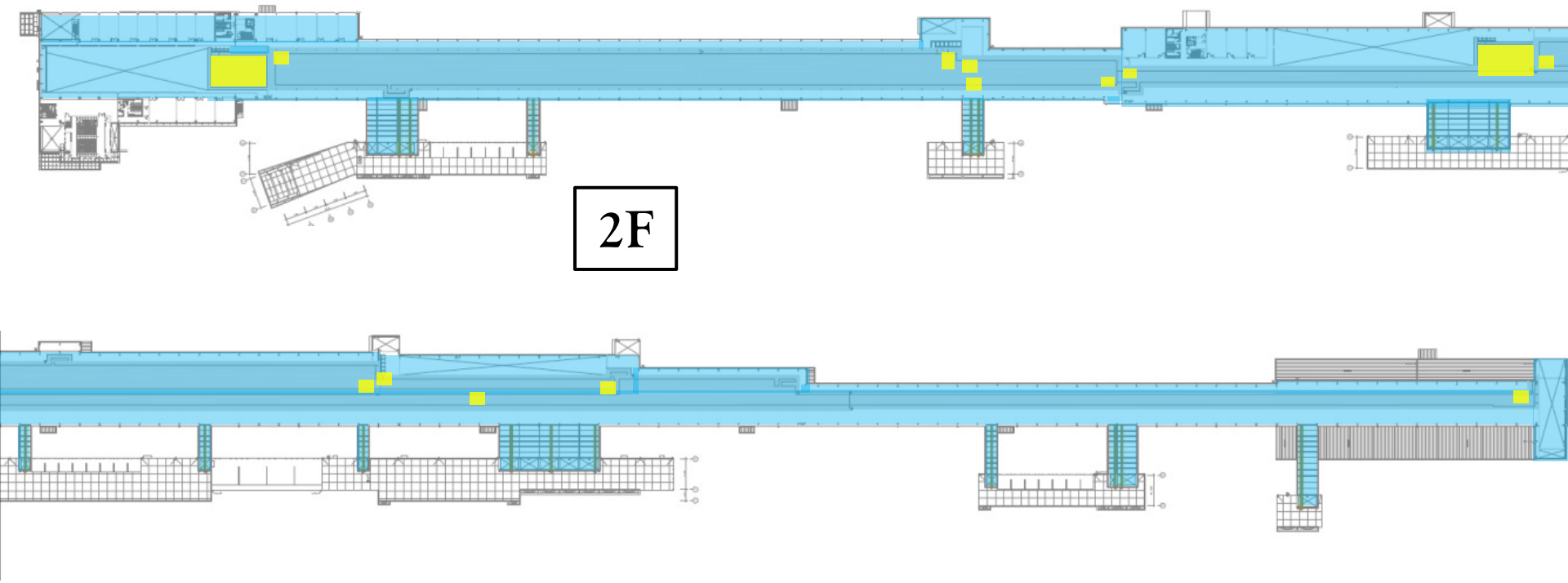
Generally Controlled Area



Area Classification of PAL-XFEL

Radiologically Controlled Area (Near the duct outlet. Fence installation)

Generally Controlled Area



Design Considerations for PSI system

Radiation Hazards to be considered

- **Interaction of electrons (240 W, 10 GeV) with accelerator and beam line components generates:**
  - **Bremsstrahlung photons**
  - **Neutrons**
  - **Gas Bremsstrahlung (no serious at PALXFEL)**
  - **Muons at forward angle (no serious at PALXFEL)**
- **X-ray generated from the undulator:**
  - **Spontaneous radiation**
  - **Coherent (FEL) radiation**
  - **(very narrowly-collimated beam)**

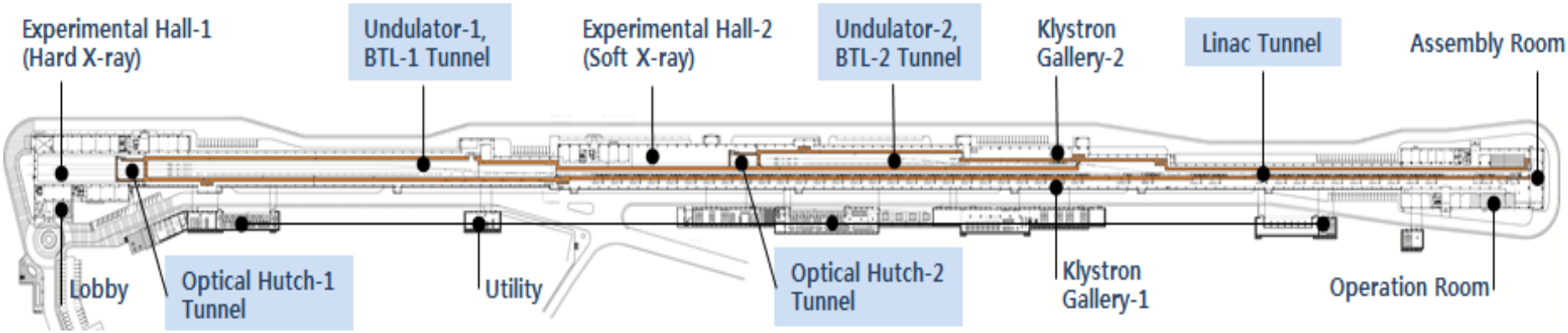
Design Aspects of Personnel Safety Interlock (PSI) System

1. **To follow the fundamental requirements of PAL PSI system**
2. **To protect the accidental hazards at XFEL facility**
3. **Beam should be down after unscheduled beam loss of one or two beam pulses (120 W /60 pps = 2 W)**

   “Kill after one beam loss”
4. **Fast response (PSIS) & Slow response (RMS)**
5. **To consider Structure Condition (on ground) and Hazard Properties (Human near the line of sight of e^-)**

Fundamental Requirements of PAL Personnel Safety Interlock (PSI) System

1. **Reliability (one any systematic, non-critical error in one year operation)**
2. **Redundancy (two or three ways from sensor to actuator)**
3. **Fail-safe (to secure safety at any condition)**
4. **Testing feature**
5. **Simplicity**
6. **Self-protection**

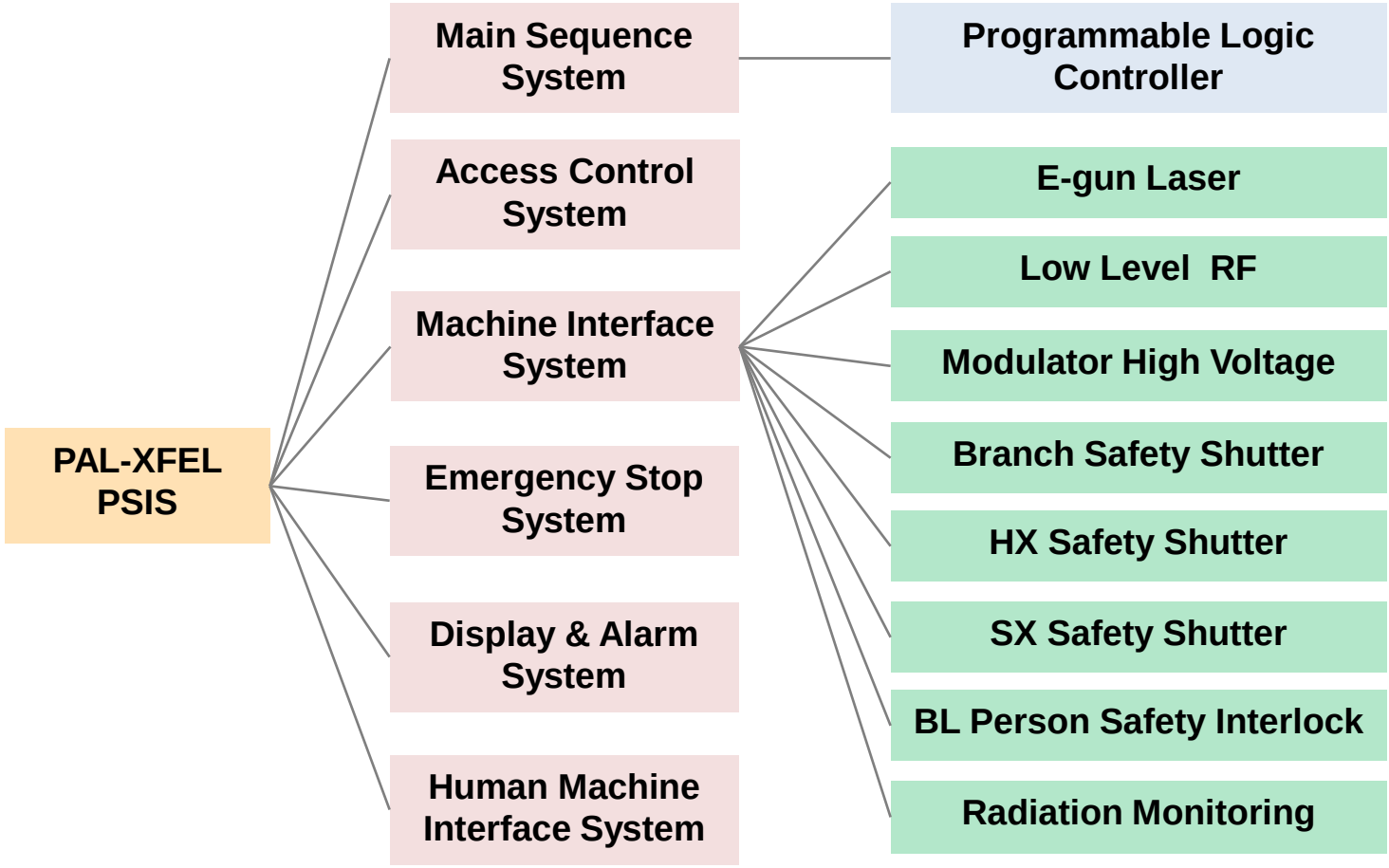


Long, long and long facility !!!

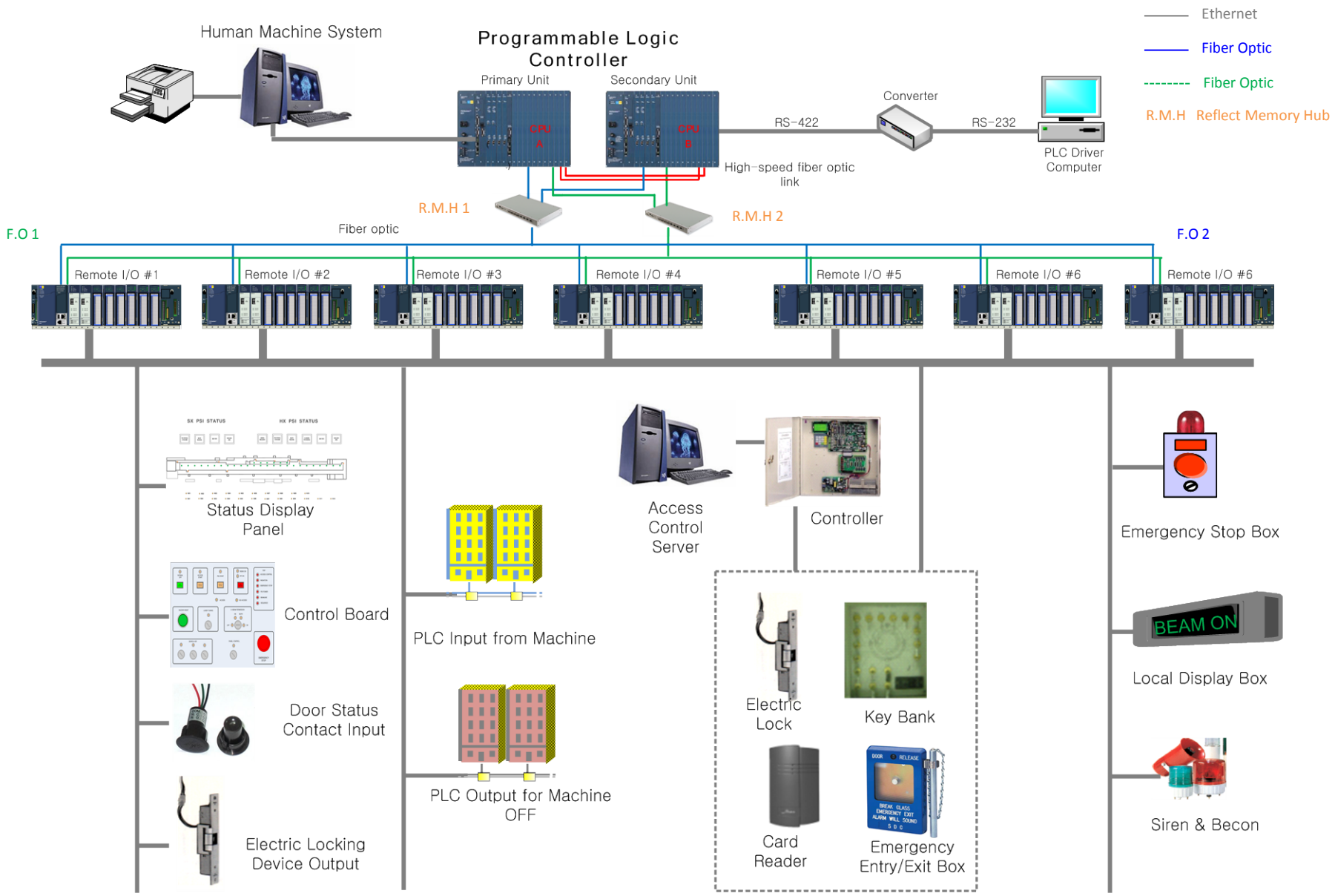
1. 60 Hz (two beam bunch at every 16.6 msec)
   : Fast response!!
2. long searching procedure : 1 km x 4km/h = 15 min)

EUROXFEL ? **ILC ?**

Composition of PSI System

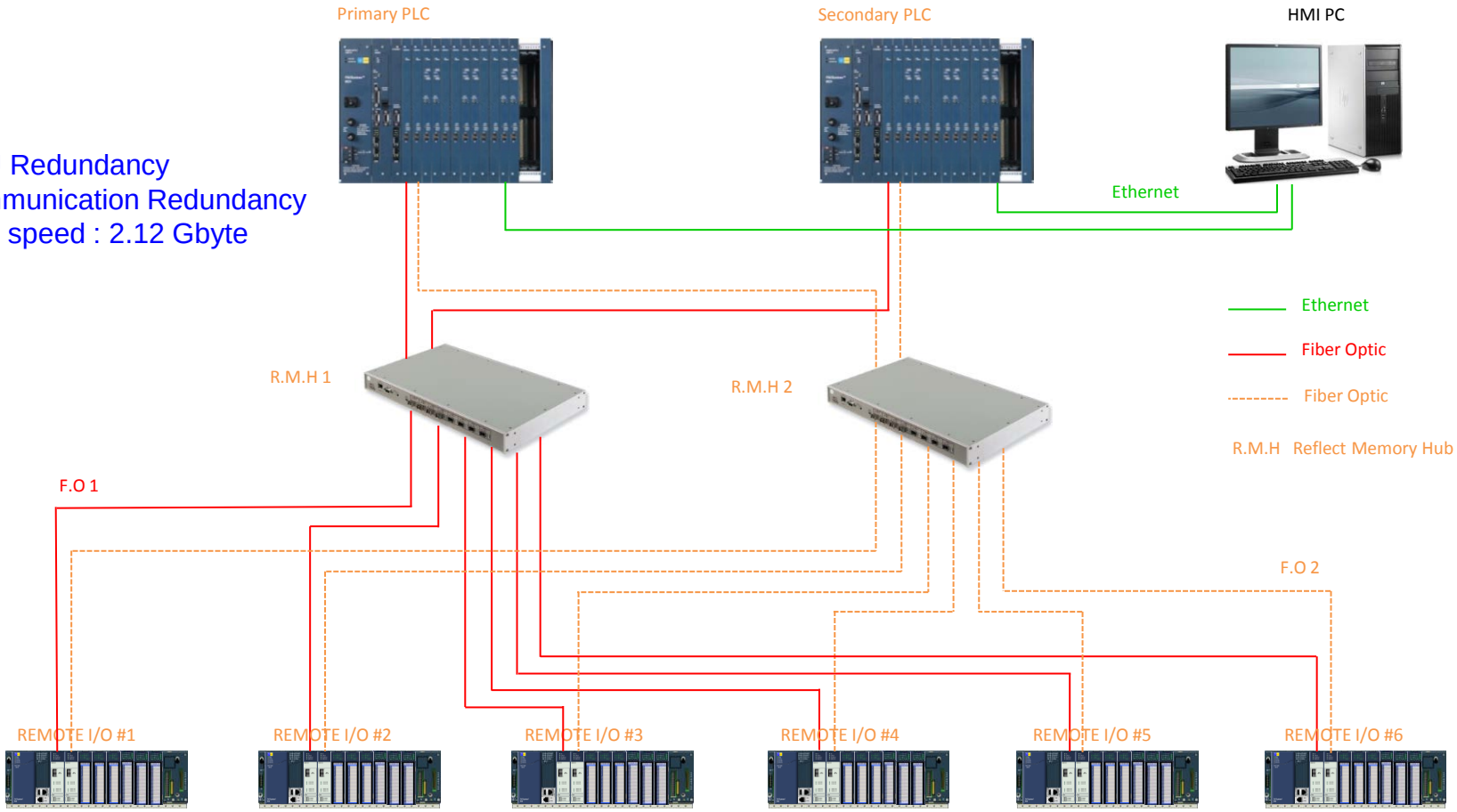


Configuration of PSI System

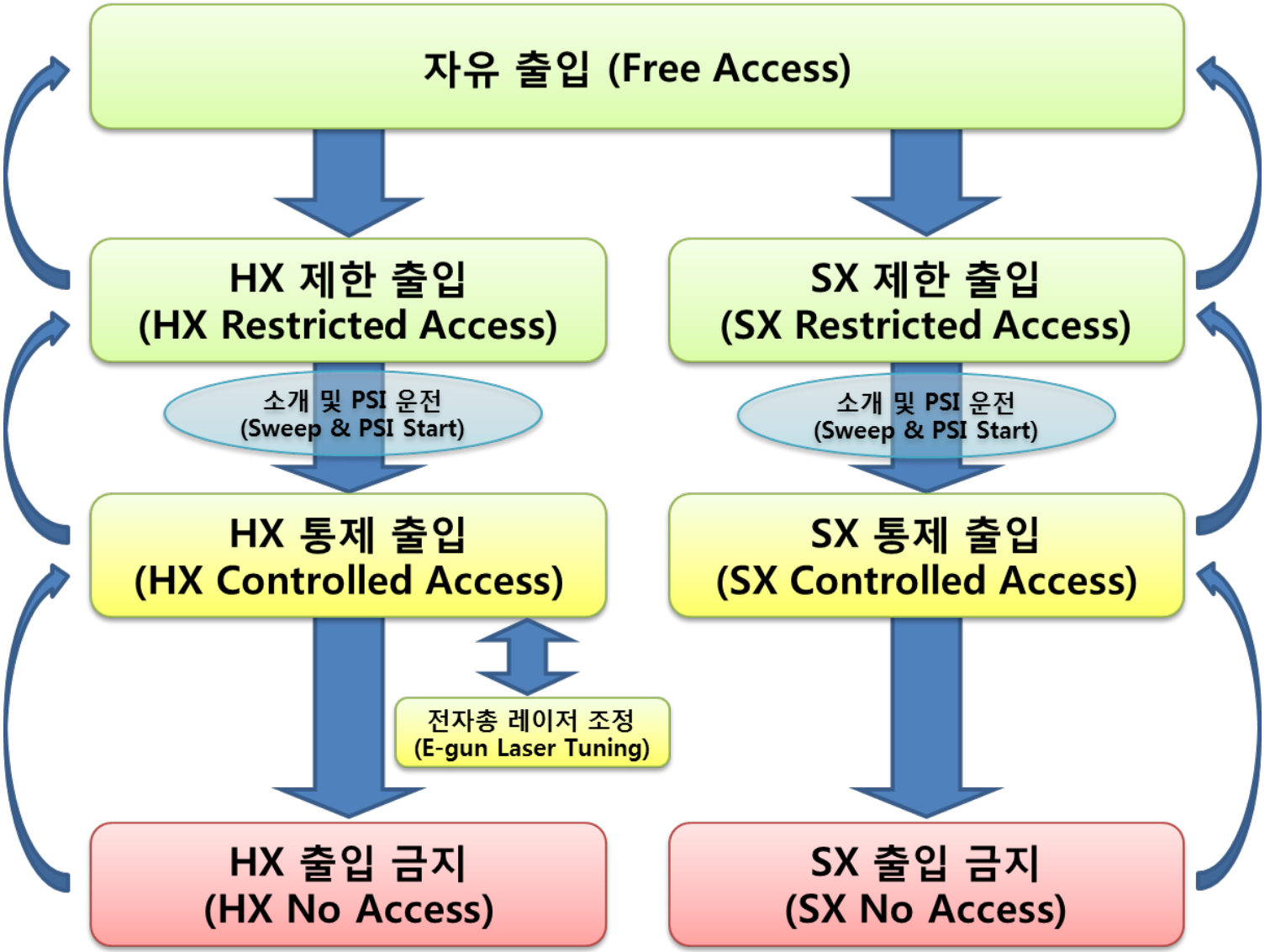


Main Sequence Control System

- CPU Redundancy
- Communication Redundancy
- High speed : 2.12 Gbyte



Access Control Mode (4 steps)

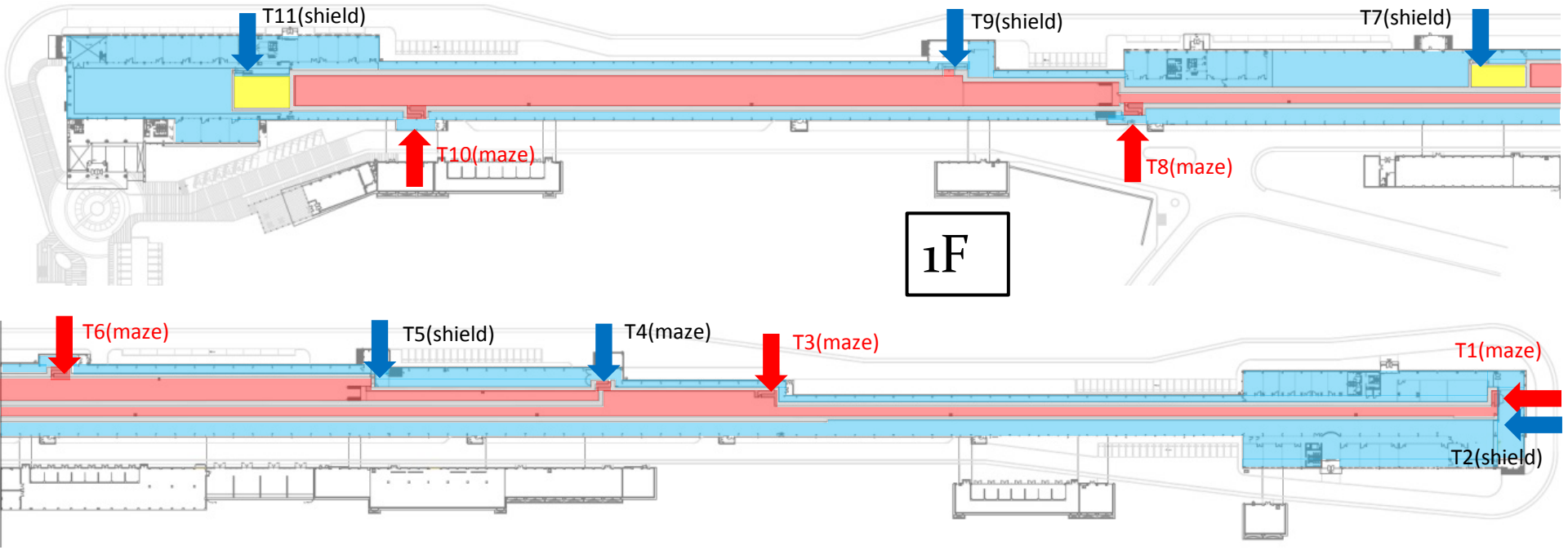


Doors for PAL-XFEL Tunnel Access

High Radiation Area (Radiologically-Controlled Area after machine OFF)

Radiologically-Controlled Area

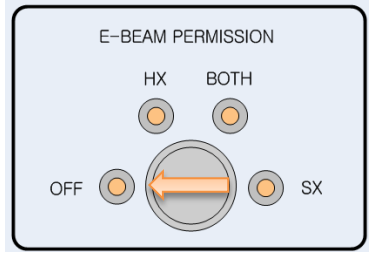
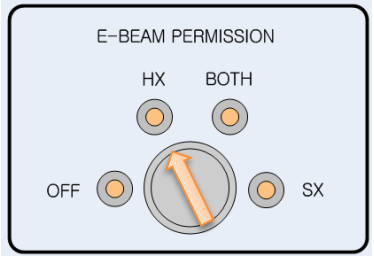
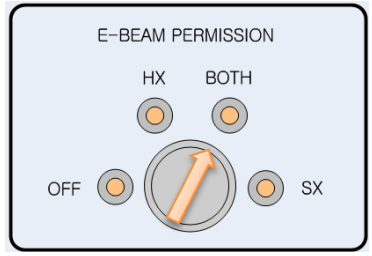
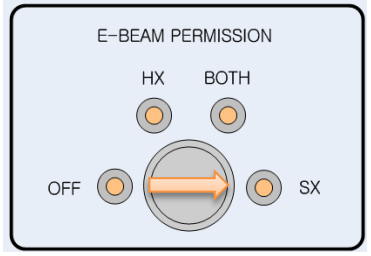
Generally-Controlled Area



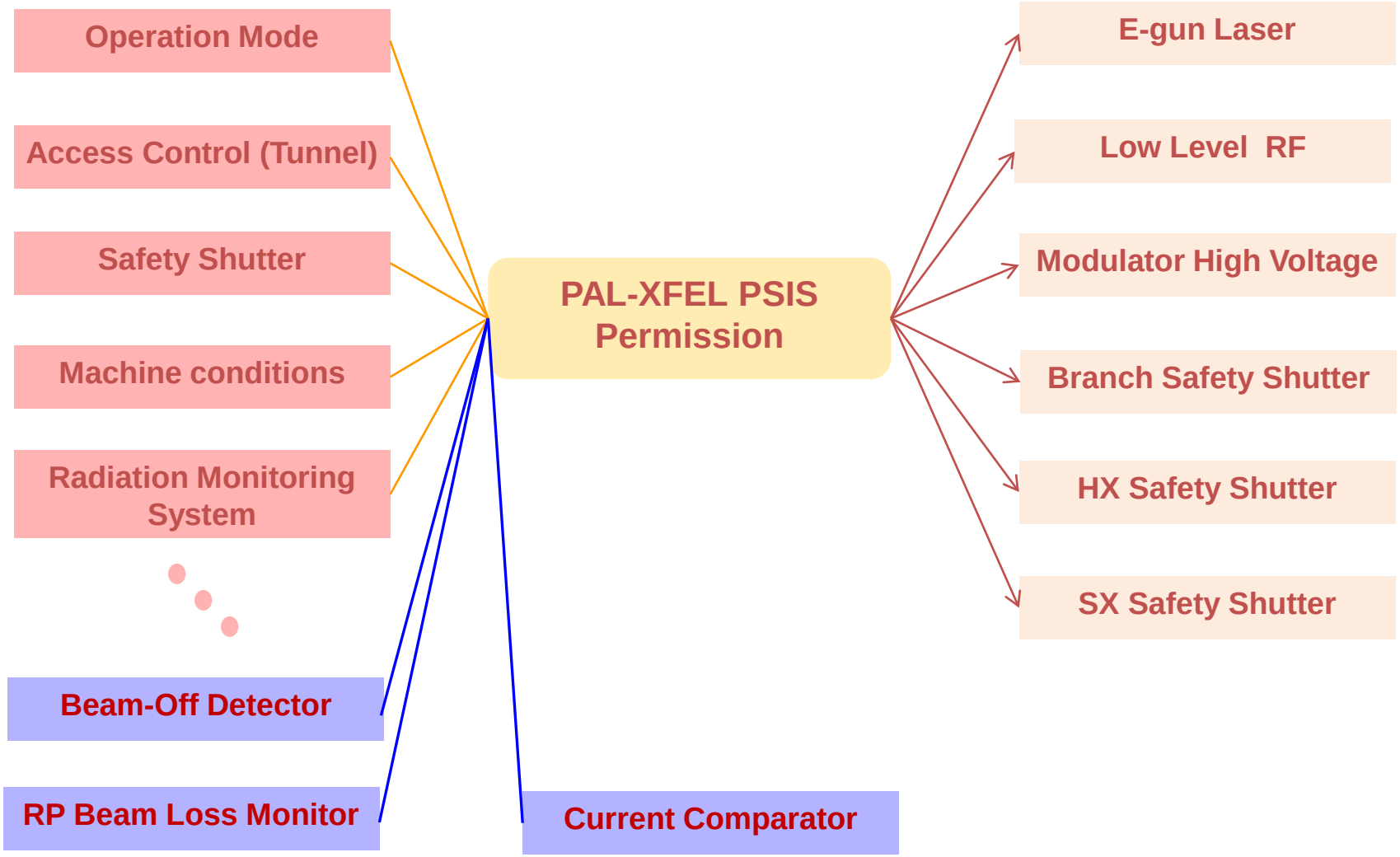
Level 1 door : Using Personal Key at Local Keybox

Level 2 door : Using Key at Remote Keybox in Control room

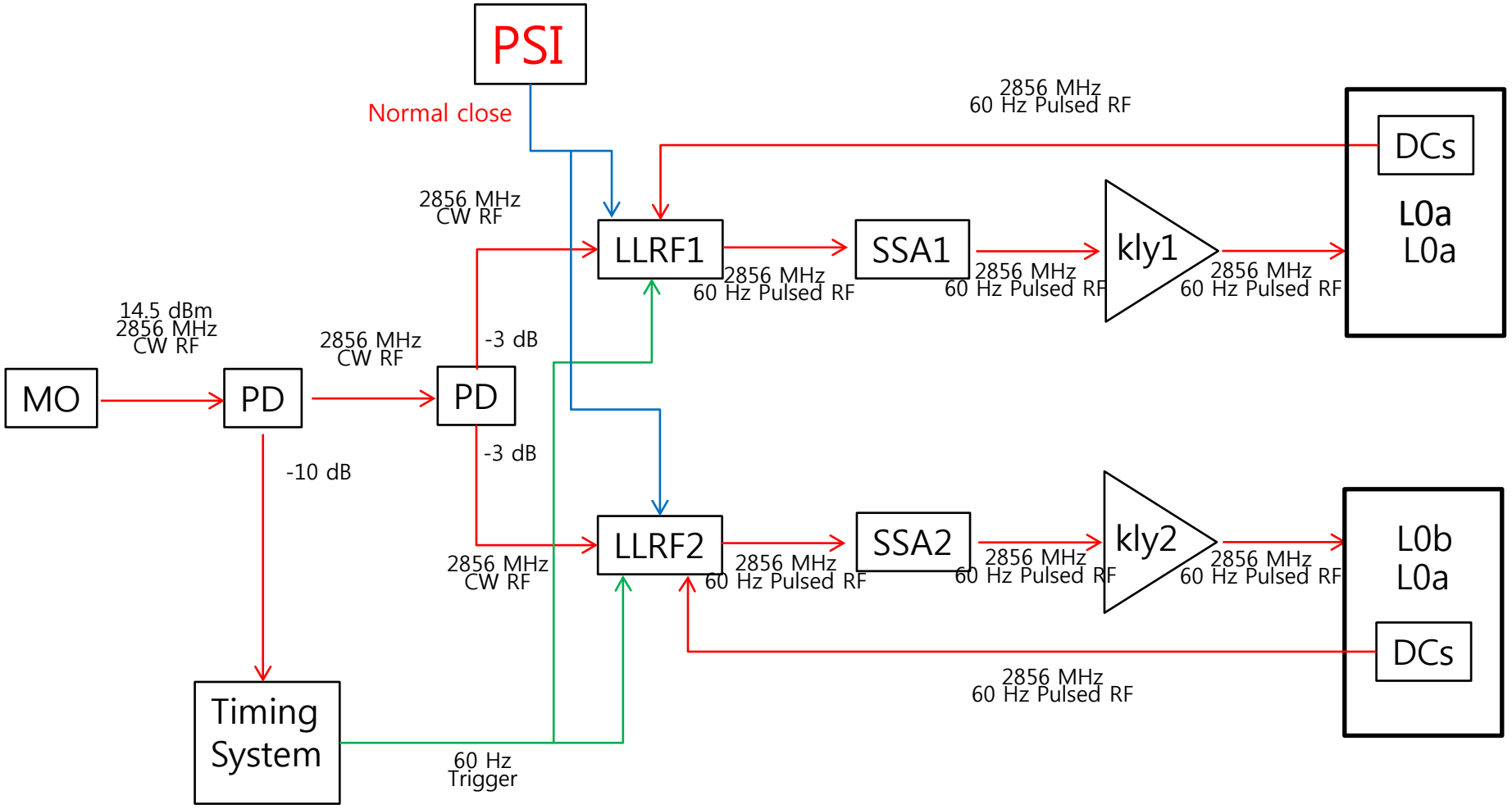
Beam Operation Modes

Beam and MIS devices	KEY Selection	HX Mode Condition	SX Mode Condition
BEAM OFF Laser Shutter Close Branch SS Close Branch magnet OFF		FREE ACCESS RESTR'D ACCESS CONTR'D ACCESS NO ACCESS	FREE ACCESS RESTR'D ACCESS CONTR'D ACCESS NO ACCESS
HX ONLY Laser Shutter OPEN Branch SS Close Branch magnet OFF		NO ACCESS	RESTR'D ACCESS CONTR'D ACCESS NO ACCESS
HX + SX (Both) Laser Shutter OPEN Branch SS OPEN Branch magnet ON		NO ACCESS	NO ACCESS
SX ONLY Laser Shutter OPEN Branch SS OPEN Branch magnet ON		NO ACCESS	NO ACCESS

Example: Machine Interface Interlock Function Process

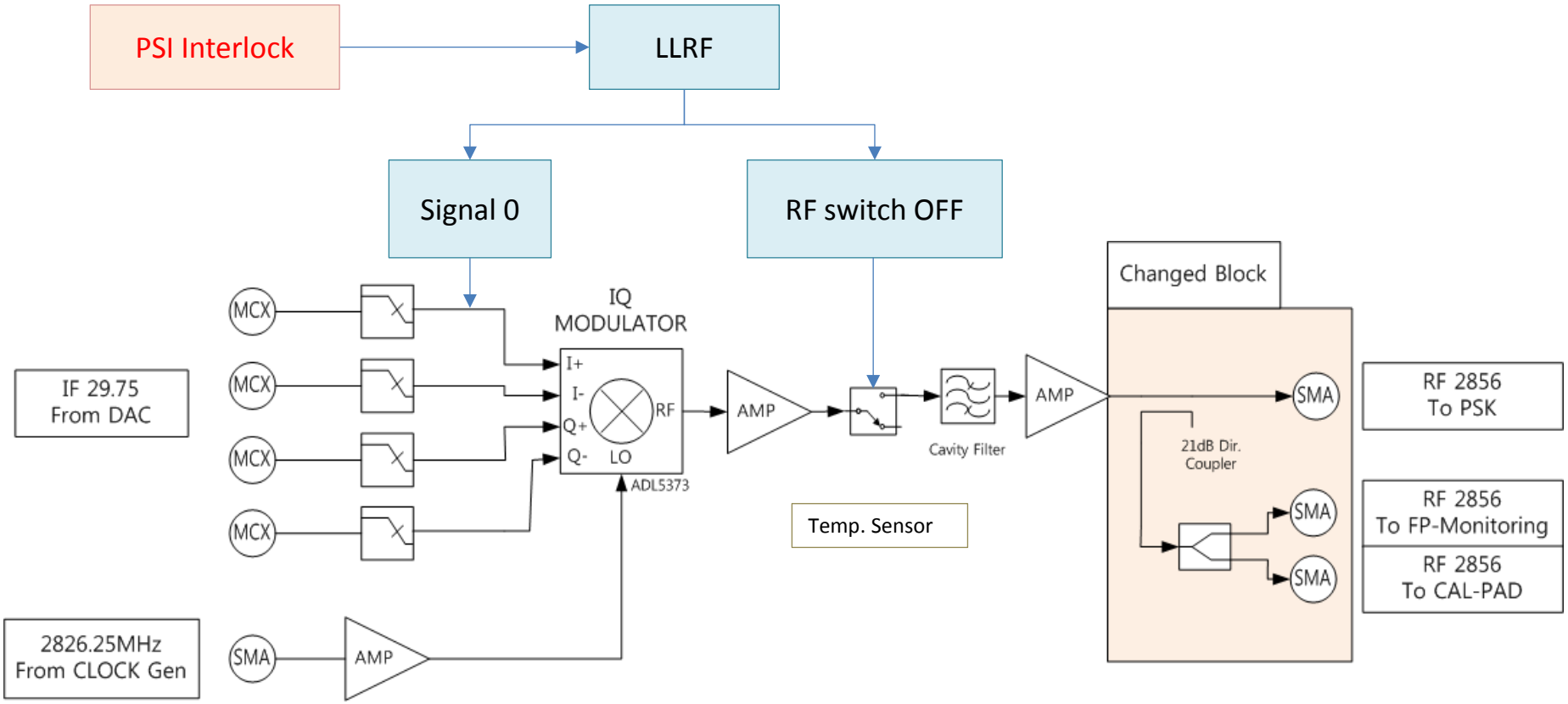


Machine Interface:
– LLRF of Modulator



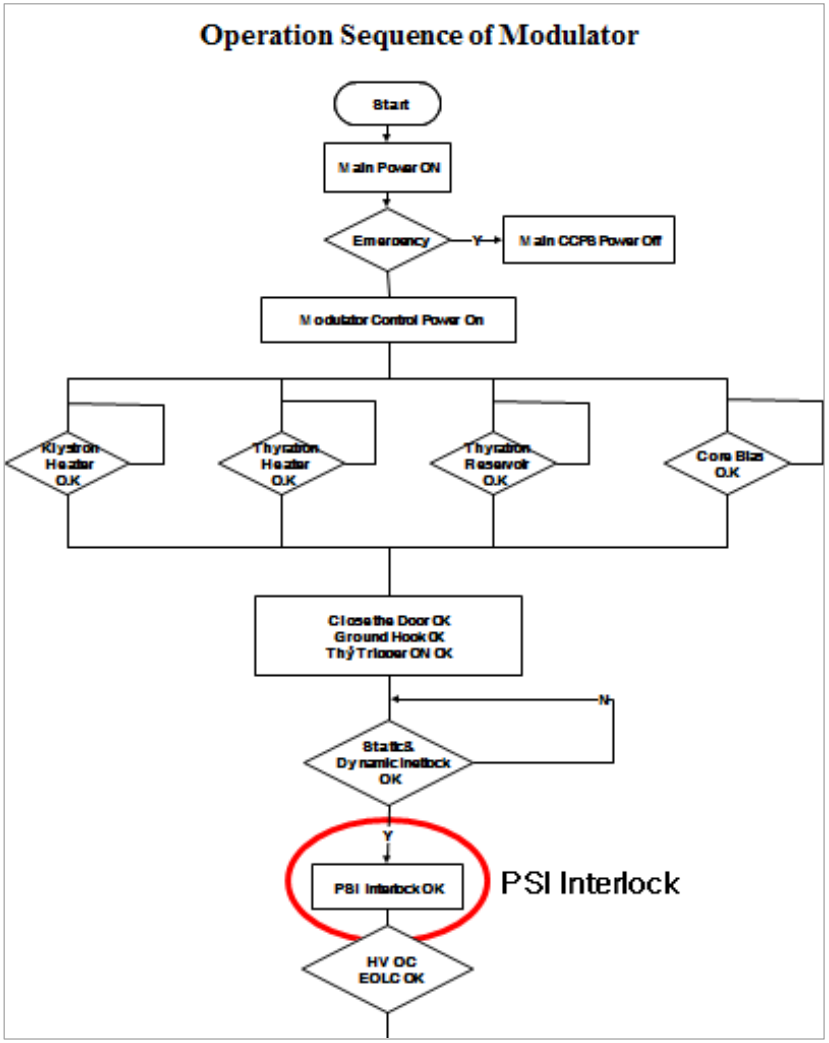
*MO: Master oscillator, PD: Power divider, DCs: Directional couplers

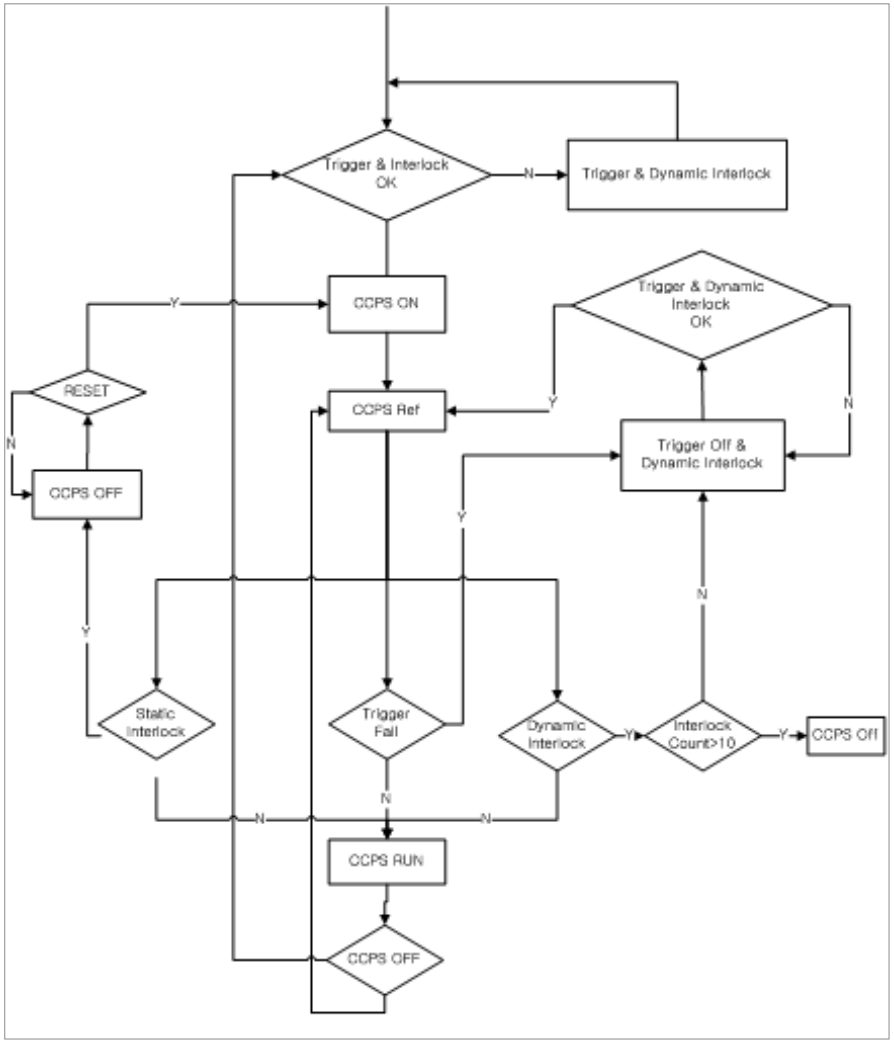
Machine Interface:
– LLRF of Modulator



Machine Interface:

– Modulator High Voltage Power Supply (HX or SX RF ON/OFF)

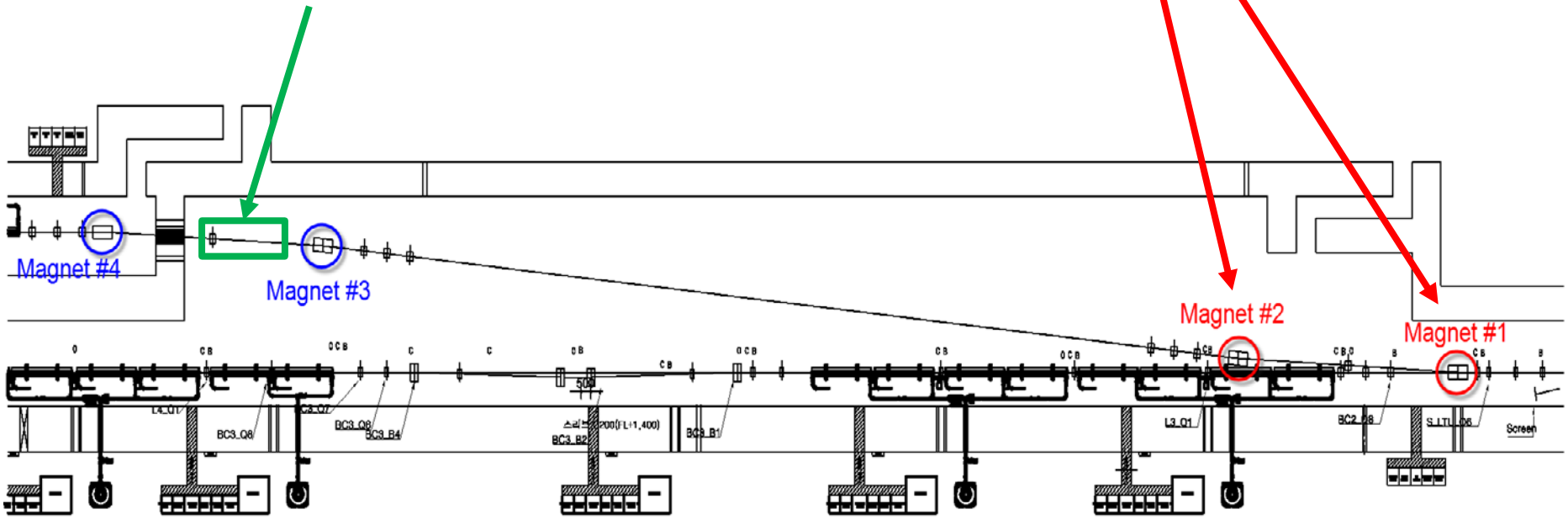




Modulator Operation Sequence

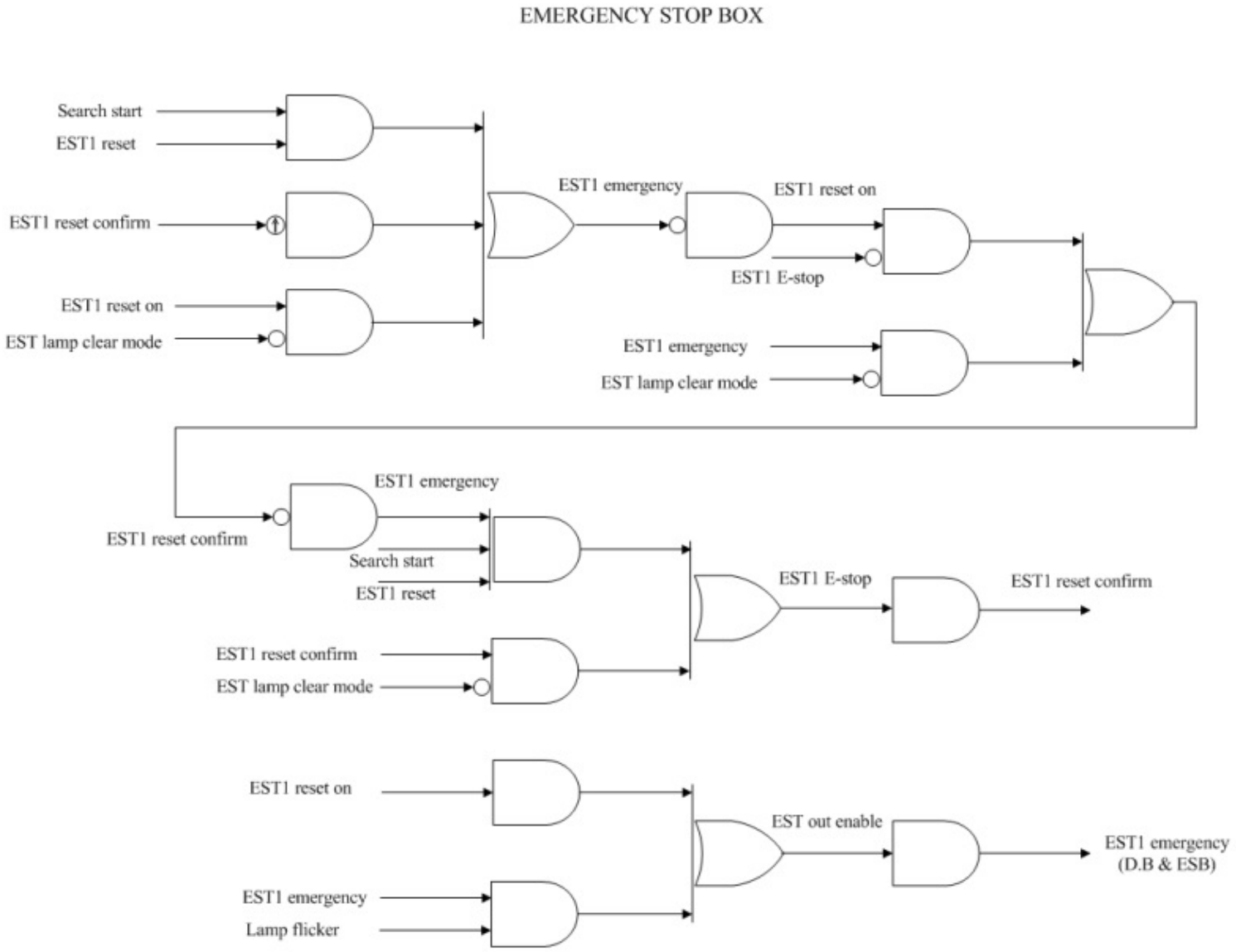
Machine Interface:
– Branch Magnet, Branch Shutter

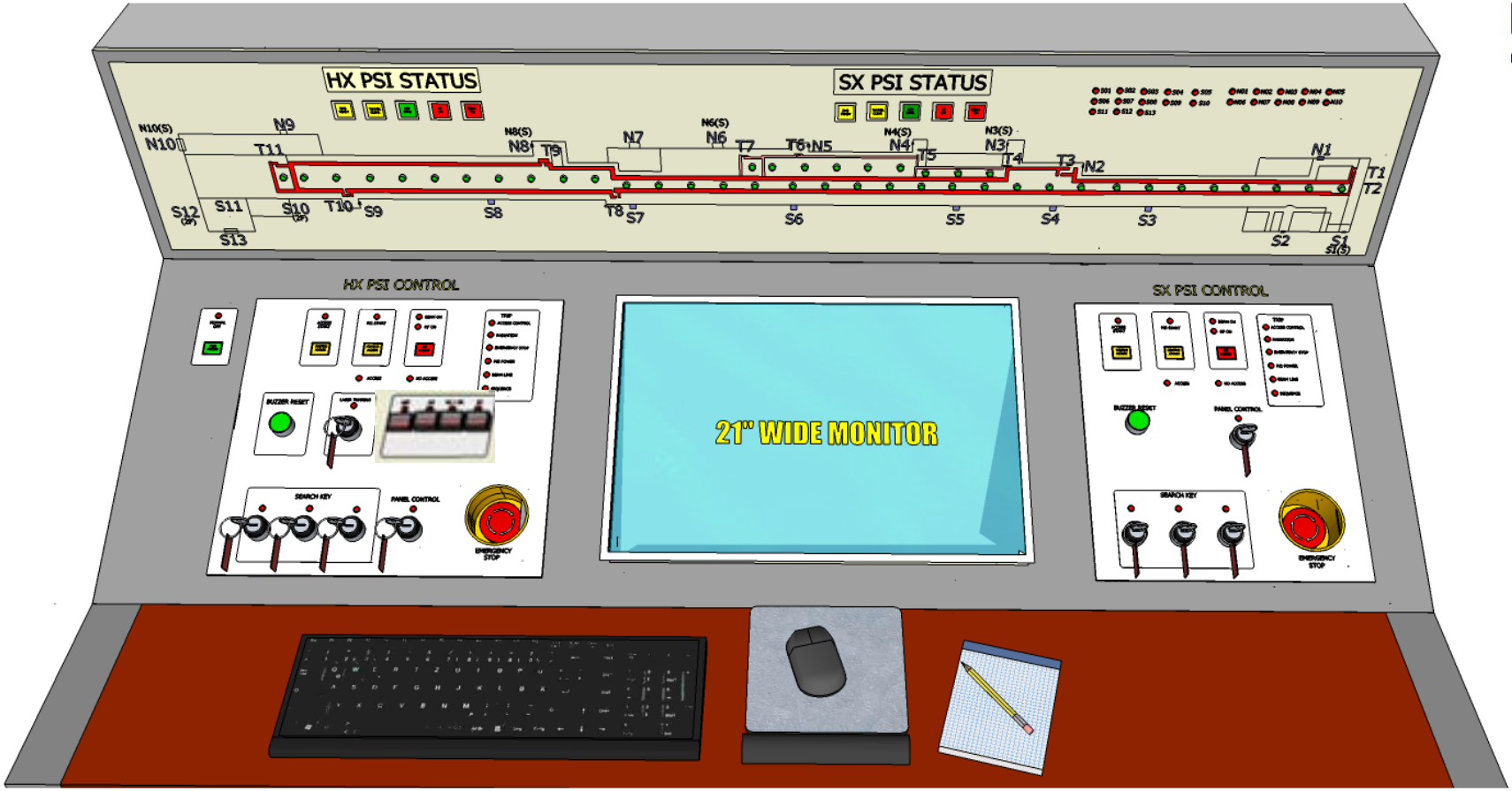
- **Branch Magnet P/S (SX e-beam ON/OFF)**
  - One power supply supports Magnet #1, #2 in serial line
- **Branch Shutter (SX e-beam ON/OFF)**
  - Downstream of Magnet #3

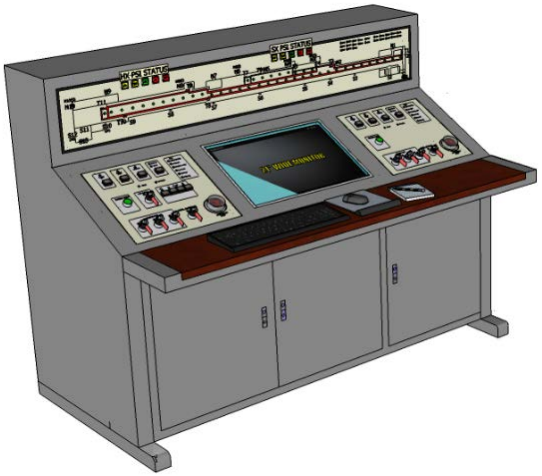


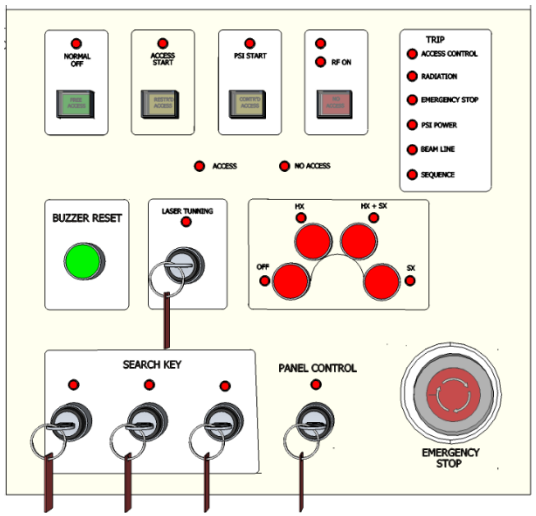
PAL-XFEL SX Branch

Flow chart example for ladder logic design




HX PSI STATUS
SX PSI STATUS
HX PSI CONTROL
SX PSI CONTROL
21" WIDE MONITOR
BUZZER RESET
SEARCH KEY
PANEL CONTROL
EMERGENCY STOP

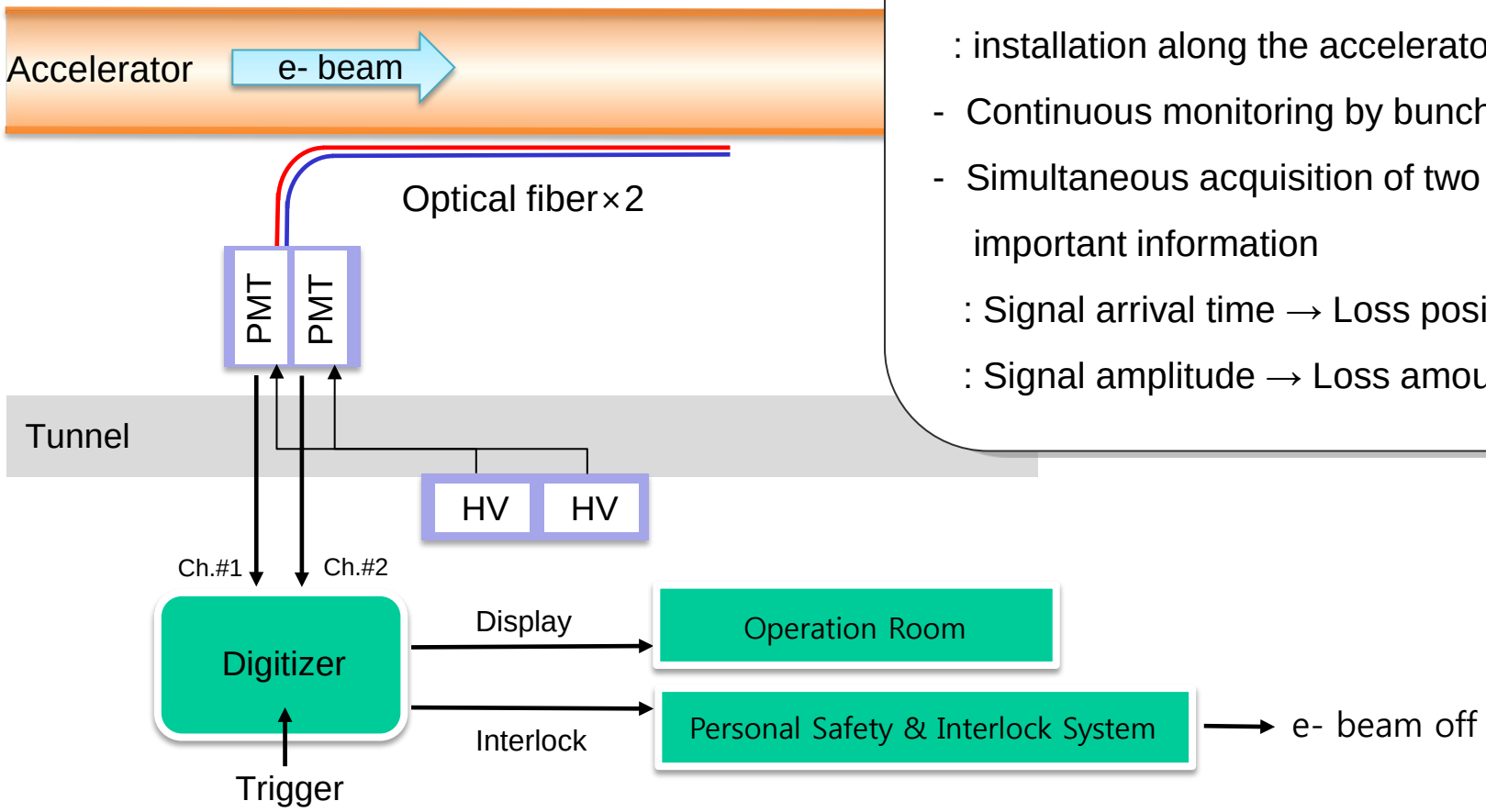



NORMAL OFF
ACCESS START
PSI START
RF ON
TRIP
ACCESS CONTROL
RADIATION
EMERGENCY STOP
PSI POWER
BEAM LINE
SEQUENCE
ACCESS
NO ACCESS
BUZZER RESET
LASER TUNNING
HX
HX + SX
OFF
SX
SEARCH KEY
PANEL CONTROL
EMERGENCY STOP

New devices as Beam Containment System

Beam Loss Monitor based on Cherenkov radiation in Optical Fiber

Details in
Dr. Jung's Presentation



Advantage of fiber-based BLM

- Long coverage
  : installation along the accelerator
- Continuous monitoring by bunches
- Simultaneous acquisition of two important information
  : Signal arrival time → Loss position
  : Signal amplitude → Loss amount

Beam-Off Detector using a proportional counter

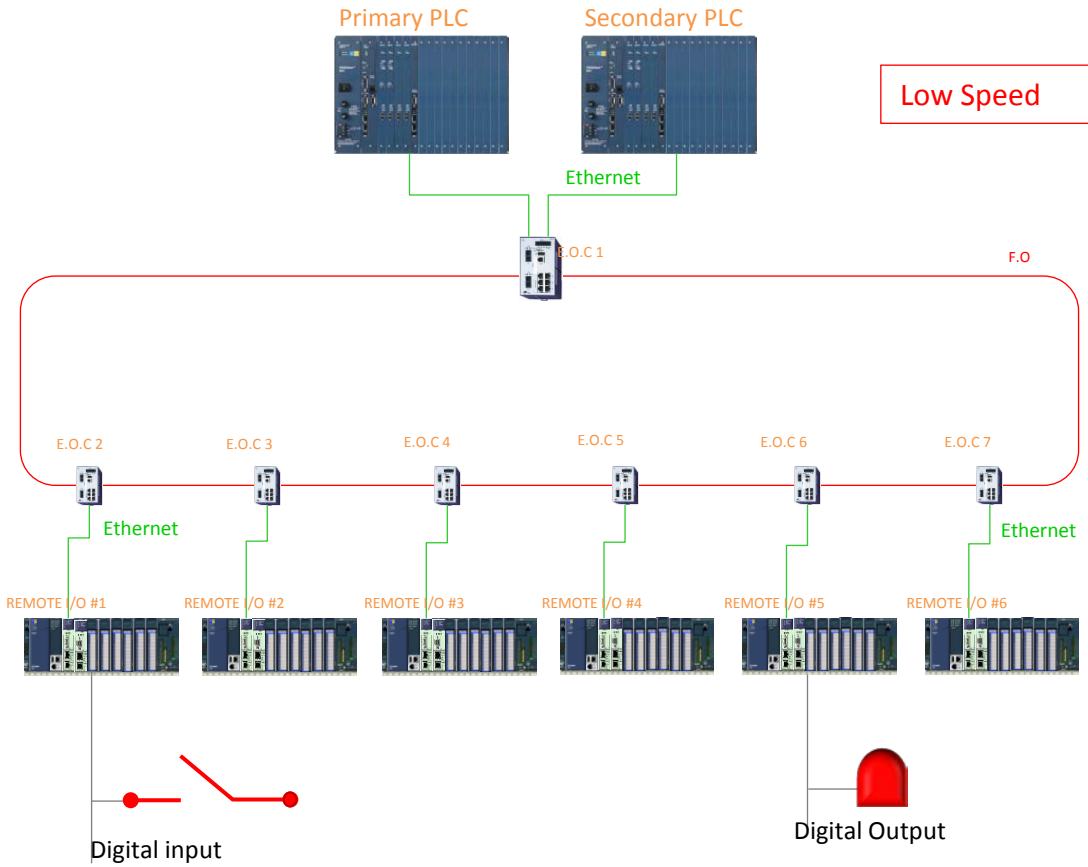
Details in
Dr. Jung's Presentation

BOD : Toshiba E6876-600 proportional counter


Kill after one beam loss

Main Sequence Control System Communication Speed

Case 1) Ethernet Communication



Low Speed

Ethernet

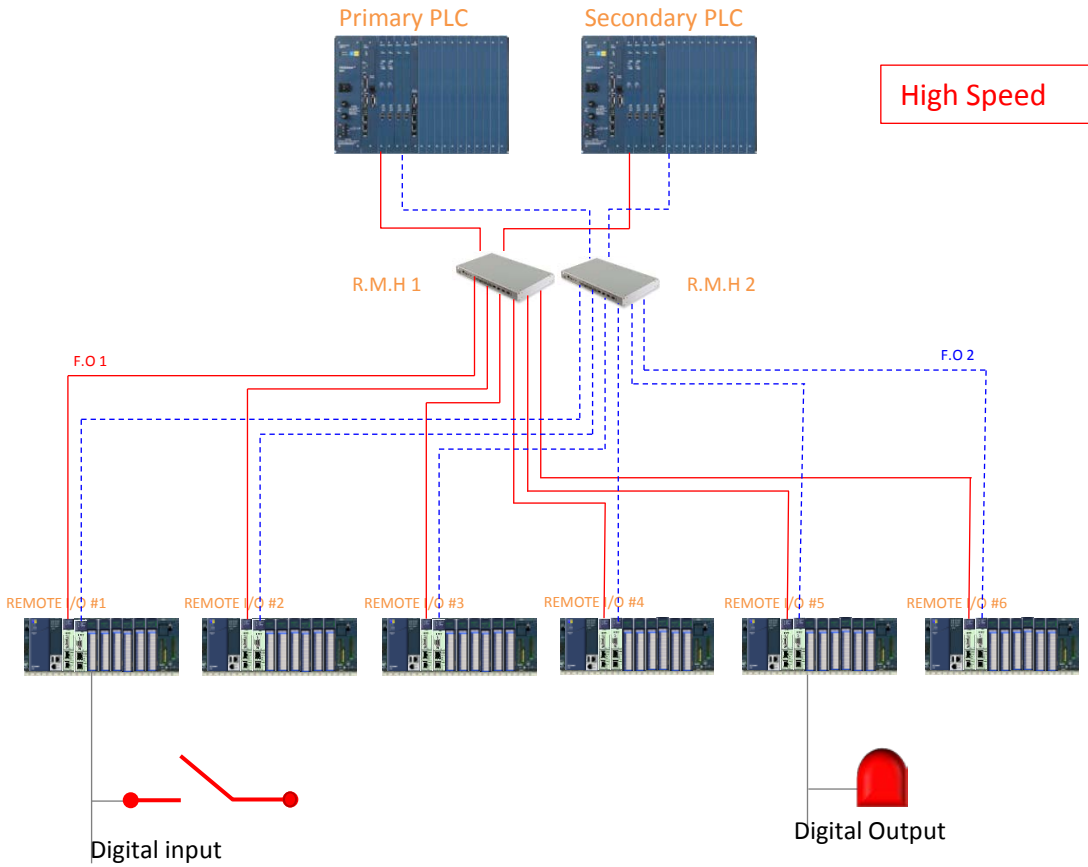
Fiber Optic

E.O.C Ethernet Optical Converter

No.	Description	Time
①	D/I On response time	0.5ms
②	Ethernet communication time	2ms
③	CPU scan time	10ms
④	Ethernet communication time	2ms
⑤	RIO scan time	5ms
⑥	D/O On response time	0.5ms
Total time		20ms

Main Sequence Control System Communication Speed

Case 2) Reflect Memory Communication



High Speed

Fiber Optic

Fiber Optic

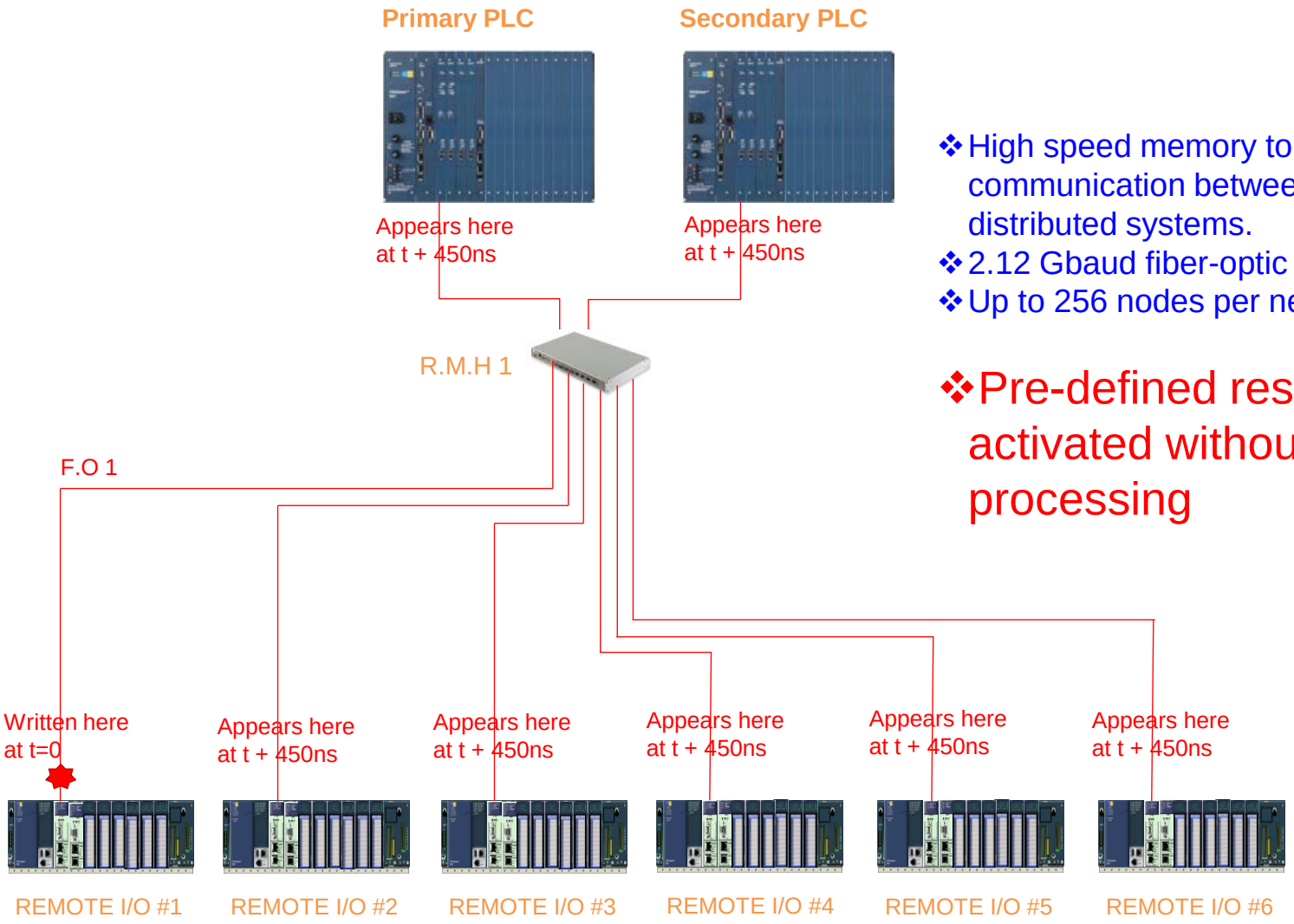
R.M.H Reflect Memory Hub

No.	Description	Time
①	D/I On response time	0.5ms
②	Memory Reflect time	450ns
③	RIO scan time	5ms
④	D/O On response time	0.5ms
Total time		6ms

BOD Signal

Klystron RF

Hard Wiring Response in PLC : Reflect Memory Communication



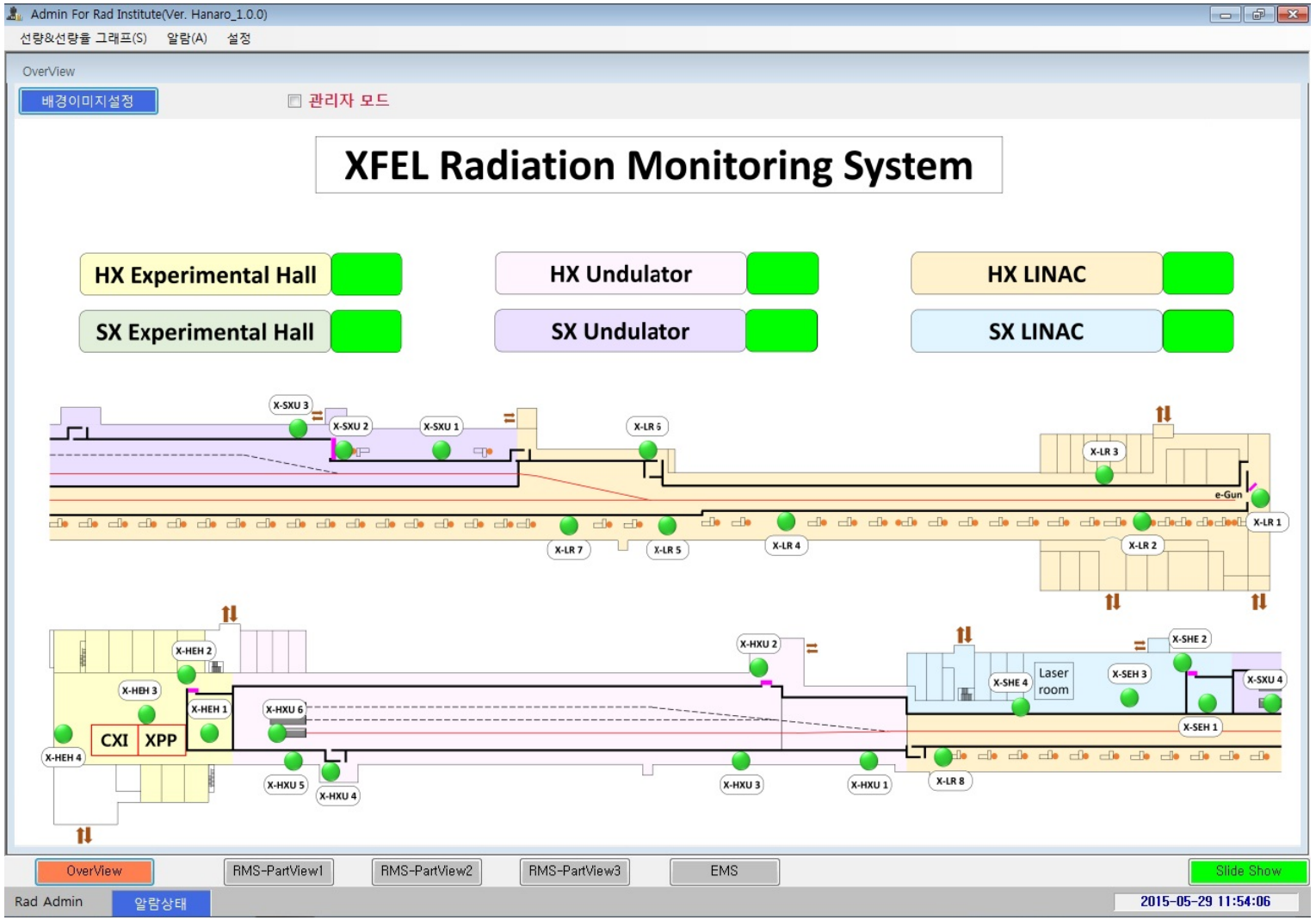
- High speed memory to memory communication between multiple distributed systems.
- 2.12 Gbaud fiber-optic network.
- Up to 256 nodes per network

- Pre-defined response is activated without CPU processing

Radiation Monitoring System

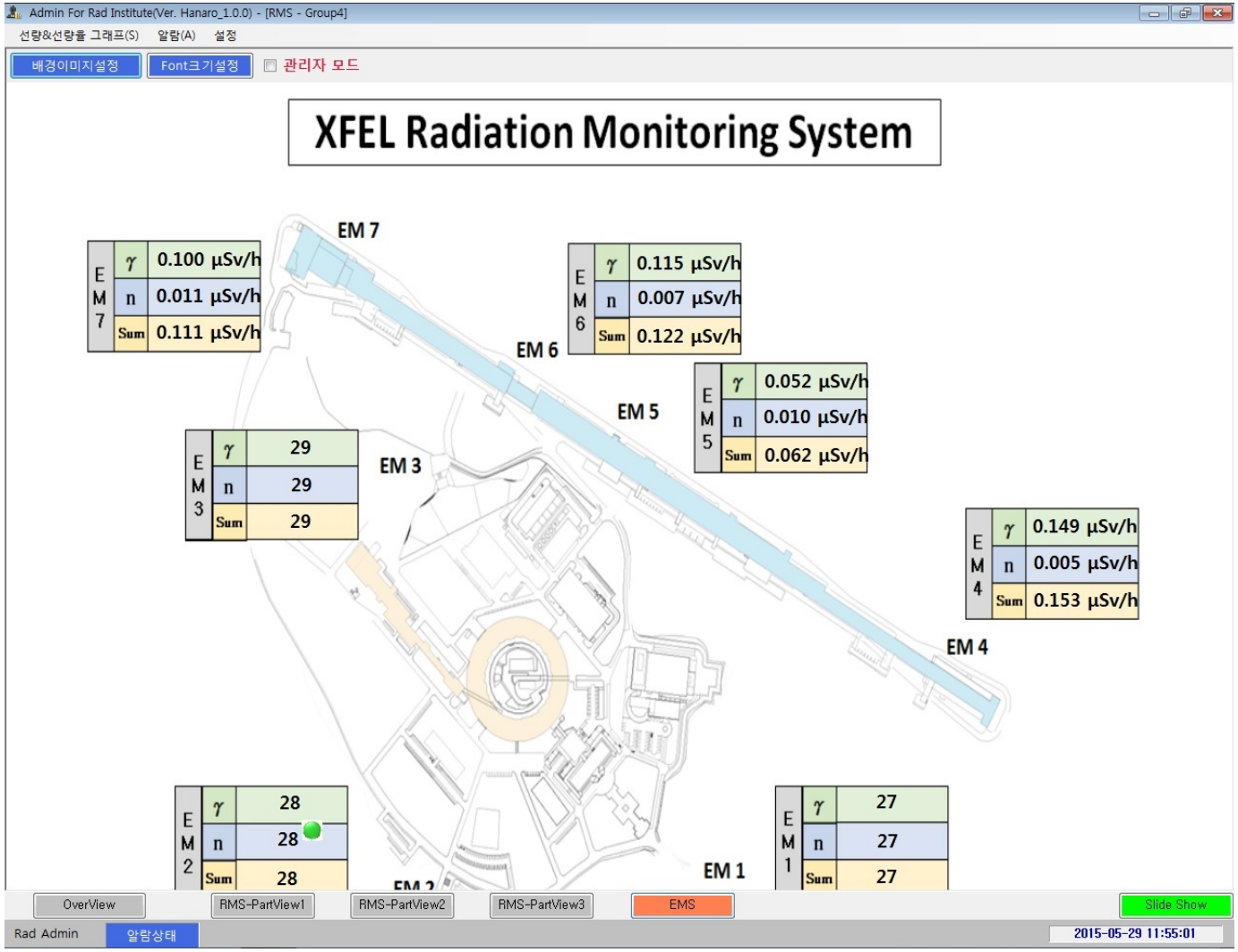
Radiation Monitoring System

- Areal Monitors



Radiation Monitoring System

- Environmental Monitors – 3 for PLS II, 4 for PALXFEL



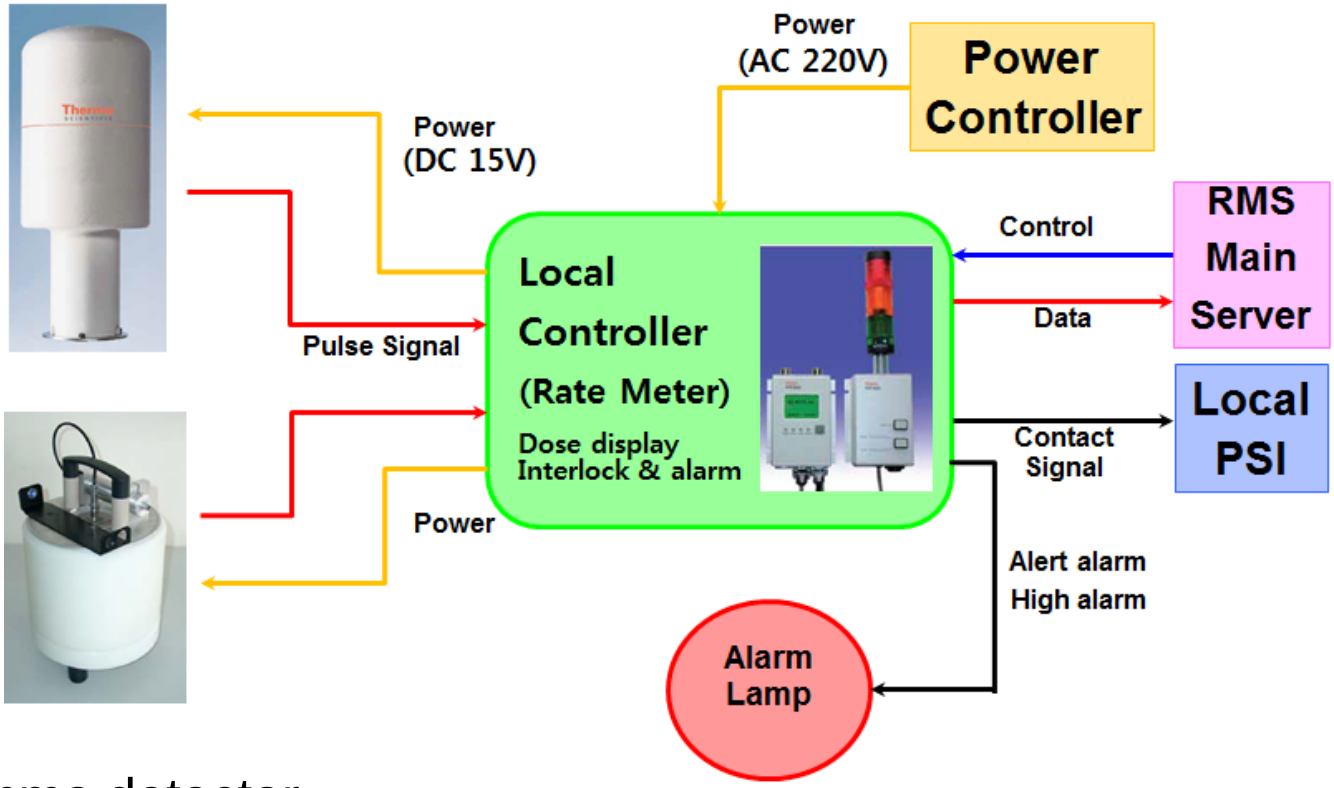
Radiation Control Policy

- Annual dose limit by Korean Nuclear Safety Act (for radiation worker)
  20 mSv (Max, 50 mSv) ÷ 2000 working hours = 10 μSv/h
- Annual dose limit of PAL management standards (ALARA)
  10 mSv ÷ 2000 working hours = 5 μSv/h

- RMS warning & interlock level

Signal Types	Limits (Dose rate)	Limit (1 h int. dose)	Action
Alert Alarm	3 μSv/h	-	Yellow light, 1-second interval beep
High Alarm	5 μSv/h	-	Red light, Continuous beep
Interlock	-	5 μSv	Generate Interlock Signal to PSI

Configuration of RMS



❑ Gamma detector

FHT 192	Ionization chamber
Measurement Ranges	Gamma dose rate measurement from 10nSv/h up to 10Sv/h
Energy Range	35 keV to 7 MeV
Sensitivity	250 fA/μSVh^{-1}

Radiation Monitoring System

❑ Neutron detector

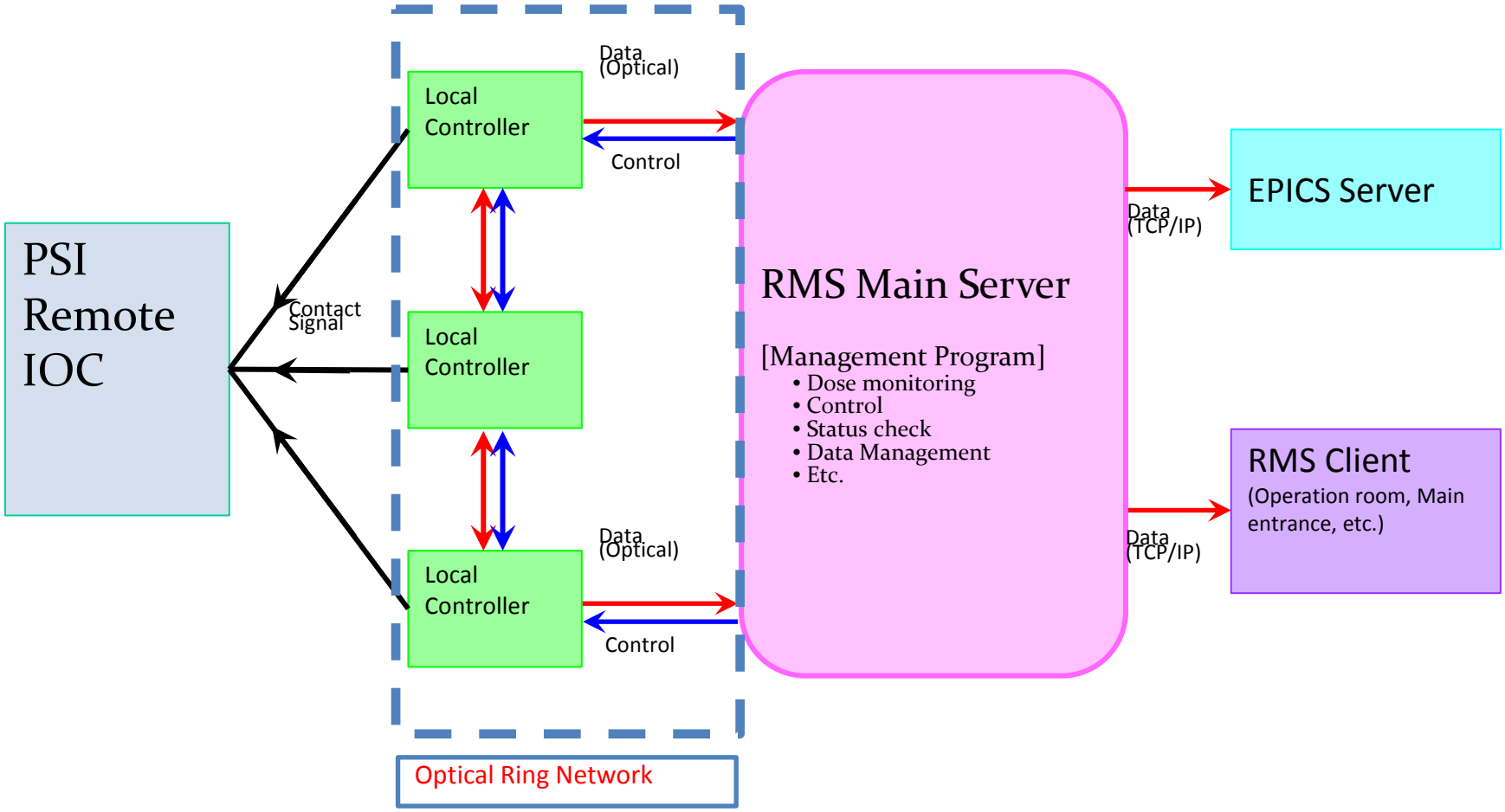
FHT 762 Wendi-2	Wide-Energy Neutron Detector (He-3)
Measurement Ranges	0.001 μSv to 100 mSv/h Cf-252
Energy Range	25meV to 5 GeV according to ICRP 74 (1996)
Sensitivity	Sensitivity: 0.84 cps/(μSv/h) at Cf-252 Gamma sensitivity : 1 to 5 μSv/h at 100 mSv/h, 662keV

❑ Local controller

FHT 6020	Ion Chamber
Detector input channels	3 channels (6-pin serial 2 ch, RS-485 1 ch)
Contact signal output	Interlock, status (power error, communication error, detector error)
Data output	Dose rate, 1 hours integrated dose, Alarm, Interlock, Status

Radiation Monitoring System

❑ Control scheme and network for radiation monitoring system



Radiation Monitoring System

❑ RMS comparison of PLS-II and XFEL

PLS-II	Items	XFEL	
5 sec	Data acquisition interval	2sec	
5 min	Dose rate integration time	Applied automatically	**50 sec for D** < 5 μSv/h **5 sec for** 5 μSv/h< **D** <400 μSv/h **0.5sec for** 400 μSv/h < **D**
5sec	Movement interval of real-time dose graph	5sec	
-	LCU data storage time	18.2 h (at 30s average dose)	
Ion chamber (HPI6035B) 80 keV ~ 1.6 MeV (30%) 1 μSv/h ~ 1 mSv/h 120 cpm/μSv/h	**Gamma detector** Energy Ranges Measurement Ranges Sensitivity	Ion chamber 30 keV ~ 7 MeV 0.1 μSv/h ~ 1 Sv/h 50 fA/μSv/h (Variable pulse width)	
BF3 counter (HPI6065DS) 25 meV – 10 MeV 0 – 10 mSv/h 0.33 cps/μSv/h	**Neutron detector** Energy Ranges Measurement Ranges Sensitivity	He-3 counter 25 meV - 5 GeV 0.01 μSv/h - 100 mSv/h 0.84 cps/μSv/h	

Summary

- 1.0 km long PALXFEL is in construction and all components are being installed until the end of this year.
- Fast response, Personal Safety & Interlock System and Slow response, Radiation Monitoring System were designed for radiation safety system of PALXFEL and are in an installation process now.
- New devices of beam containment system and A interlock policy, “kill after one beam loss”, are introduced to the PSI system of PALXFEL.
- Hard wiring in PLC, new reflect memory communication is applied and will be verified by testing process in the commissioning period.
- The securing ability of radiation safety will be confirmed in this year.

Thank You for Your Attentions !

Melting of Cu/Ni Cover Foil for In-vacuum undulator