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Renewal of control system and reliable long term operation of LHD cryogenic system

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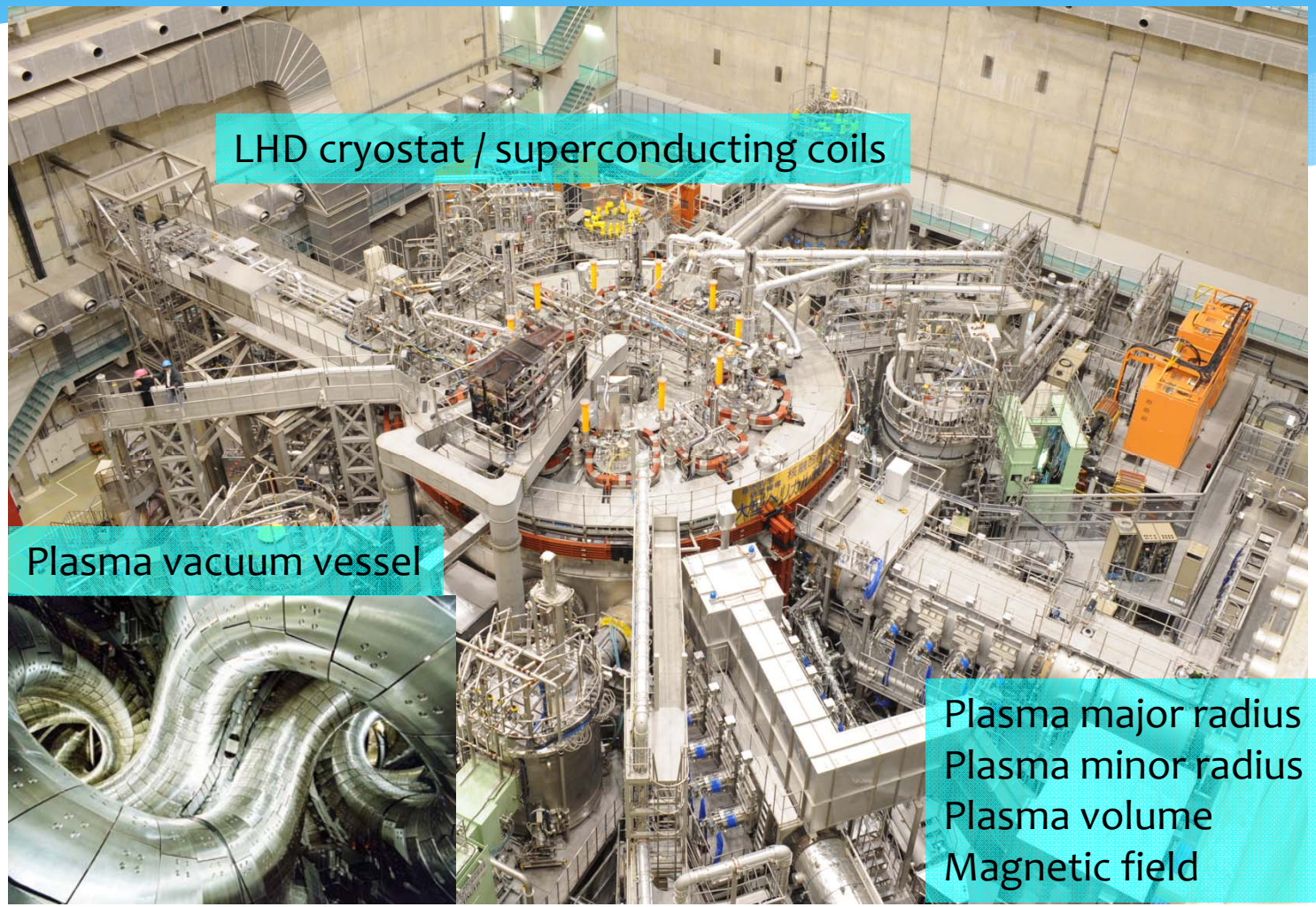
Introduction

* The Large Helical Device (LHD) is a heliotron-type fusion plasma experimental machine
* LHD consists of a fully superconducting magnet system cooled by a helium refrigerator having the total equivalent cooling capacity of 9.2 kW@4.4 K.
* 17 times of plasma experimental campaigns have been performed successfully from FY1997 with high reliability of 99%.
* The improvements have been done to prevent serious failures and to pursue further reliability.

Large Helical Device (LHD) heliotron-type fusion plasma experimental machine



Plasma major radius	3.9 m
Plasma minor radius	0.6 m
Plasma volume	30 m^3
Magnetic field	3 T

LHD superconducting coils

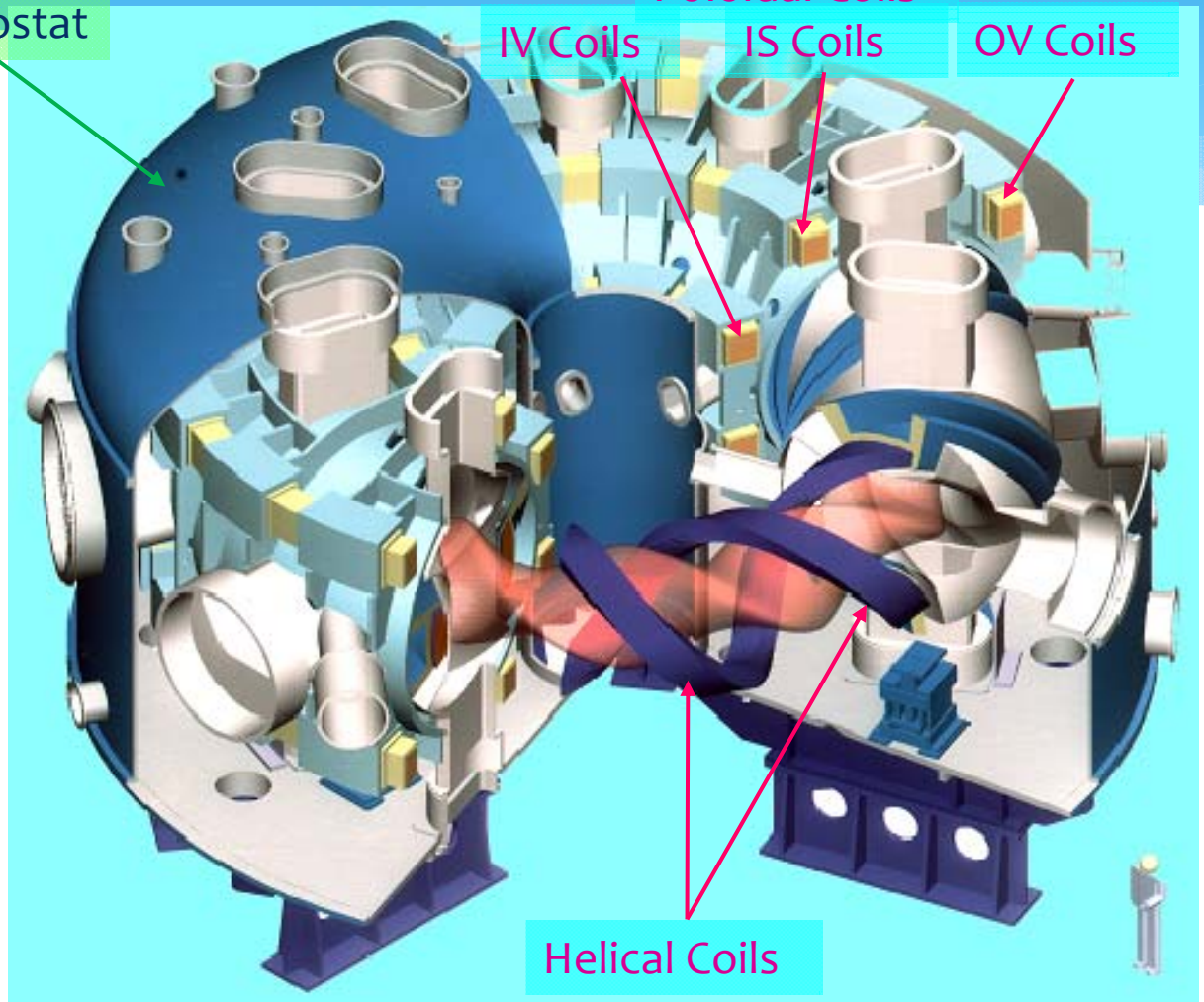
LHD Cryostat

Poloidal Coils

IV Coils

IS Coils

OV Coils



Helical Coils

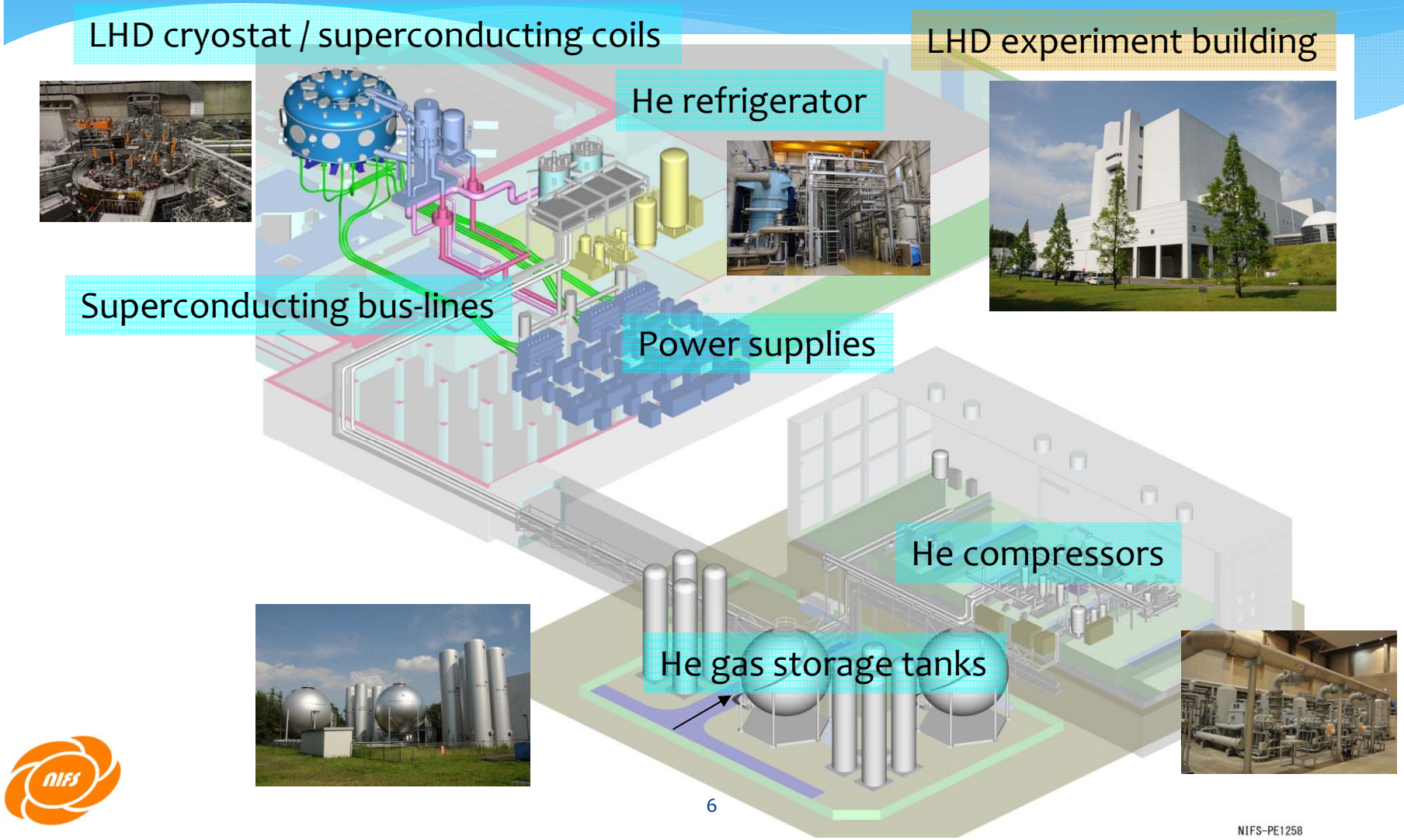
Outer dia.
13.5 m

Height.
8.8 m

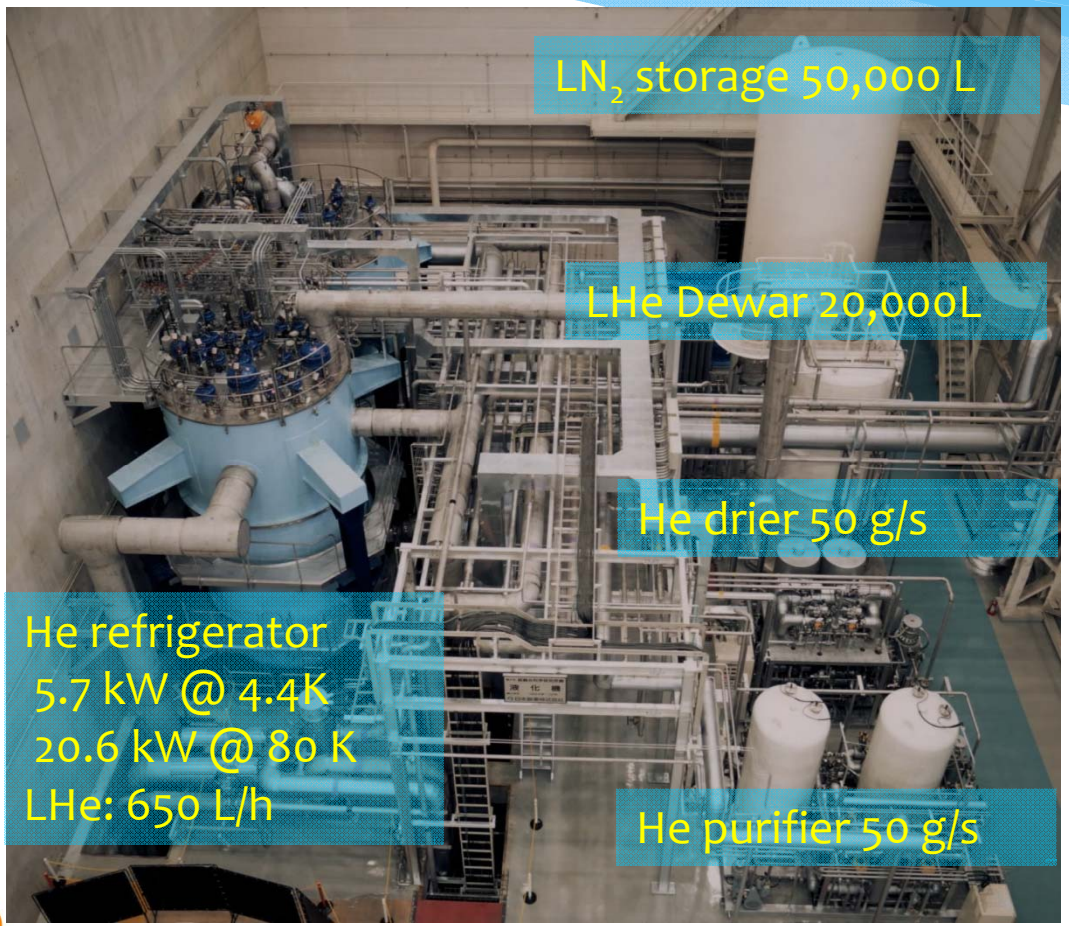
Cold mass
822 t

Total weight
1500 t

LHD cryogenic system

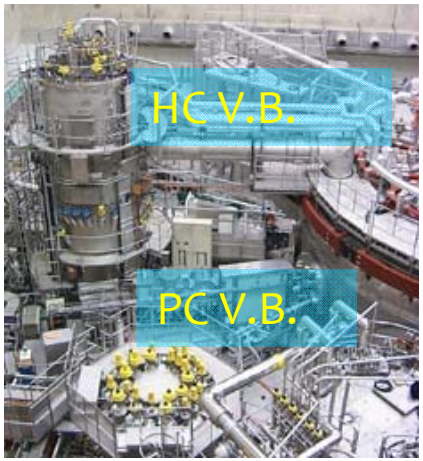


LHD helium refrigerator

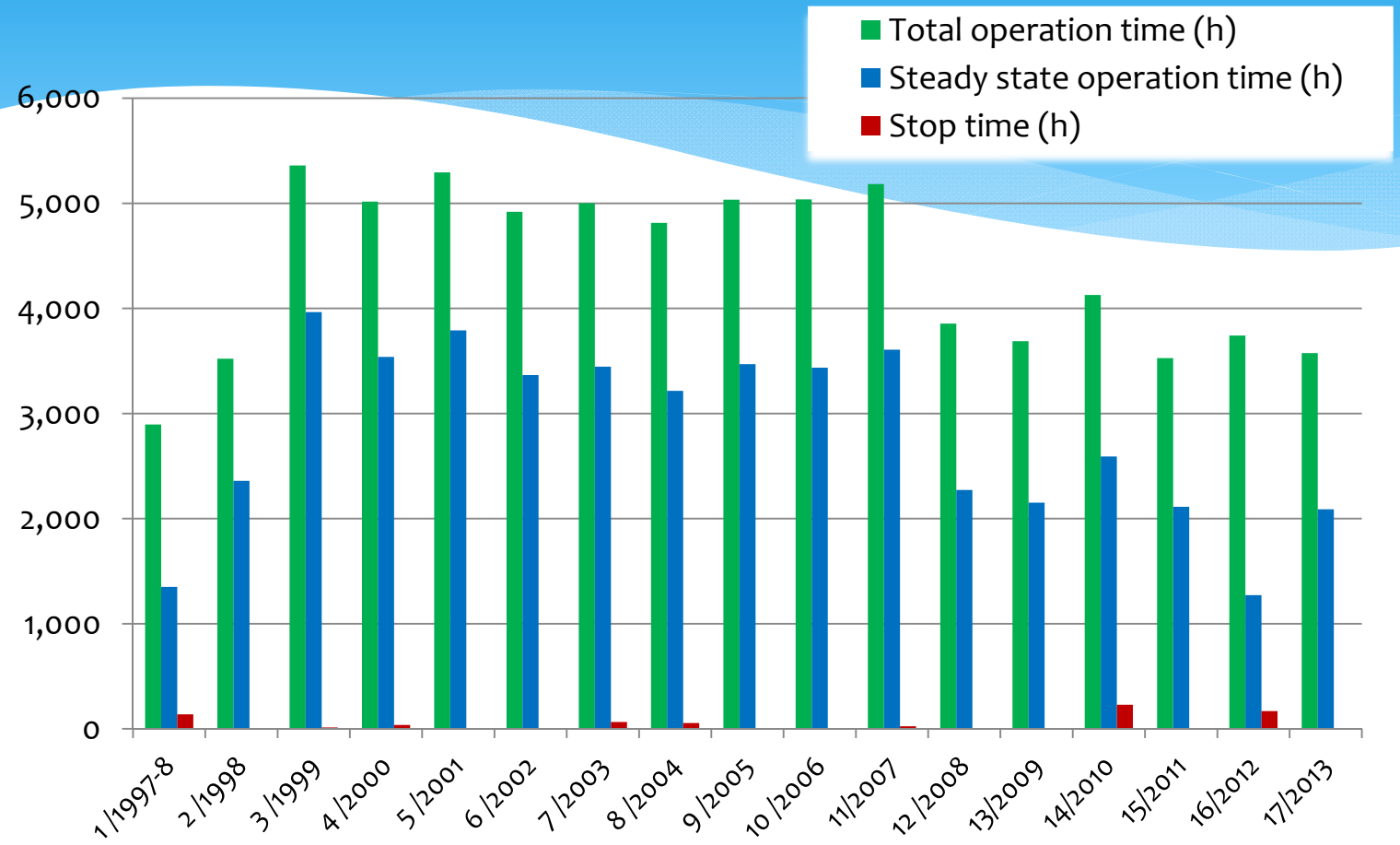


He gas storage tanks
2,200 m³, 2 MPa

8 Screw compressors
750 g/s + 210 g/s

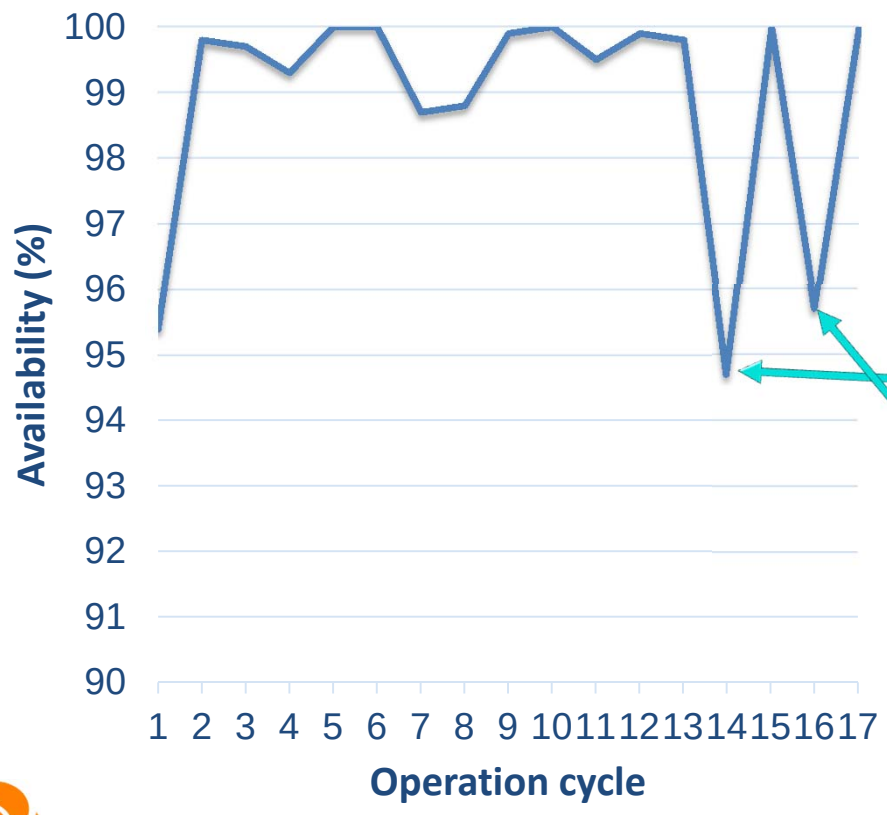


Operation time of LHD cryogenic system



* Total operation time: 74,595 h
* Steady state operation time: 48,031 h
* Stop time: 742 h

Availability of LHD cryogenic system



$$Availability = \frac{MTBF}{MTBF + MTTR}$$

MTBF: mean time between failures

MTTR: mean time to repair

- 14th cycle operation thrust bearings of screw compressors broke down
- 16th cycle operation electric insulation tube of poloidal coil generated a cold leakage

Failure analysis of LHD cryogenic system

Cause of failure	Number of failures	Total down time (h)	MTTR (h)
Control system	11	287.4	26.1
Compressors	5	268.2	53.6
Superconducting coils	1	169.0	169.0
Loss of electric power	5	10.0	2.0
Utility	4	7.5	1.9
Miss operation	1	0.1	0.1
Total	27	742.2	27.5

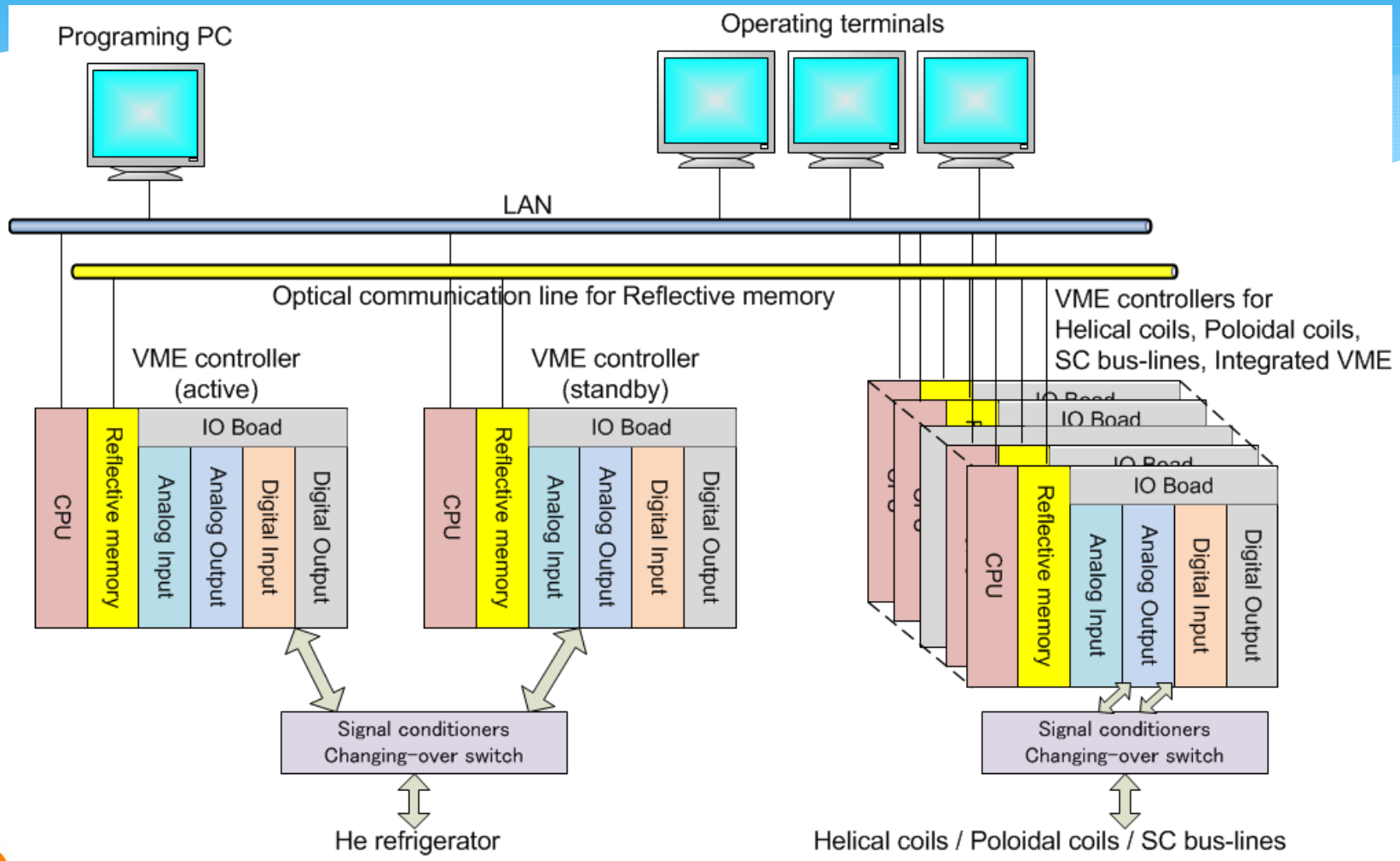
Improvements of LHD cryogenic system

* Addition of redundant compressors
  * Two kinds of redundant compressors were added to back up even when which one of 8 compressors breaks down
* Renewal of cryogenic control system
  * Down-sizing of control devices has been done from VME controllers to compact PCI controllers in order to simplify the system configuration and to improve the system reliability

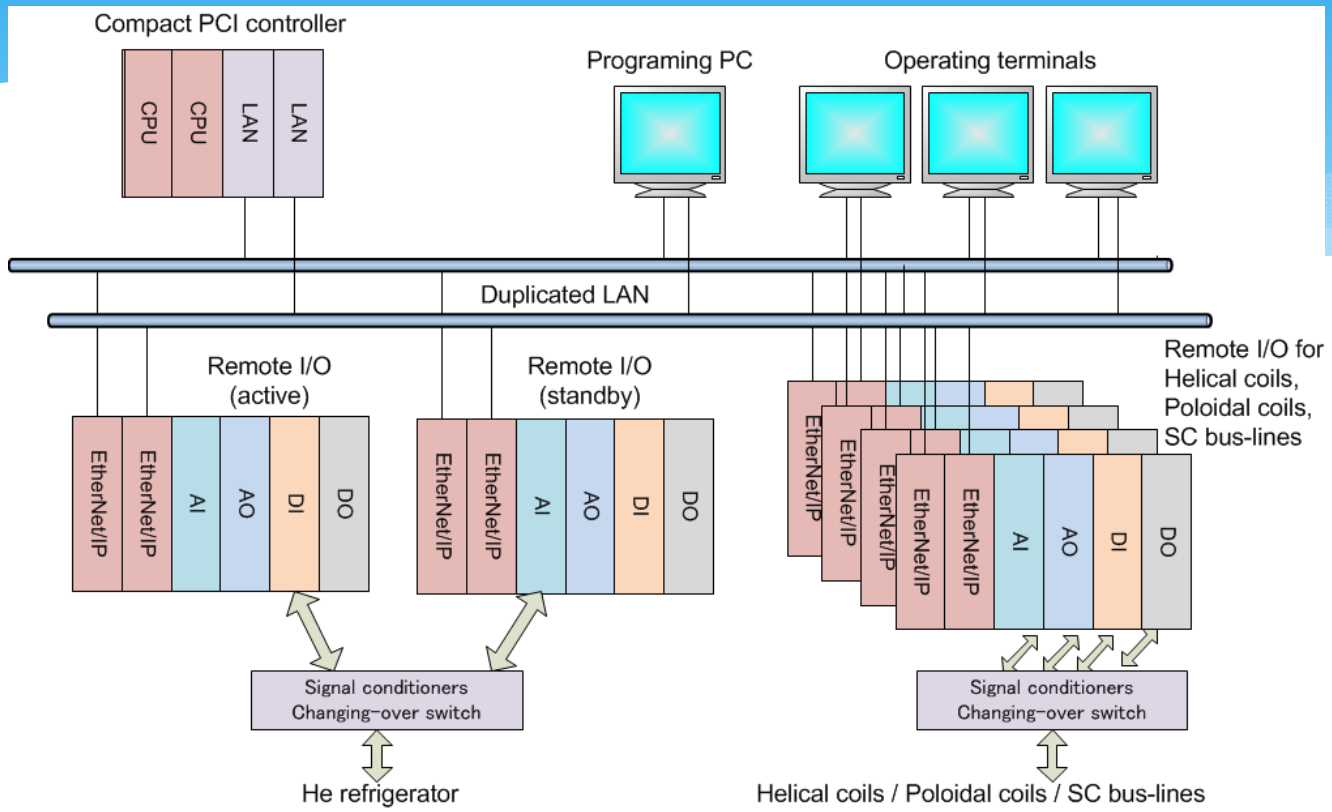
Problems of existing cryogenic control system

* Expansion and complication of control system
  * Distributed, redundant system with automated fault diagnosis
  * 12 VME controllers
    AI:1045, Ao:216, Di:896, DO: 768
* Advantage of open system is losing
  * Reliability depends on products of a specific manufacture (Reflective memory)

Existing cryogenic control system



Renewal of cryogenic control system



* New system is composed of compact PCI controller and remote I/O connected with EtherNet/IP
* Making the system redundant by doubling CPU, LAN, and Remote I/O respectively

Summary

* Highly reliable operations of the LHD cryogenic system have been achieved during 16 years from 1997
  * Total operation time: 74,595 hours
  * High availability: 99 %
* Smooth renewal of the cryogenic control system completed successfully in 2013
  * Development of new control system was executed in 2011
  * Field tests have been done in 2012
* It is necessary to establish the diagnostic working beforehand the aging of the superconducting coils.