Commissioning of the cryogenic hydrogen system

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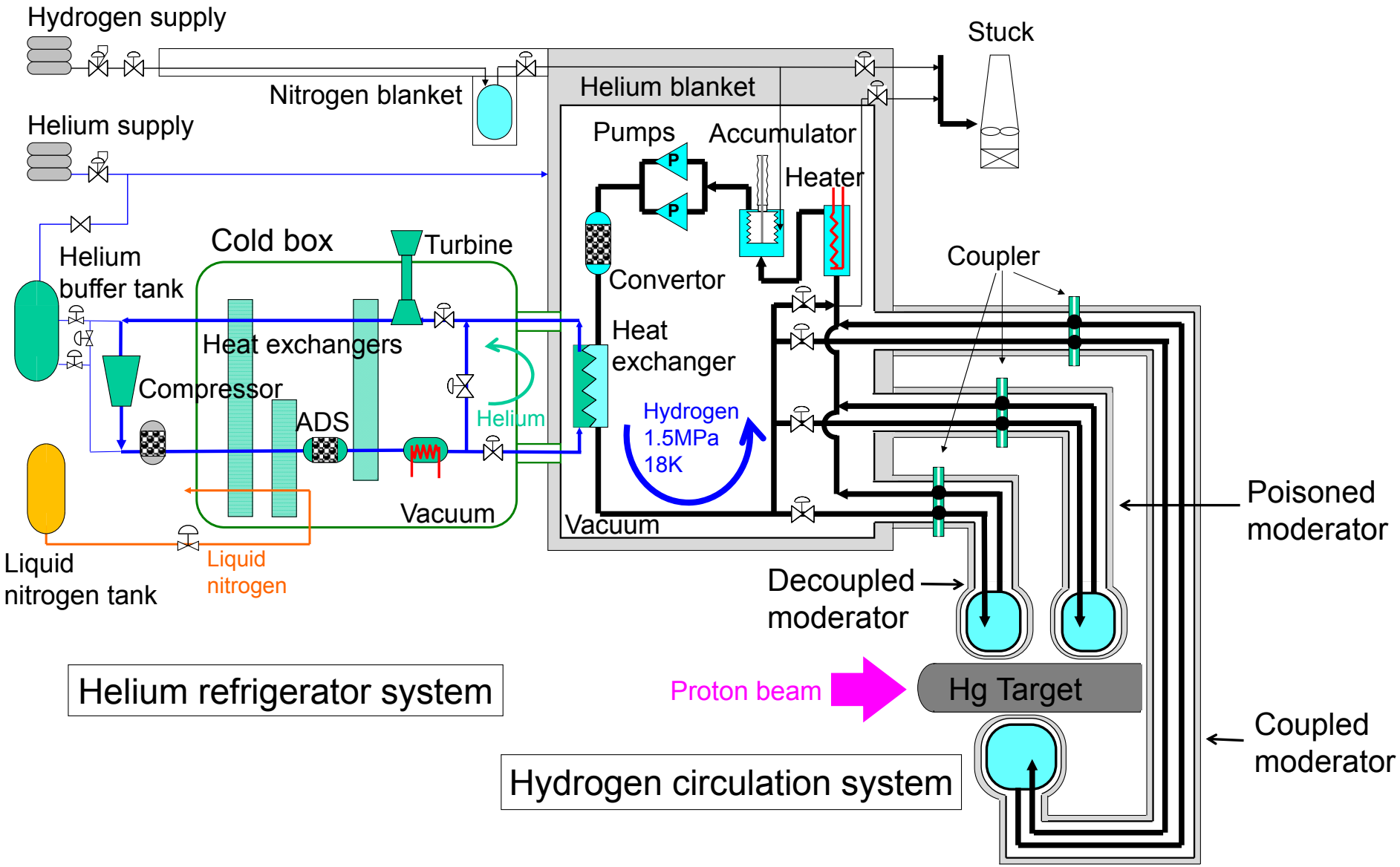
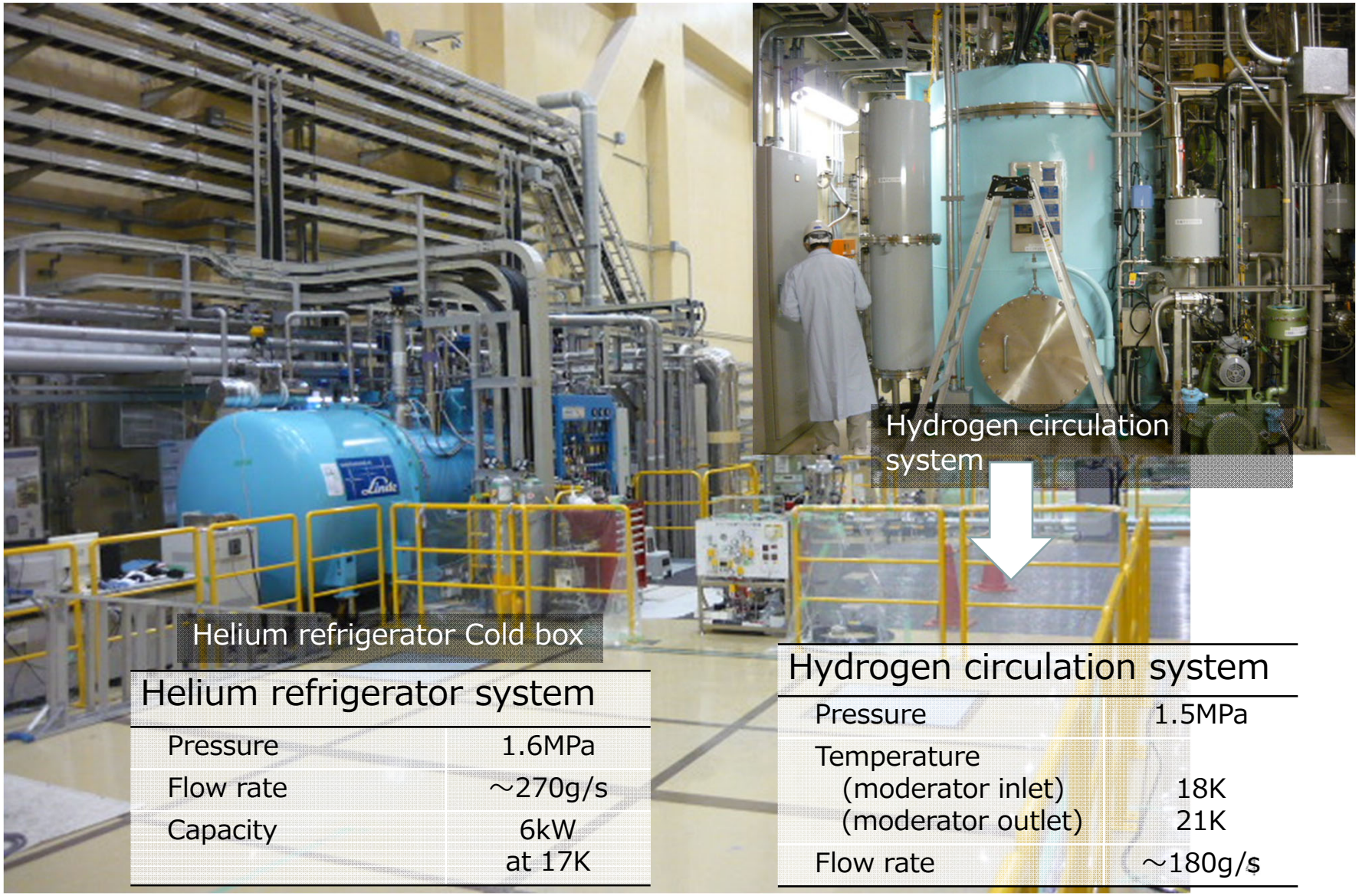
1. Cryogenic hydrogen system



1. Cryogenic hydrogen system



Helium refrigerator system	
Pressure	1.6MPa
Flow rate	~270g/s
Capacity	6kW at 17K

Hydrogen circulation system	
Pressure	1.5MPa
Temperature (moderator inlet)	18K
(moderator outlet)	21K
Flow rate	~180g/s

2. Outline of commissioning

⓪ Construction of each components

- Basic inspections (leak, pressure, welding, etc.)

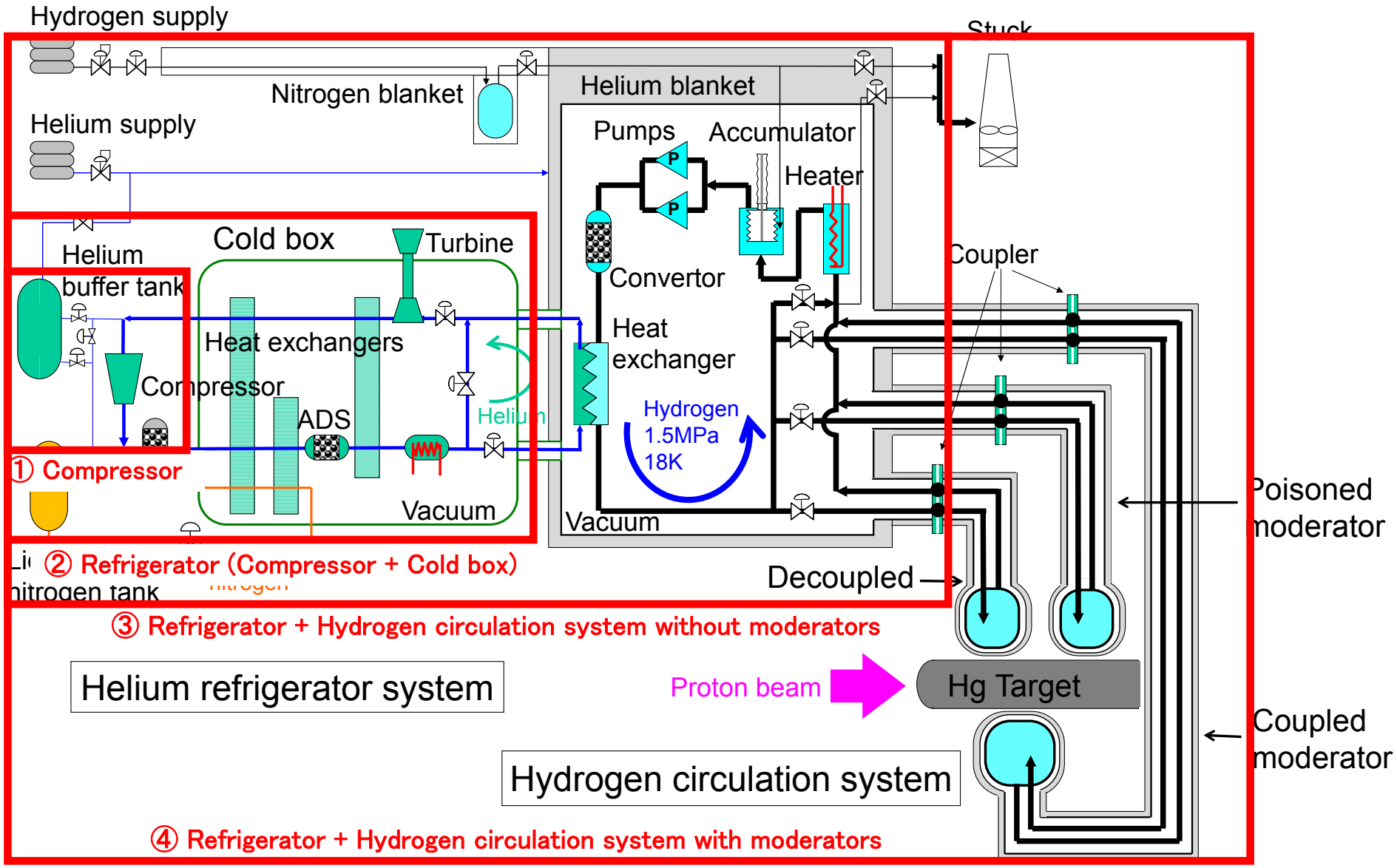
① Helium compressor

② Helium refrigerator (Compressor + Cold-box)

③ Helium refrigerator + Hydrogen circulation system without moderators

④ Helium refrigerator + Hydrogen circulation system with moderators

2. Outline of commissioning



3. Commissioning items

Categories	Confirmation	Details
⓪Construction of components	Required inspection	Several check
① He compressor	・Specification of compressor ・Working conditions	・Flow rate / Compressed pressure/ Suction pressure / Oil concentration ・Vibration / Noise / Motor power
② He refrigerator (compressor + cold box)	・Preparation ・Specification of refrigerator	・Operation sequence / Purification ・Operation (cool-down/warm-up) /Refrigerator capacity with/without liquid nitrogen /Consumption of liquid nitrogen /Process flow, operating condition
③ Hydrogen circulation system without moderators	・Preparation ・Specification of hydrogen circulation system, Operation by helium and hydrogen	・Operation sequence / Purification ・Operation (cool-down/warm-up) /Performance of hydrogen pumps, accumulator, heater /Process flow, Operating condition (confirmed by helium and hydrogen) /Operation mode
④ Hydrogen circulation system with moderators	・Flow condition with moderators ・Integrated test of whole system	・Operation sequence / Purification ・Operation (cool-down/warm-up) /Process flow, Operating condition (confirmed by helium and hydrogen) /Emergency release test

3. Commissioning items

① Helium compressor

Confirmation items	Criteria	Results
Flow rate	> 0.285 kg/s	0.291 kg/s
Compressed pressure	> 1.6 MPaG	1.61 MPaG
Suction pressure	< 0.21 MPaG	0.209 Mpa
Oil concentration	< 1 wt. ppm	< 0.1 wt. ppm
Vibration	< 40 μm	< 10.7 μm
Noise	< 100 db(A)	< 92.3 db(A)
Motor power	< 730 kW	709 kW

3. Commissioning items

② Helium refrigerator

Confirmation items	Criteria	Results
Operation sequence	—	Prepared
Purification	N_2 concentration: < 4 ppm	2.97 ppm
Operation (cool-down/warm-up)	Normal	Satisfied
Refrigerator capacity with/without liquid nitrogen	> 6 kW at 17K with LN_2 > 2.5 kW at 19 K without LN_2	6.446 kW 2.642 kW
Consumption of LN_2	< 125 L/h	< 93.18 L/h
Process flow, operating condition	Normal	Satisfied

3. Commissioning items

③ Hydrogen circulation system without moderators

Confirmation items	Criteria	Results
Operation sequence	—	Prepared
Purification	O_2 concentration: < 0.5 ppm	0.1 ppm
Operation (cool-down/warm-up)	Normal	Satisfied
Hydrogen pump	> 0.082 kg/s for one > 0.162 kg/s for both	0.09544 / 0.08366 kg/s 0.1748 kg/s
Accumulator	Stroke: 0 – 80 mm	Satisfied
Heater	Test power: 4 kW	Satisfied
Process flow, operating condition (confirmed by helium and hydrogen)	Normal	Satisfied
Operation mode	Normal	Satisfied

3. Commissioning items

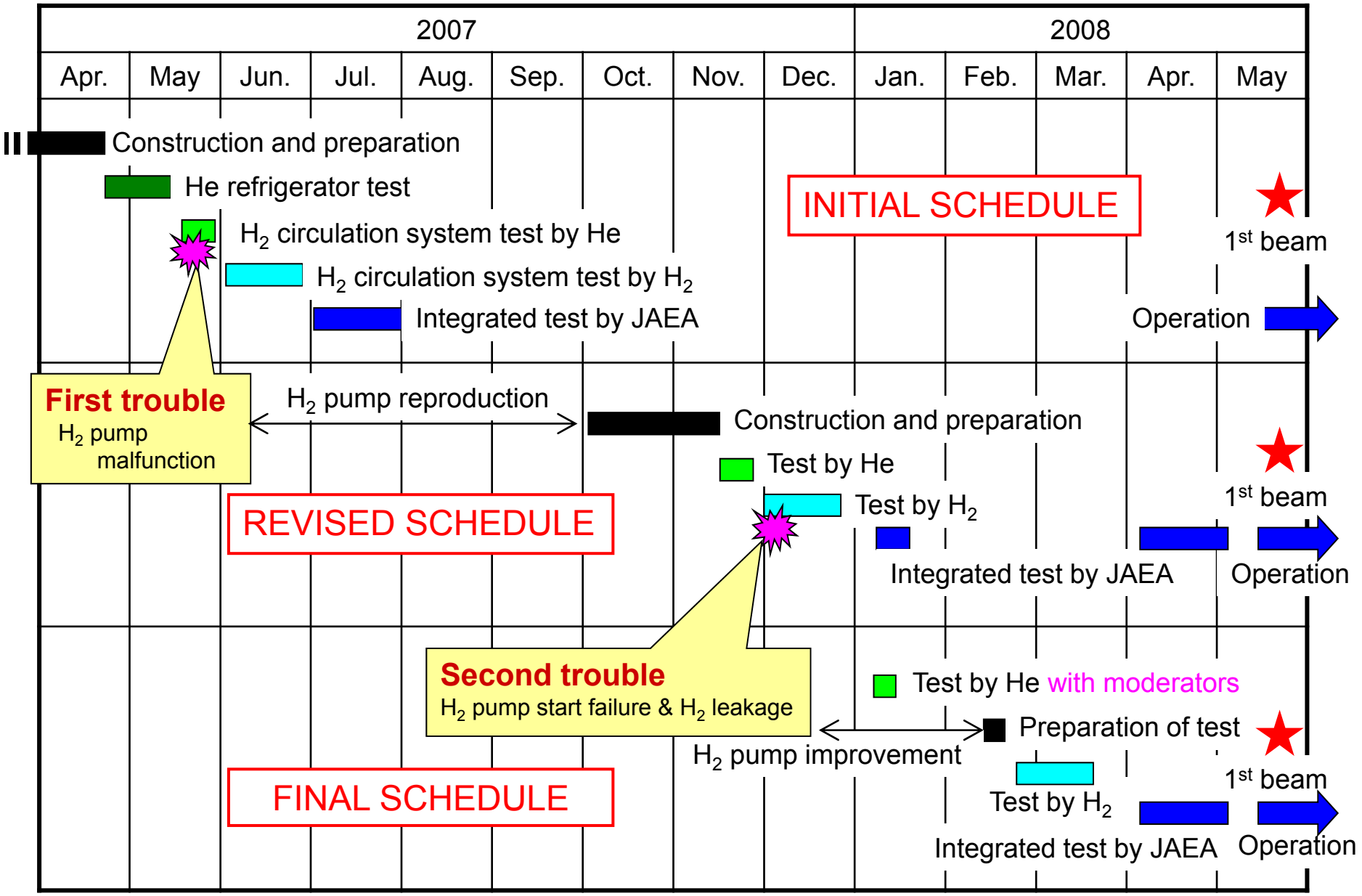
④ Hydrogen circulation system with moderators

Confirmation items	Criteria	Results
Operation (cool-down/warm-up)	Normal	Satisfied
Process flow, operating condition (confirmed by helium and hydrogen)	Normal	Satisfied
Emergency release test	Normal	Satisfied

(Vacuum system)

Confirmation items	Prediction	Results
Vacuum value at hydrogen circulation unit (300 K)	< 4E-2 Pa	3.64E-4
Vacuum value at hydrogen circulation unit (20 K)	< 6E-4 Pa	9.60E-5
Vacuum value at moderators (300 K)	< 1E-3 Pa	7.62E-4

4. Schedule


2007
2008
Apr.
May
Jun.
Jul.
Aug.
Sep.
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
May
Construction and preparation
He refrigerator test
H2 circulation system test by He
H2 circulation system test by H2
Integrated test by JAEA
INITIAL SCHEDULE
1st beam
Operation
First trouble
H2 pump malfunction
H2 pump reproduction
Construction and preparation
Test by He
Test by H2
REVISED SCHEDULE
1st beam
Integrated test by JAEA
Operation
Second trouble
H2 pump start failure & H2 leakage
Test by He with moderators
Preparation of test
H2 pump improvement
FINAL SCHEDULE
Test by H2
1st beam
Integrated test by JAEA
Operation

First trouble H_2 pump malfunction

What happened?

— When we ran the H_2 pump in helium environment as a start-up test in May 2007, the impeller was damaged due to getting into touch with its casing.

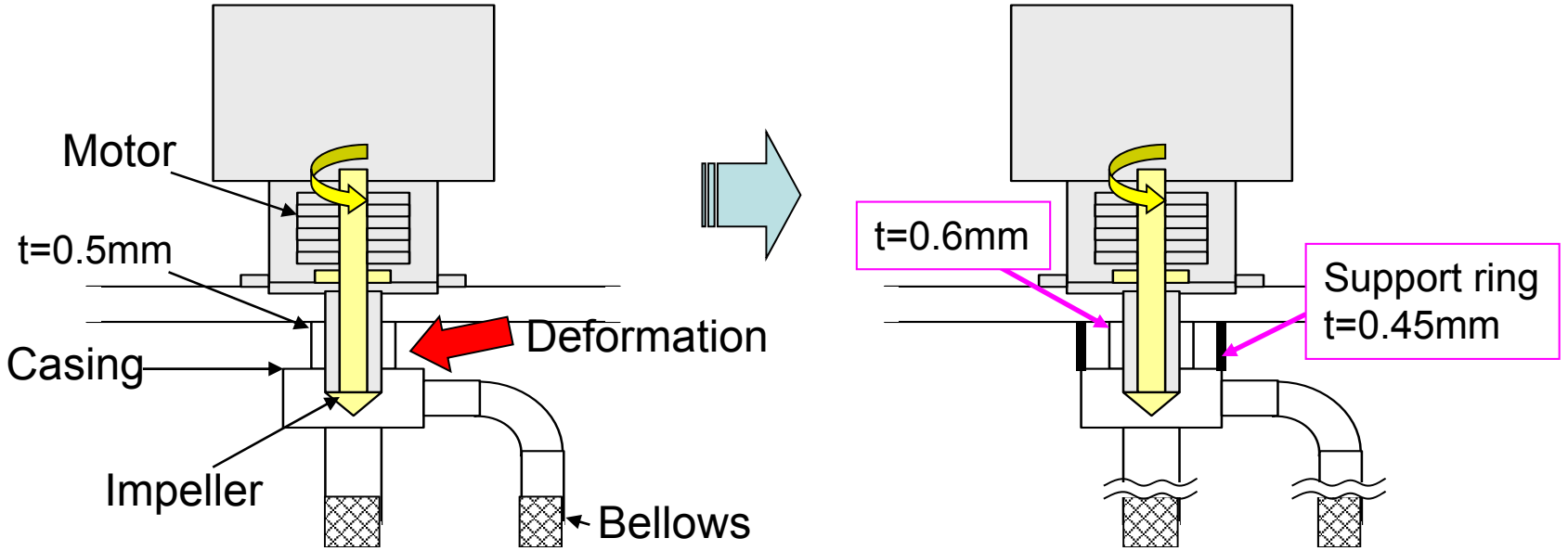
Reason

— This was because the casing was deformed by a former pressure proof test. Strength of the casing was insufficient to endure against elongation of bellows.

Measures

— The thickness of the casing was increased, and a support ring was added.

— It took 4 months to remanufacture the two pumps, and the manufacturing was completed in Nov. 2007.



Second trouble **H_2 pump start failure** & H_2 leakage

What happened?

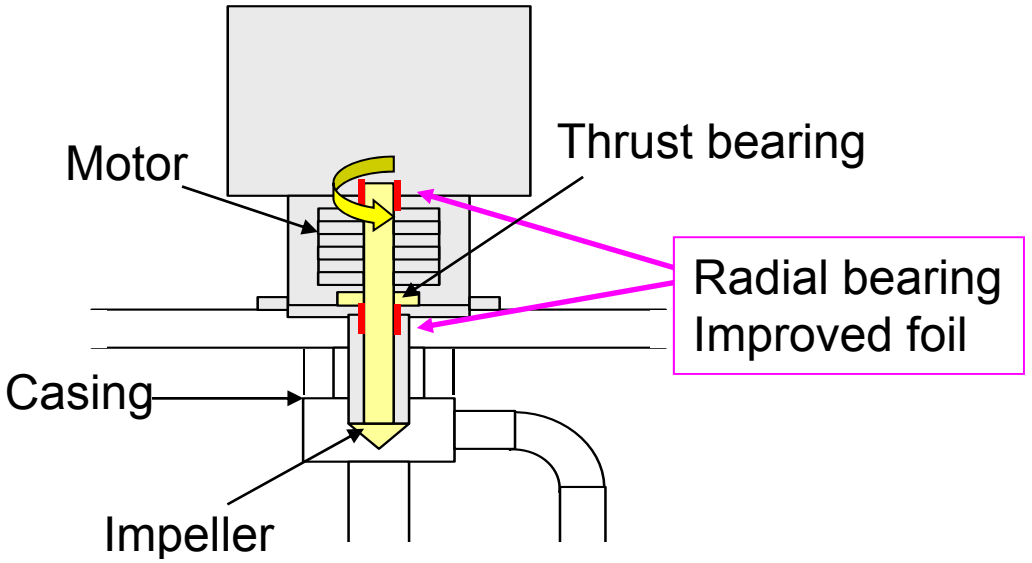
— In Dec. 2007, a He gas circulation test by the cryogenic hydrogen system was succeeded at 20K. After that, we started-up the H_2 pumps in hydrogen environment at a room temperature. However, the pump-B did not start-up, the pump-A occasionally failed to start-up.

Reason

— The pump was adopted a supercritical helium pump for International Thermonuclear Experimental Reactor (ITER). This trouble was due to differences of viscosity and frictional resistance in the gas bearing of the H_2 pump between hydrogen and helium.

Measures

— We improved sliding surface of the radial bearing to increase stiffness and to decrease friction.



Second trouble H_2 pump start failure & **H_2 leakage**

What happened?

— We tried to carry out the cryogenic test in hydrogen environment with only pump-A, because the pump-A might work. The hydrogen leakage occurred through an O-ring seal of the pump when the temperature just passed through the critical temperature (34K).

Reason

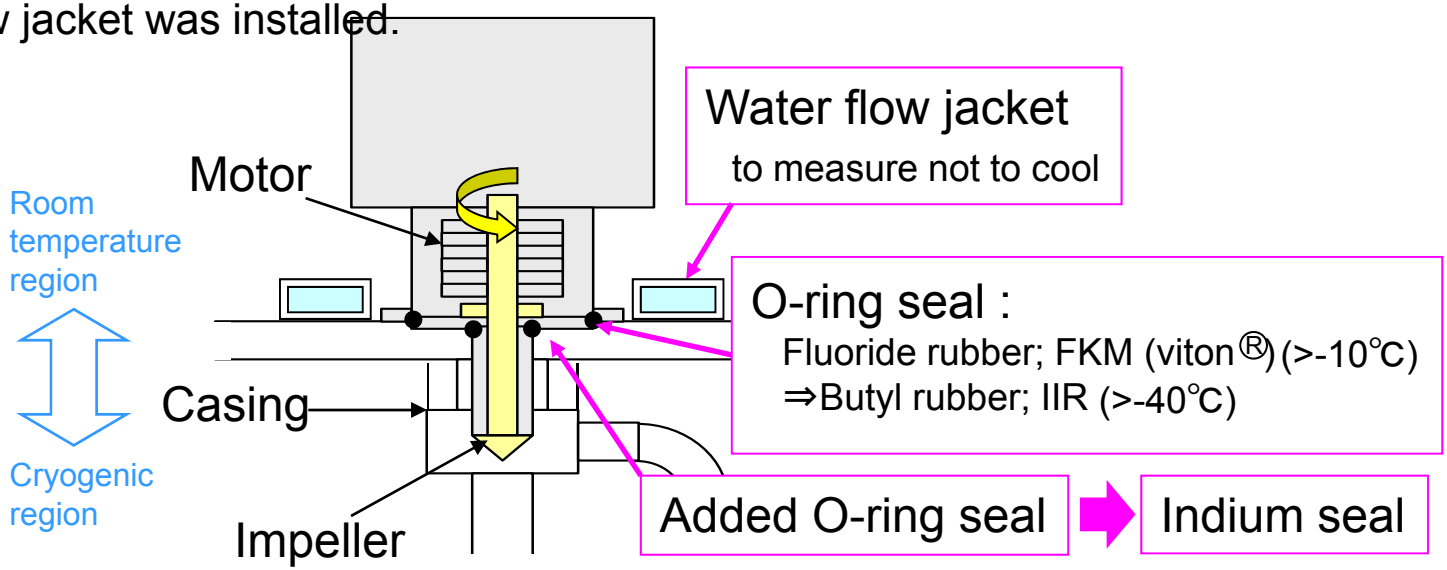
— A possible reason is that hydrogen gas flow from a cryogenic region to a room temperature region to freeze an O-ring.

Measures

— New O-ring seal was installed. →Indium seal

— Material of the frozen O-ring was changed from FKM to IIR.

— A water flow jacket was installed.



5. Lessons learned

Properties of hydrogen

- Low viscosity
  - Development of the baring of pump for hydrogen

- Very leaky
  - Adding a O-ring seal and changing the seal material
  - Butyl robber and indium for the pump, Diflon© for valves

Summary

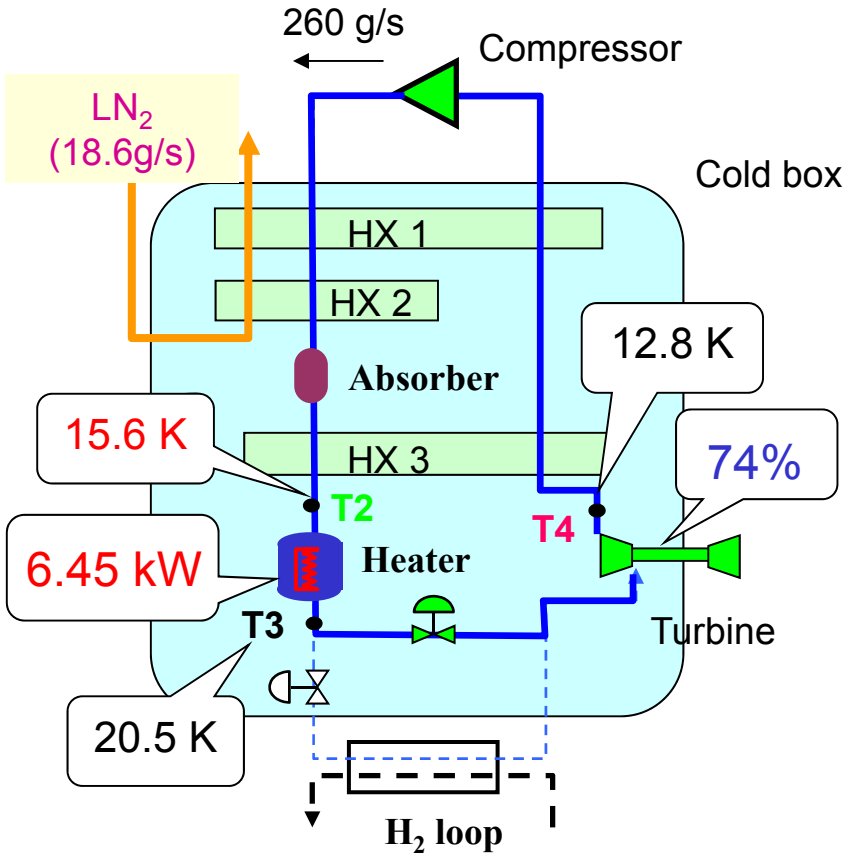
Commissioning, the cryogenic operation tests were scheduled to completed in about four months.

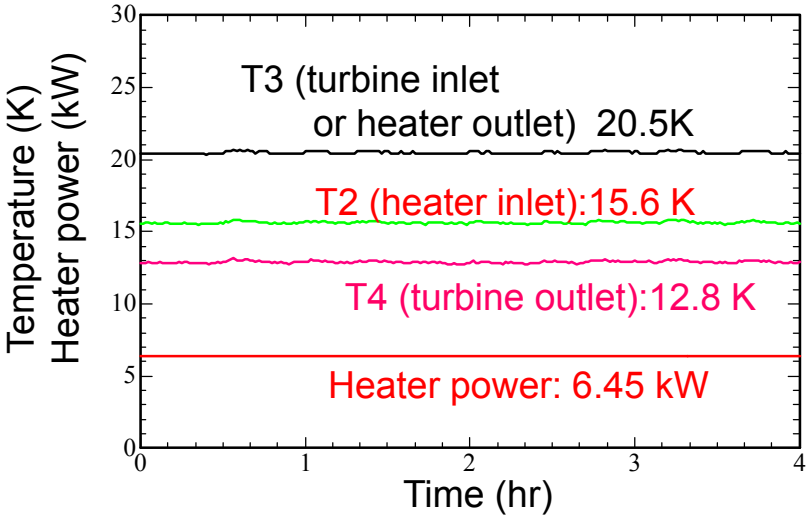
It took about a year to complete the final preparation for Day-1 due to the troubles of the hydrogen pump.

Reference

② Helium refrigerator

- Refrigeration power : 6.45 kW at 15.6 K (achieved)
  > 6 kW at 17 K (spec.)



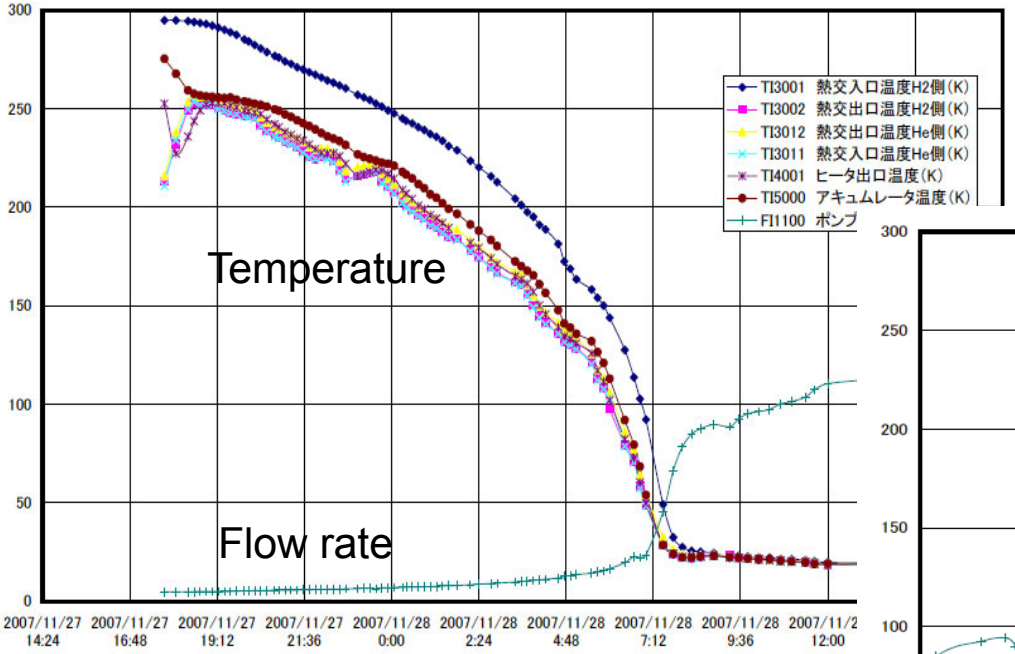


Cold box

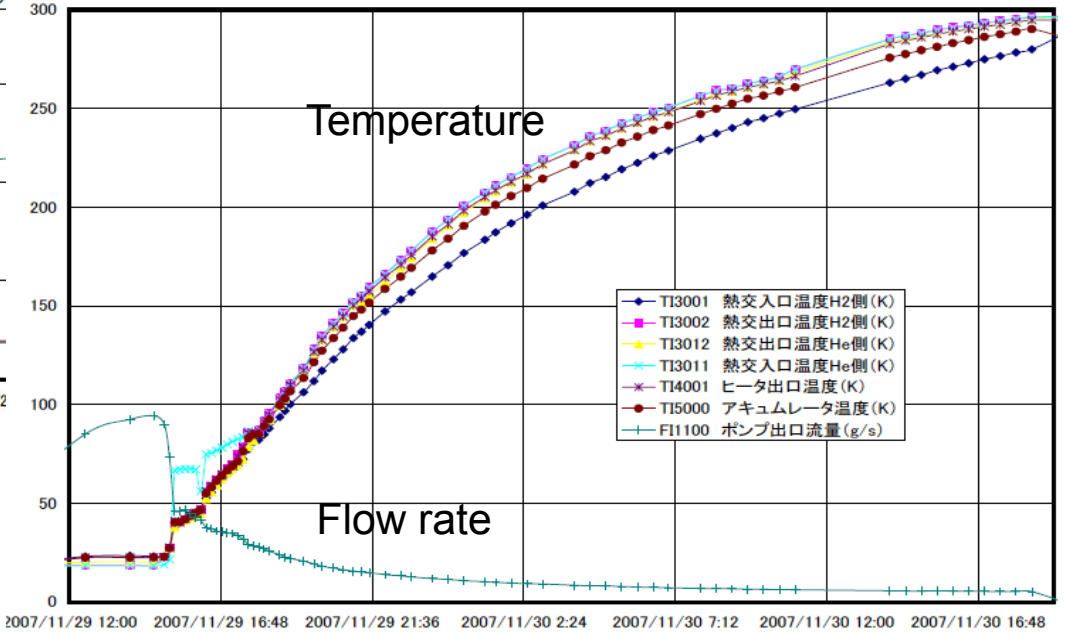
③ Hydrogen circulation system without moderators

Operating test by helium gas

Temperature and flow rate of helium in the cryogenic hydrogen circulation system at cool-down and warm-up



Cool-down

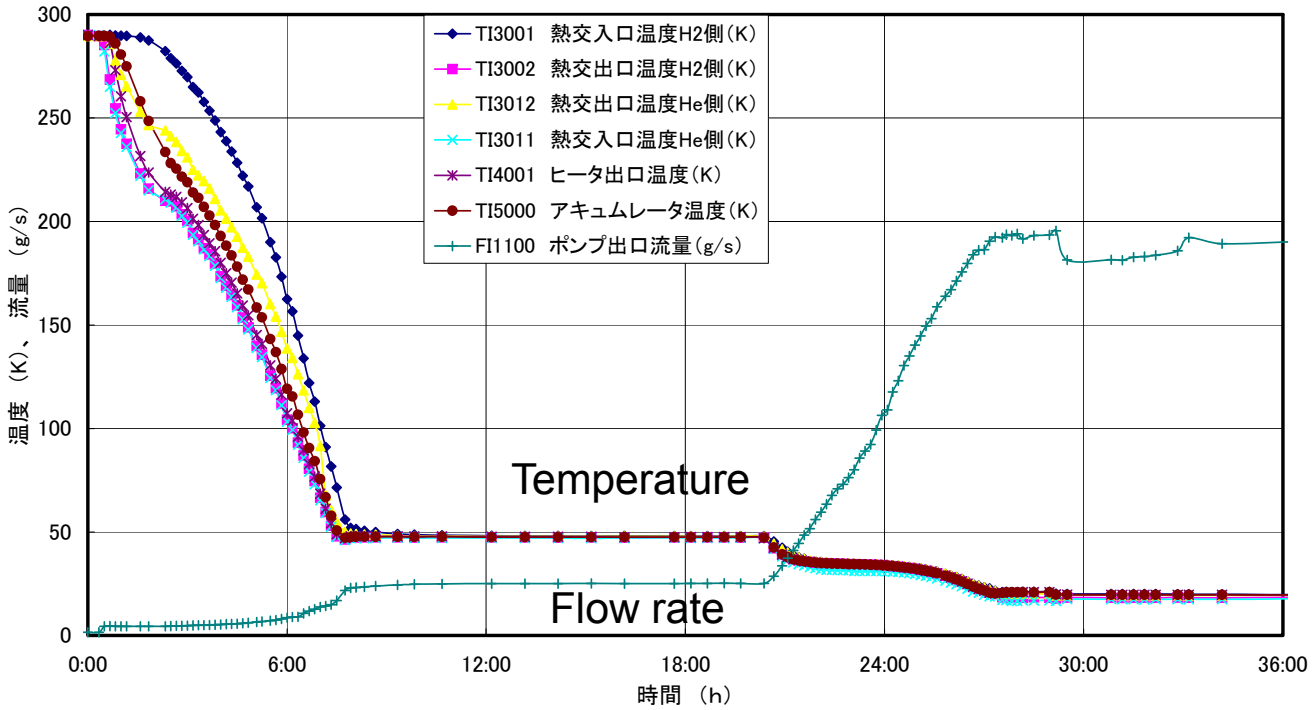


Warm-up

③ Hydrogen circulation system without moderators

Operating test by hydrogen gas

Temperature and flow rate of hydrogen in the cryogenic hydrogen circulation system at cool-down

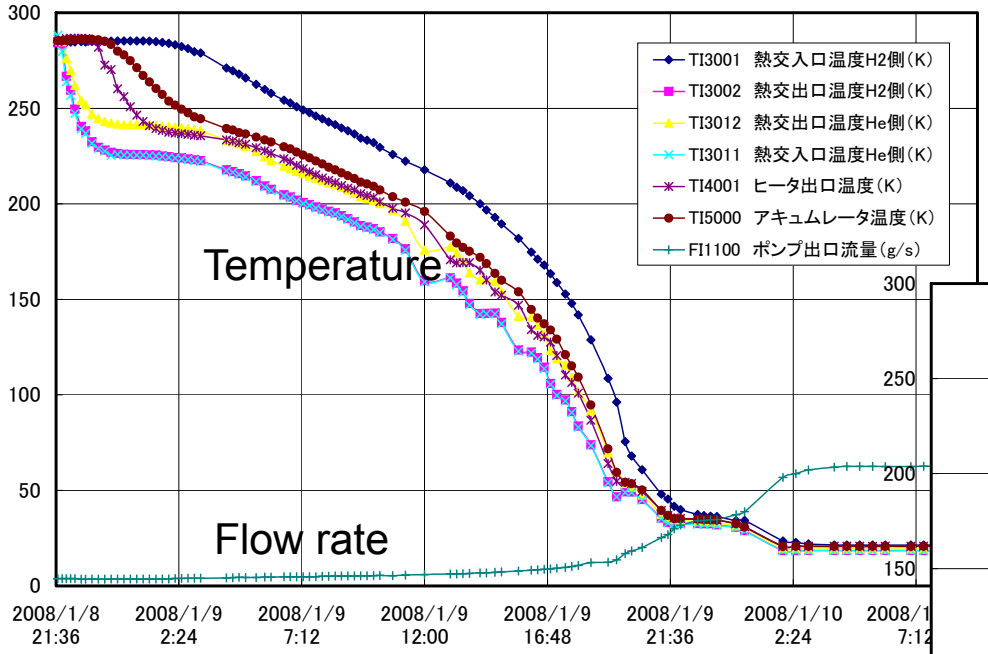


Cool-down

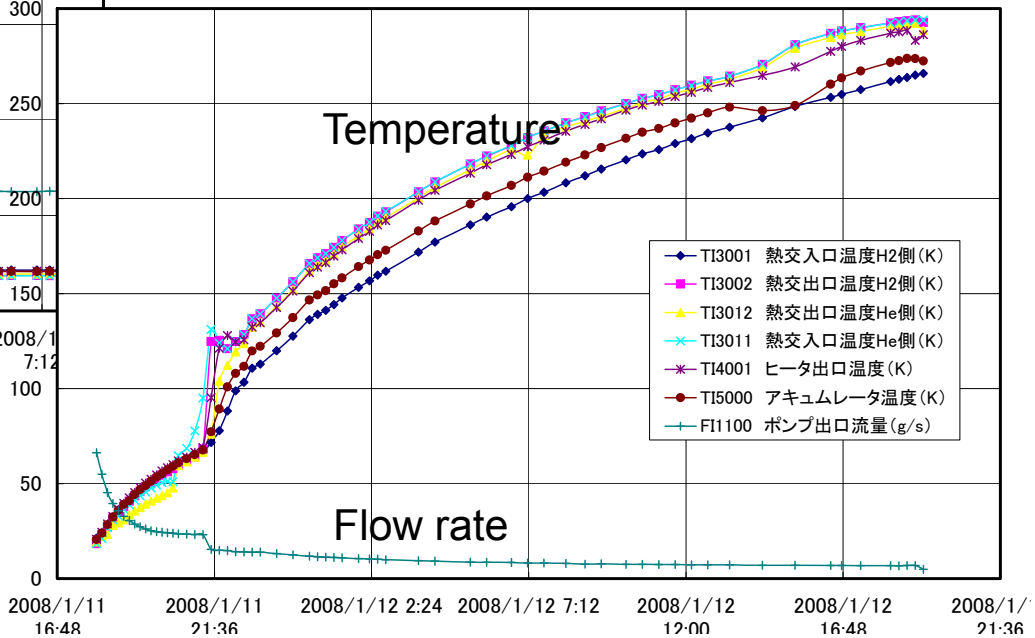
④ Hydrogen circulation system with moderators

Operating test by helium gas

Temperature and flow rate of helium in the cryogenic hydrogen circulation system at cool-down and warm-up



Cool-down



Warm-up

④ Hydrogen circulation system with moderators

Operating test by hydrogen gas

Temperature and flow rate of hydrogen in the cryogenic hydrogen circulation system at cool-down and warm-up