Superconducting magnet system of LHD

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Outline

- History
- Engineering achievements related to construction
- Operation for ten years
- Future
- Outlook for DEMO

History

Japanese F.Y.

1990 1995 2000 2005 2009

NIFS Foundation

R&D 1991-1997

First plasma 1998

Construction

Between campaigns
Inspections & upgrading

Operation

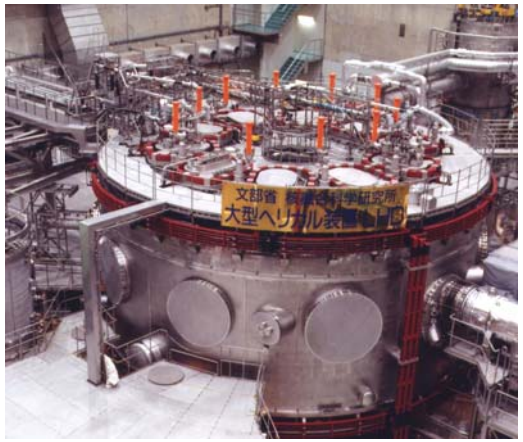
1 2 3 4 5 6 7 8 9 10 11 12

Experimantal campaign

The first SC helical coil 1989

0.6 m in dia.

On-site winding of helical coil



LHD in 1998

2006 Decrease of the temperature of helical coil 4.4 K to 3.5 K

2008 Upgrading of power supply for poloidal coil 30 V to 200 V

Achievements in fusion engineering

1. **FULLY superconducting magnet system**
   - Helical and poloidal coils
   - Support structure and posts
   - Cryostat
   - On-site fabrication

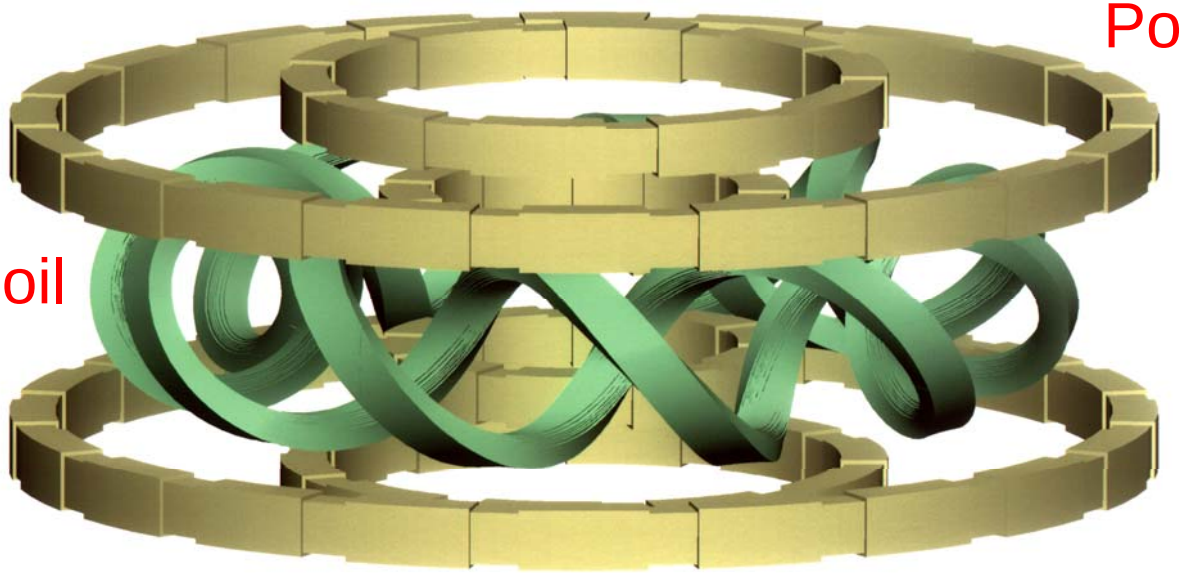
1998 LHD
2006 EAST
2008 KSTAR

2. **World's largest helium refrigerator and power supply for fusion**
3. **Advanced technologies**
   - Superconducting bus-line
   - Cable-in-conduit conductor

Superconducting coils

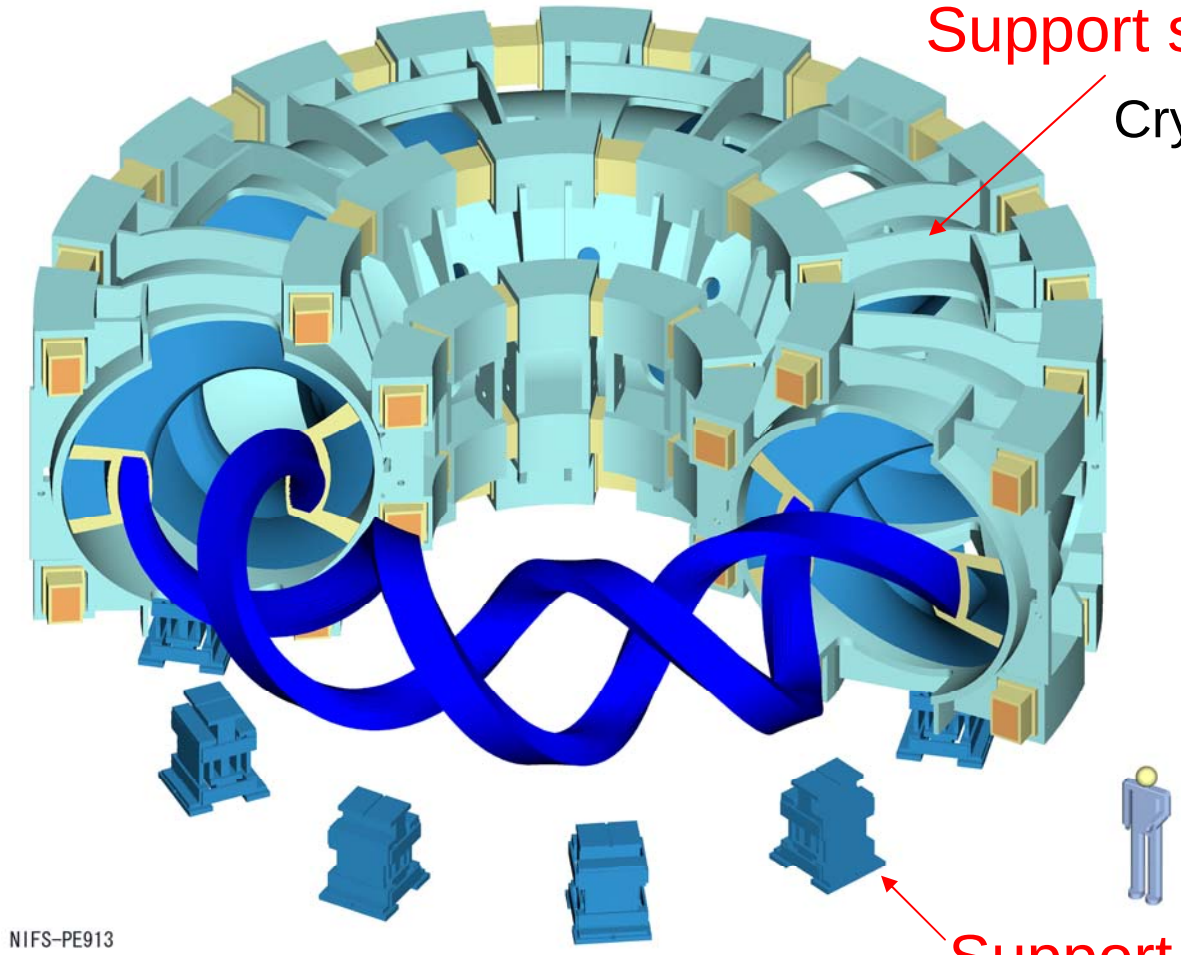
Poloidal coil

Helical coil



Toroidal field: 3 T
Maximum field: 6.9 T
Magnetic energy: 0.9 GJ

Supporting structure & post



Support structure

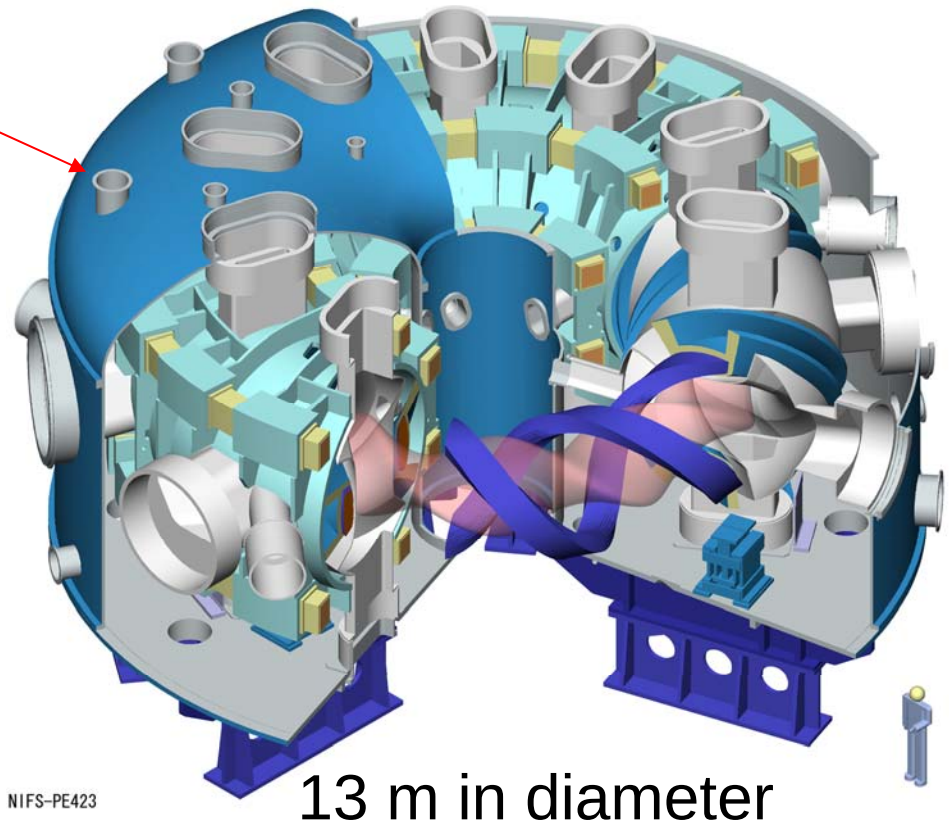
Cryogenic temp.

Support post

Support 850 t

Blade spring

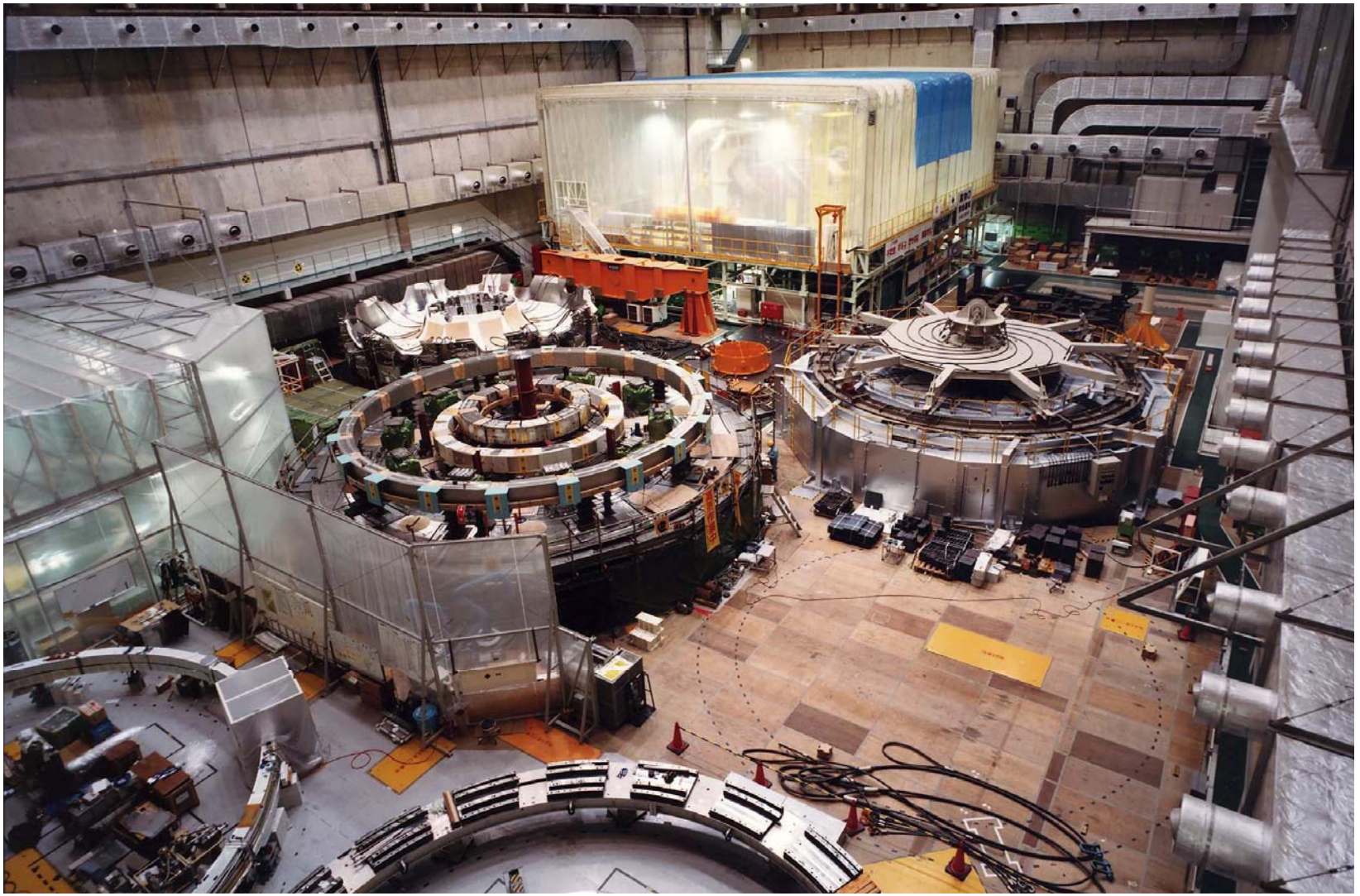
Cryostat



13 m in diameter
9 m in height
1,500 t

The largest superconducting magnet system

On-site magnet fabrication



Achievements in fusion engineering

1. **FULLY superconducting magnet system**
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   - Support structure and post
   - Cryostat
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Refrigerator & Power supply

Refrigerator
9 kW @ 4 K

Power supply
6 sets
15-23 kA, 33-45 V

SC bus-line
55m, 9 lines

Helium compressor & storage tank

Integration and linkage of components

Achievements in fusion engineering

1. **FULLY superconducting magnet system**
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   - Superconducting bus-line
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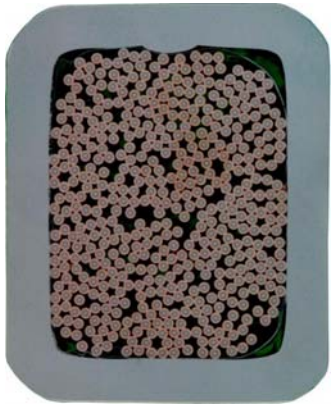
Cable-in-conduit conductor

- Superconductors of the LHD poloidal coils are the first cable-in-conduit conductor in the world operating over the long term in the fusion device
- Cable-in-conduit conductors are now used or adopted in most of fusion devices
  - W7-X, EAST, KSTAR, SST-1, JT-60SA, ITER



LHD poloidal coil

27.5 mm x 31.8 mm

31.3 kA @ 5 T

ITER PF coil

From the presentation at SOFT2008

DEMO

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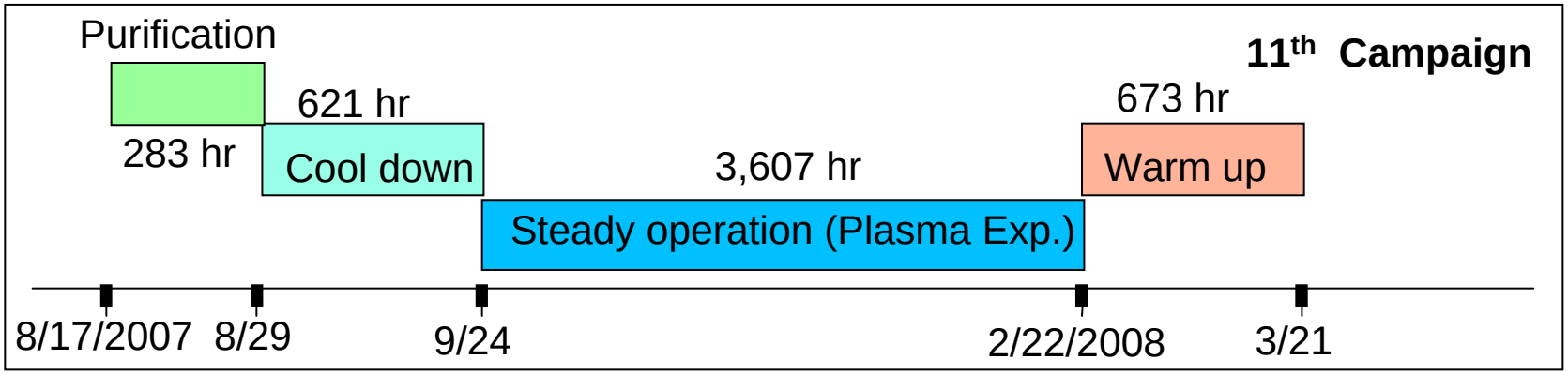
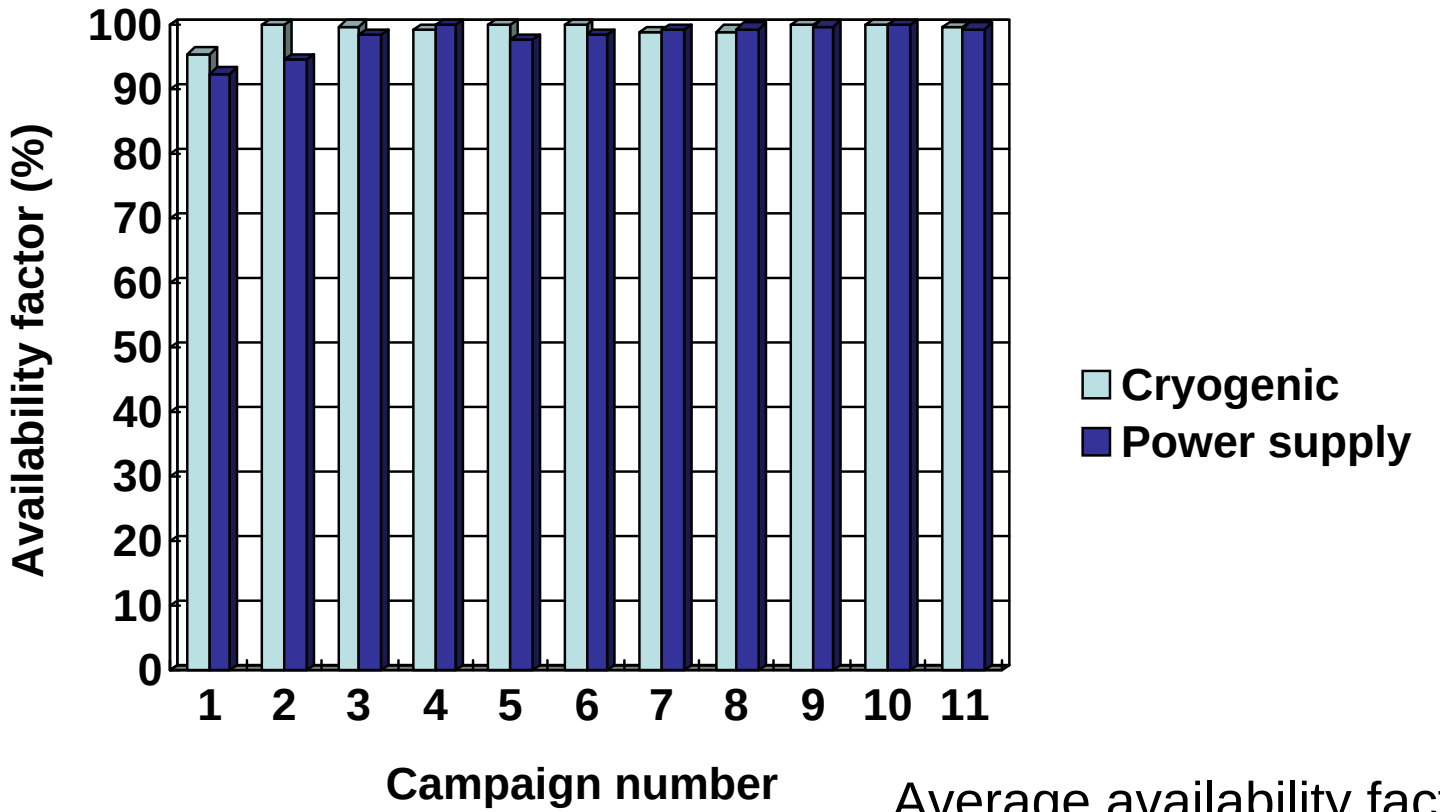
Operation experience

- **Total operating time (steady-state)**
  - Cryogenic system: 35,000 h (~four years)
  - Power supply system: 7,000 h
- **Over 1,000 excitations**
- **No degradation in the magnet**



Availability factor

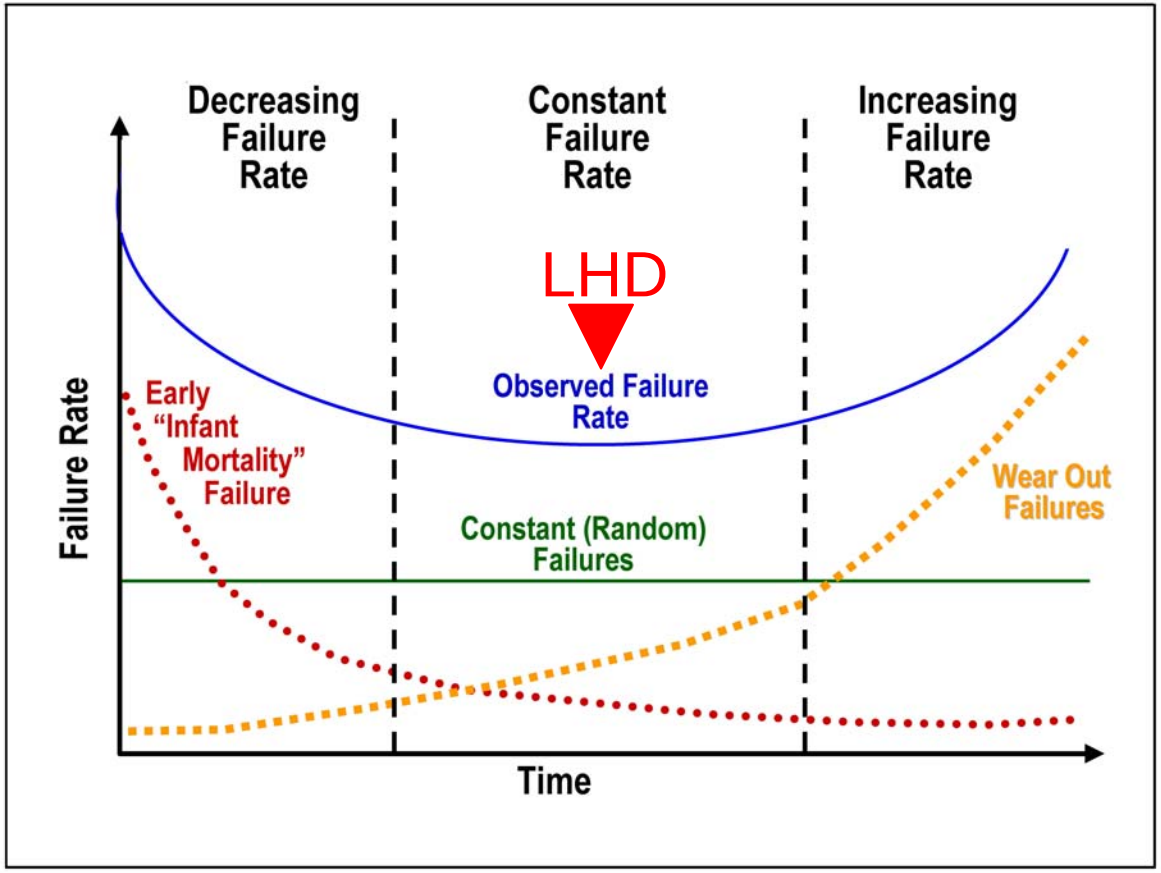
Normal operating time/scheduled operating time



Average availability factor
Cryogenic system: 99%
Power supply: 98%

Future

Bathtub curve



Predictive maintenance to avoid wear out failures
Will wear out failures occur in the magnet?

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Outlook for DEMO

- **The system components of the LHD superconducting magnet are the same as those of DEMO**
  - Superconducting coil, support structure, support post, cryostat, bus-line, cryogenic system, power supply

- **Design philosophy and operation experience of the LHD superconducting magnet system can be applied to the design of DEMO**

- **Technical Issues**
  - High-performance superconductor
  - High-performance structural material
  - Protection from unexpected accidents
  - Cost reduction

Summary

- **The development of the LHD superconducting magnet system is a milestone in fusion engineering**
- **The operation of LHD for ten years demonstrates high reliability of the superconducting magnet system for fusion**
- **The LHD-type helical energy reactor FFHR is now under design on the basis of experience on LHD**