S1-G Cryomodule Thermal Tests (Proposal)

KEK, Norihito Ohuchi

Measurements of thermal characteristics of Module A and C

- Scheduled test period for thermal measurements
  - 1 week before summer shut down
    - Preparatory measurement of the static heat load of the Module-A and C
  - 3 weeks after summer shut down
- Heat load measurements
  - Heat loads of the modules are mainly measured by the mass flow rate of evaporated 2K LHe.
  - Static heat load of Module A and C
  - Dynamic heat load of DESY, FNAL and KEK cavities at the average gradient of 31.5 MV/m
  - Heat loads at 4K are measured during the cool-down of modules (back-up measurement).
- Temperature profile
  - The temperature profiles of the components are automatically measured during all test period.
    - Cool-down and warm-up stages (two times)
    - Operating conditions of cavities.
  - Temperature measurement by Cernox, PtCo and CC.
- Position change of cavities and GRP during cold test
  - Positions of KEK cavities by Wire Position Monitor (WPM)
  - Positions and deformations of GRPs of Module A and C by WPM and strain gauges
  - Positions of GRP of Module A by Laser Position Monitors
    - The measurement will be performed in the first experimental term. In the second term, the holes on the vacuum vessel and 80K shield are closed for the heat load measurements.

Heat load measurements-1

- Mass flow rate of evaporated 2K LHe is measured by the volume flow meter at room temperature and atmosphere pressure after the pump units.
  - The precision of the measurement is in the range of 0.2 W from the STF experiment .
  - The measuring range of the volume flow meter is 0-3.2g/s. The smaller size flow meter will be prepared.
- Static heat load measurement of Module A and C
  - The static heat load of Module A and C is measured at the same time, not separated.
  - Measuring period at 2K: 1 week in the second test term
    - Two days: static heat load measurements
    - Two days: the calibration of these measurements by the heater
    - One day: preparation of the measurements
    - The measurement will be scheduled after the cavity performance tests in the second term.
  - Preparatory measurement of static heat load during the last week in the first term: 1 week
    - The Module-A has holes for measuring the movement of the gas return pipe by the laser position monitors.
    - The static heat load measurements and the calibration by the heater will be done for two days, respectively.
  - Heat load measurements at 4K during the cool downs in the first and second terms.
    - Three days: before cooling the system down to 2K and after keeping the level of 4K liquid helium at the operating condition, the heat loads of two modules and 2K cold box will be measured.
    - This measurements are required for confirmation of system soundness in the thermal performance.

Heat load measurements-2

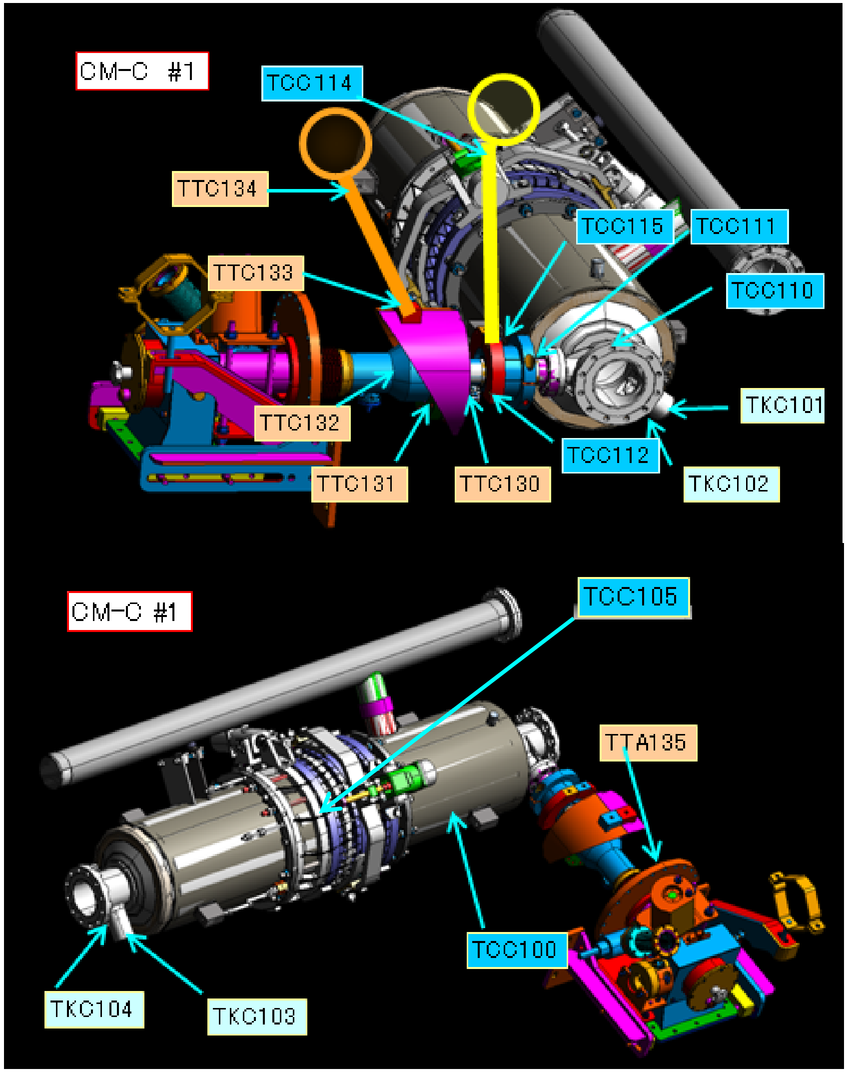
- Dynamic heat load measurement of DESY, FNAL and KEK cavities at the average field gradient of 31.5 MV/m
- At the first stage:
  - Dynamic heat load measurement of each cavity at its maximum operating field.
    - Heat load of each cavity in the detuned condition should be measured in the same day after the dynamic measurement.
    - One day for measuring one cavity in the maximum field and the detuned conditions is required.
    - In total, the period of 8 days should be scheduled.
- At the second stage:
  - Dynamic heat load of eight cavities, all together at the average field gradient of 31.5 MV/m.
    - Two days will be requested.

- For these measurements, the cryogenic system need to be a stable condition thermally. For one parameter change, it takes two hours for the system to be stable.

Temperature profiles of the components

- Temperature profiles of the components are measured during the cool-down and warm-up, and in parallel with the heat load measurements.
- The measured temperature profiles are compared with thermal calculation results of the components.
- Temperature sensors for Module-A and C:
  - Cernox (2K – 100K) : 50
  - Calibrated carbon resistor (2K – 100K) : 32
  - PtCo (2K – 300K) : 51
  - CC thermocouple (70K – 300K) : 68

Temperature sensors on cavity jacket and input coupler



Tag No	Position of measurement
TCC100	Helium Vessel
TKC101	HOM coupler in the input coupler side-top
TKC102	HOM coupler in the input coupler side-bottom
TKC103	HOM coupler in the non-input coupler side-top
TKC104	HOM coupler in the non-input coupler side-bottom
TCC105	Piezo
TCC110	Connection area of input coupler with beam pipe
TCC111	5K thermal intercept of input coupler (beam pipe side)
TCC112	5K thermal intercept of input coupler (body)
TCC114	5K thermal intercept of input coupler (cooling pipe side)
TTC115	5K thermal intercept of input coupler (intercept side)
TTC130	80K thermal intercept of input coupler (beam pipe side)
TTC131	80K thermal intercept of input coupler (body)
TTC132	80K thermal intercept of input coupler (vacuum vessel side)
TTC133	80K thermal intercept brade of input coupler (coupler side)
TTC134	80K thermal intercept brade of input coupler (cooling pipe side)
TTC135	Input coupler (room temperature and in the vacuum vessel)

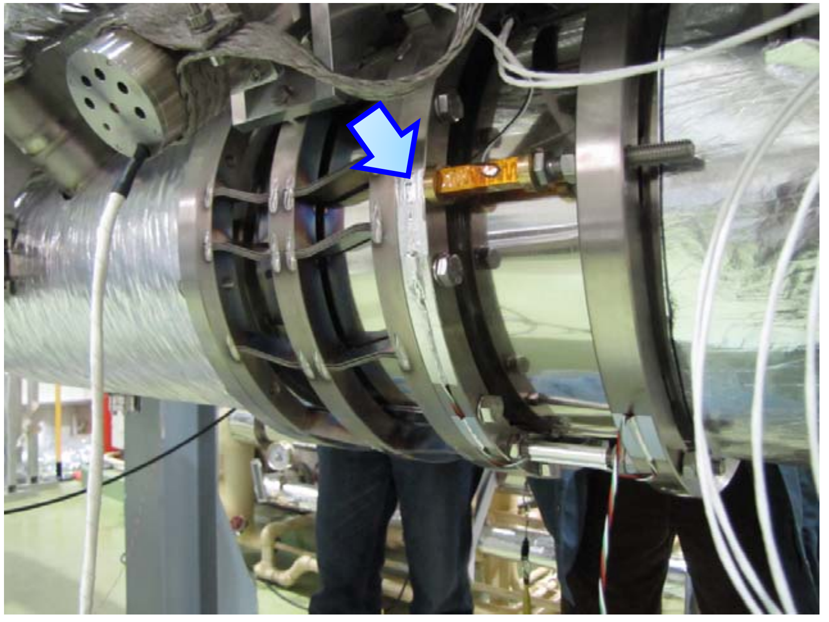
Cernox:7, Carbon resistor:4, CC: 6

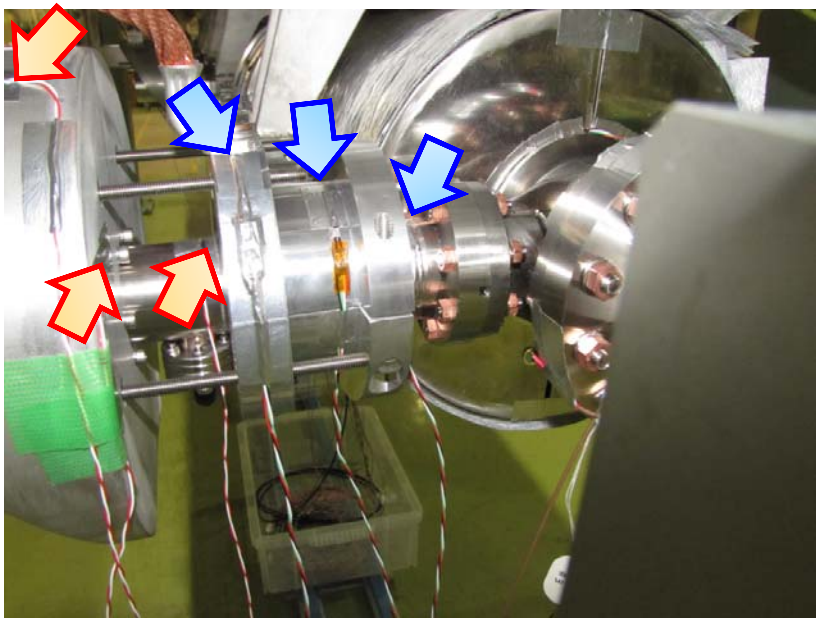
Cavity vessel= 1

Input coupler= 11 (including thermal intercepts)

HOM coupler= 4

Piezo= 1

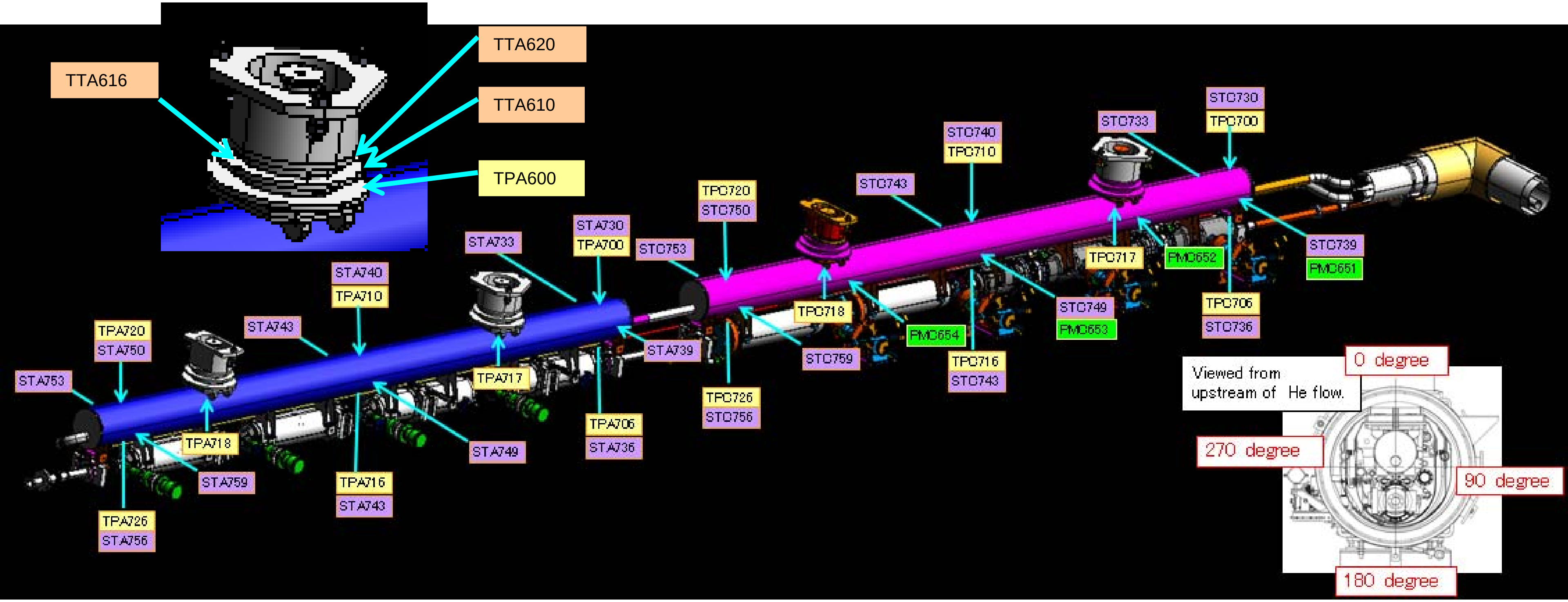





AES004
TKC104
TKC103


AES004 TCC100 100mm

Sensors on GRP and support posts



PtCo : 20, CC thermocouples : 12
GRP= 16
Support Post= 20

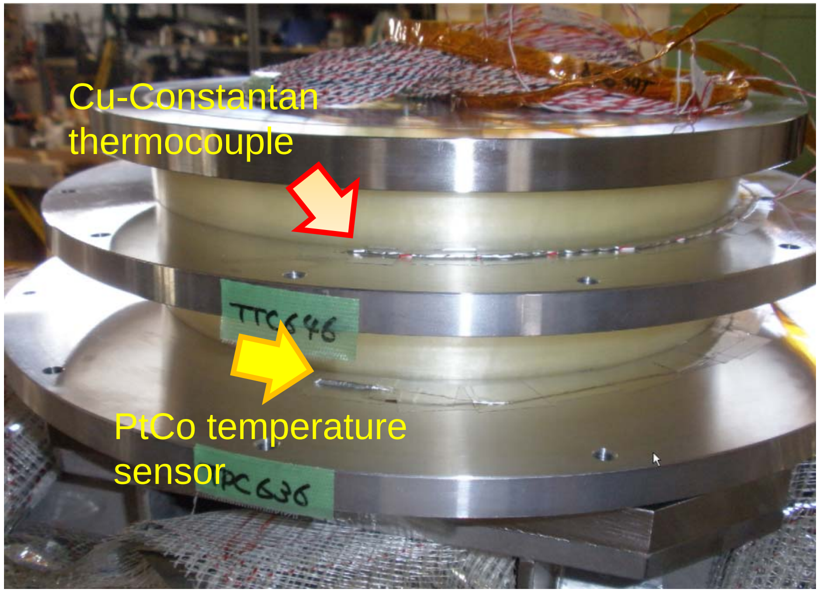
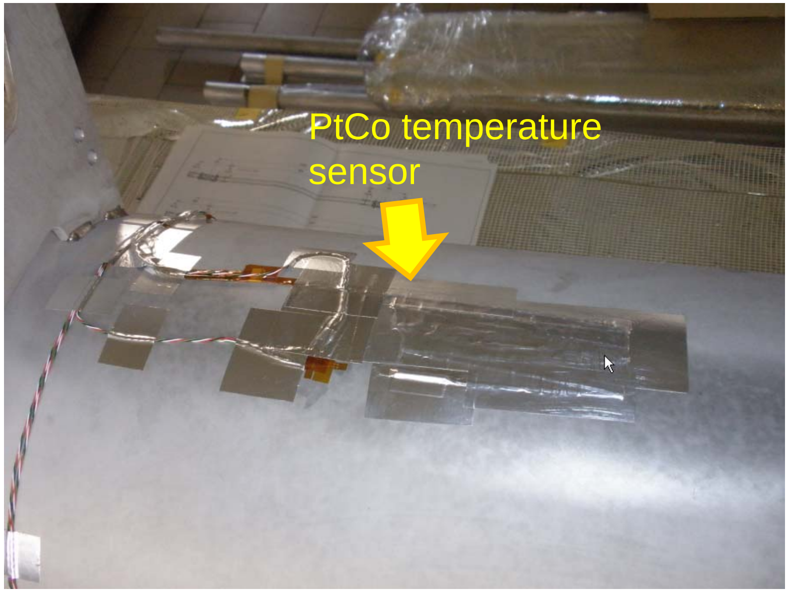
For measuring the GRP deformation
Strain gauge: 24 positions
(3 positions along the GRP axis, and 4 azimuthal positions for one GRP)

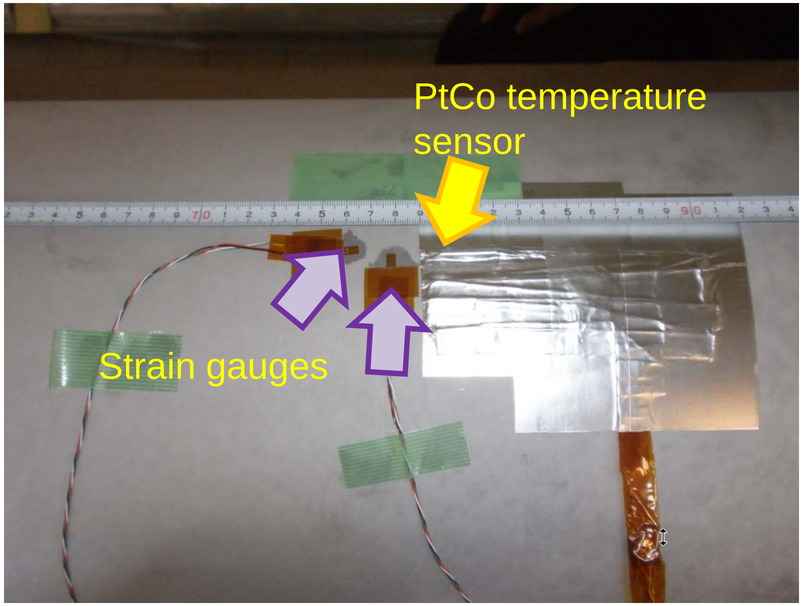
Module-A GRP

Tag No	Position of measurement
TPA700	Upstream-top (Module-A connection side)
TPA706	Upstream-bottom
TPA710	Center-top
TPA716	Center-bottom
TPA717	Connection area between S.P and GRP(F)
TPA718	Connection area between S.P and GRP(M)
TPA720	Downstream-top (end flange side)
TPA726	Downstream-bottom
STA730	0 degree in the side of Upstream
STA733	90 degree in the side of Upstream
STA736	180 degree in the side of Upstream
STA739	270 degree in the side of Upstream
STA740	0 degree in the center
STA743	90 degree in the center
STA746	180 degree in the center
STA749	270 degree in the center
STA750	0 degree in the side of end flange
STA753	90 degree in the side of end flange
STA756	180 degree in the side of end flange
STA759	270 degree in the side of end flange

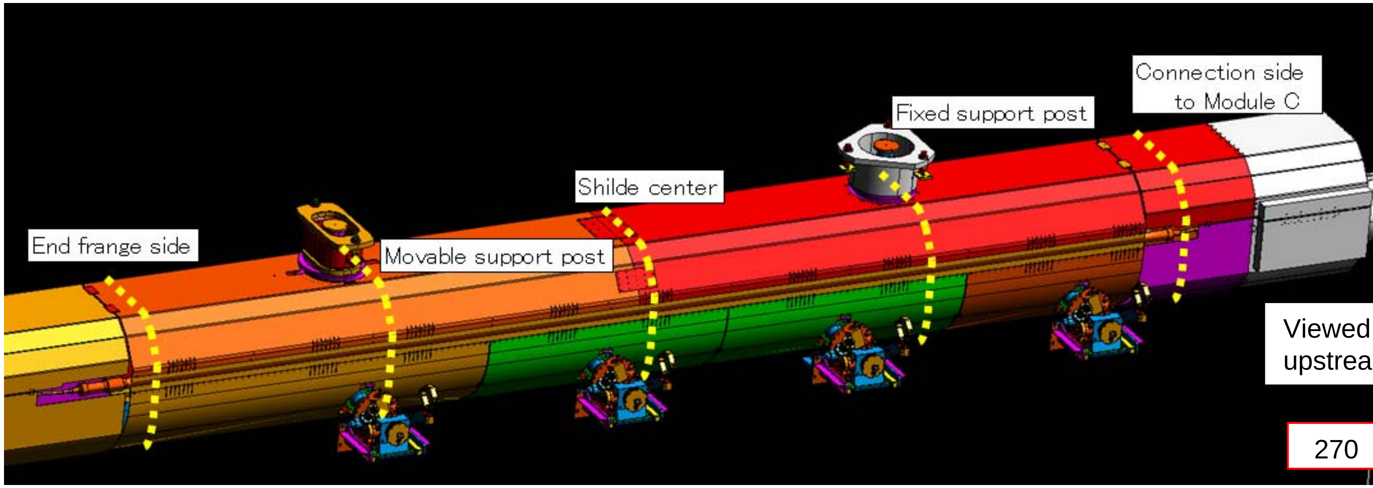
Module-C GRP

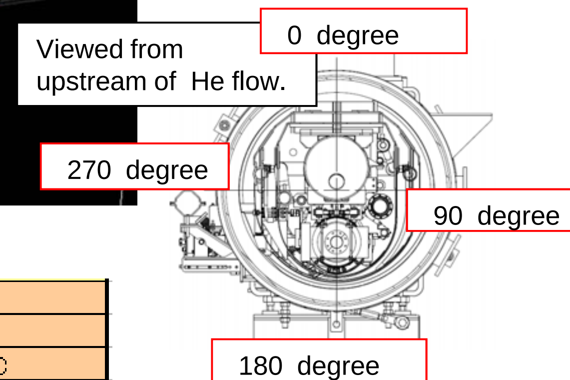
Tag No	Position of measurement
TPC700	Upstream-top (Module-C connection side)
TPC706	Upstream-bottom
TPC710	Center-top
TPC716	Center-bottom
TPC717	Connection area between S.P and GRP(F)
TPC718	Connection area between S.P and GRP(F)
TPC720	Downstream-top (end flange side)
TPC726	Downstream-bottom
STC730	0 degree in the side of Upstream
STC733	90 degree in the side of Upstream
STC736	180 degree in the side of Upstream
STC739	270 degree in the side of Upstream
STC740	0 degree in the center
STC743	90 degree in the center
STC746	180 degree in the center
STC749	270 degree in the center
STC750	0 degree in the side of end flange
STC753	90 degree in the side of end flange
STC756	180 degree in the side of end flange
STC759	270 degree in the side of end flange


Cu-Constantan
thermocouple
TTC646
PtCo temperature
sensor

PtCo temperature
sensor


PtCo temperature
sensor
Strain gauges

Temperature sensors on thermal shields





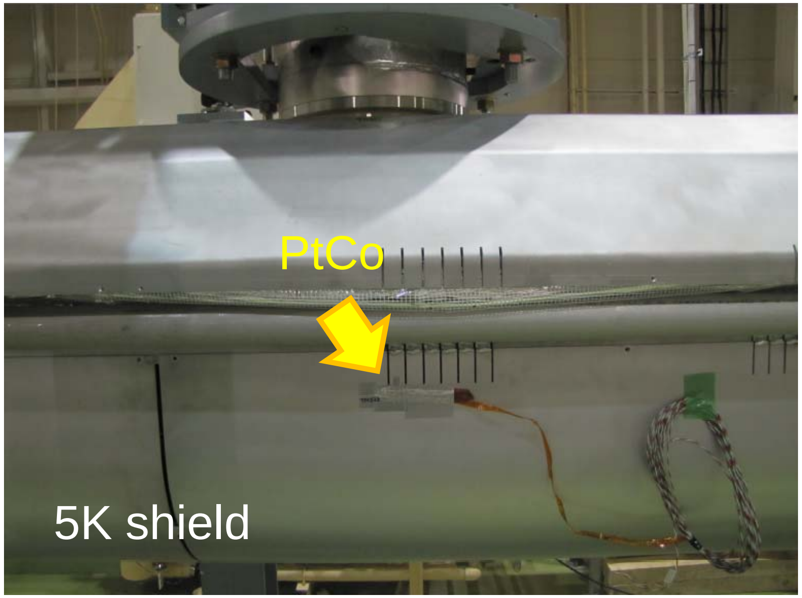
Tag No	Position of measurement
TPC510	0 degree in the side of module-C
TPC513	90 degree in the side of module-C
TPC516	180 degree in the side of module-C
TPC519	270 degree in the side of module-C
TPC529	90 degree at fixed support post
TPC533	90 degree at shield center
TPC536	180 degree at shield center
TPC539	270 degree at shield center
TPC549	270 degree at movable support post
TPC550	0 degree in the side of end flange
TPC553	90 degree in the side of end flange
TPC556	180 degree in the side of end flange
TPC559	270 degree in the side of end flange

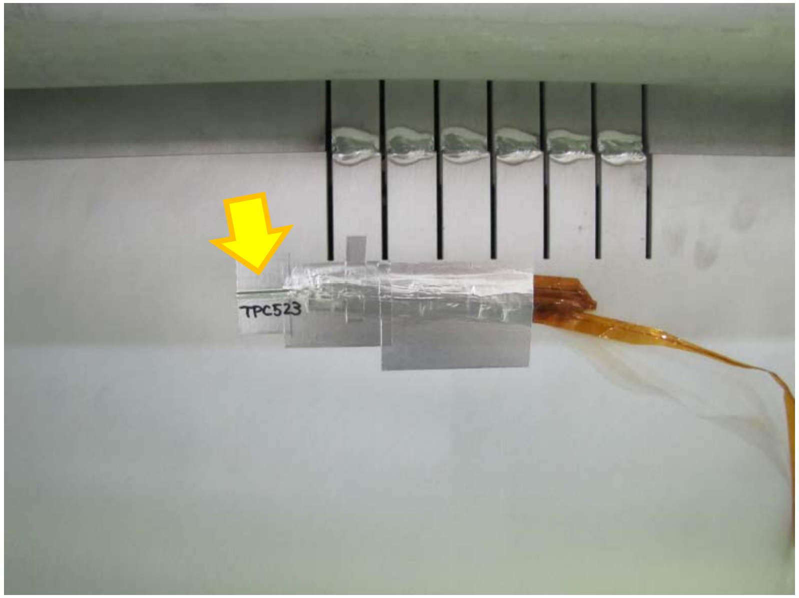
Module-C:
PtCo 13

TTC810	0 degree in the side of module-C
TTC813	90 degree in the side of module-C
TTC816	180 degree in the side of module-C
TTC819	270 degree in the side of module-C
TTC830	0 degree in the center
TTC833	90 degree in the center
TTC836	180 degree in the center
TTC839	270 degree in the center
TTC850	0 degree in the side of end flange
TTC853	90 degree in the side of end flange
TTC856	180 degree in the side of end flange
TTC859	270 degree in the side of end flange

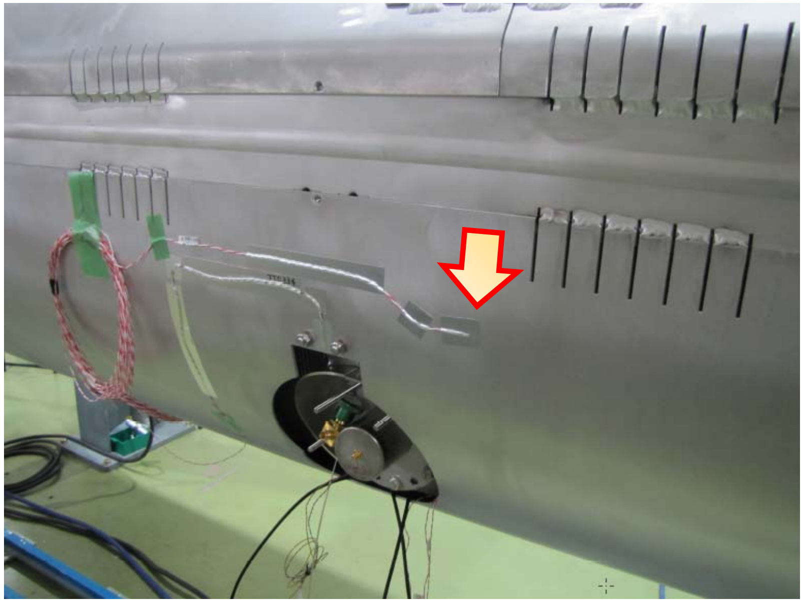
Module-C:
Cu-Constantan thermocouple 12

For Module-A and -C
5K shield
PtCo : 27
80K shield
CC : 24


PtCo
5K shield


TPC523

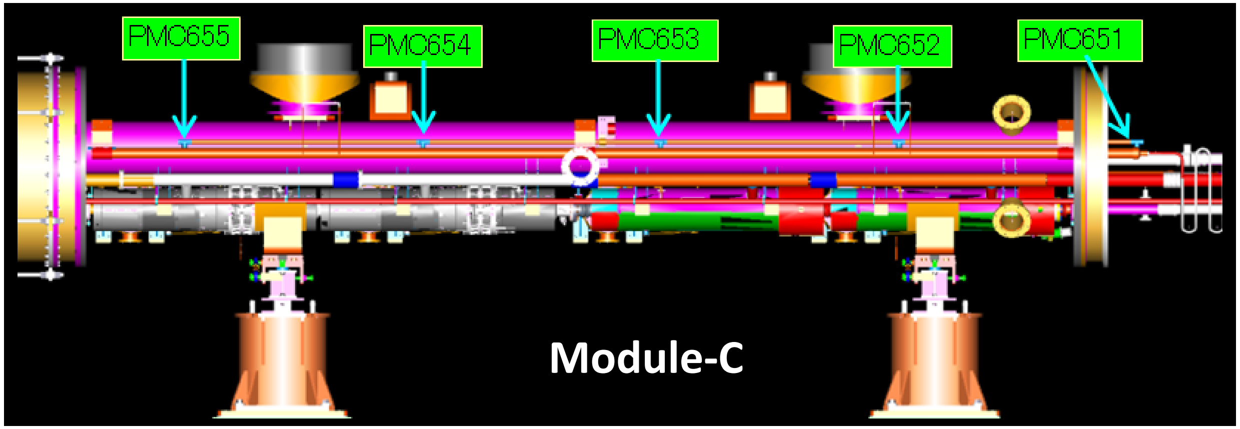

80K shield

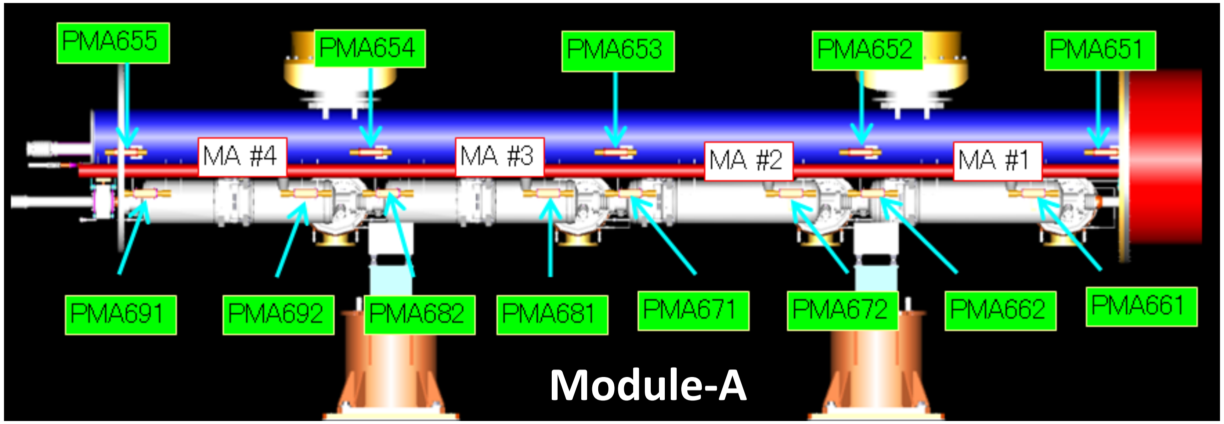


Position measurement of cavities and GRP

Measurement of position of cavities and GRP by WPM

- Module-C
  - 5 WPMs are assembled on the GRP.
- Module-A
  - 5 WPMs on the GRP and 2 WPMs for each cavity are assembled. In total, 13 WPMs.



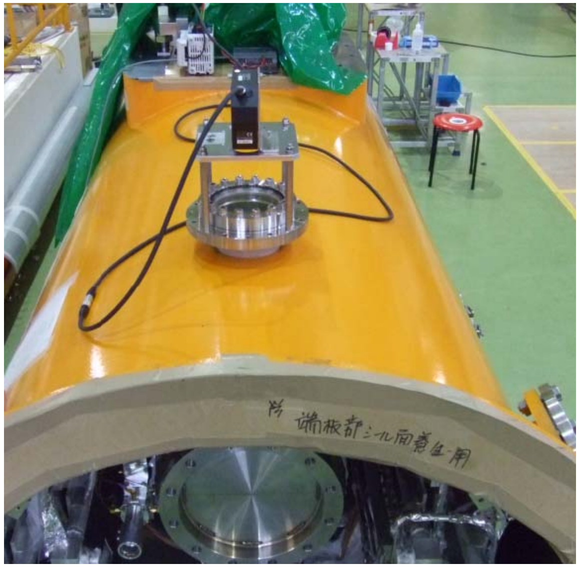


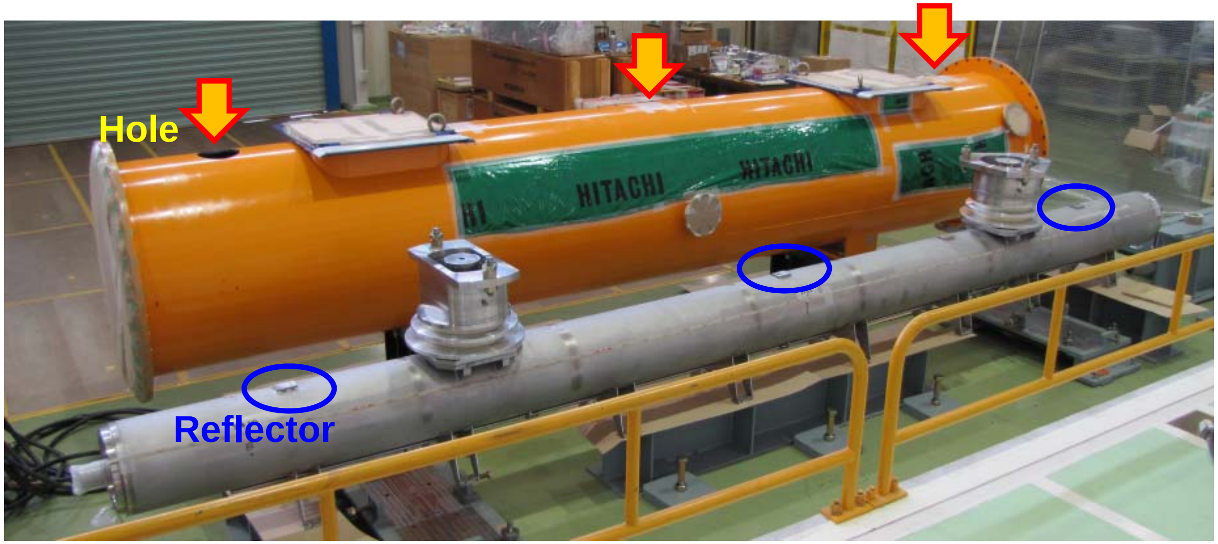
Measurement by laser position monitor

The laser position monitors were applied for measuring the change in the GRP shape of Module-B.

3 laser position monitors are used for measuring the GRP deformations of Module-A during the cold test before summer shut-down.   Precision of the measurement is in the level of a few micro-meter.

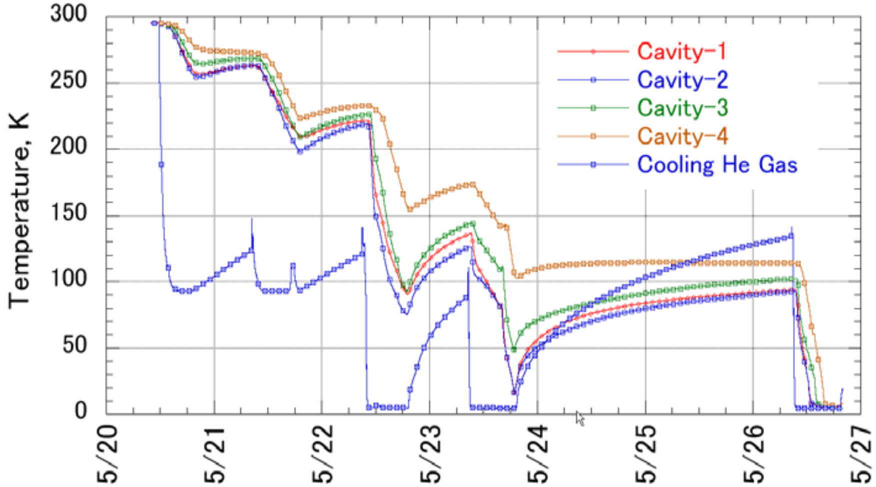
- For this measurement, the thermal radiation shields need to have holes to introduce laser to the GRP.
- Measurement with these monitors are scheduled in the first test term.
- In the second term, the windows on the vacuum vessel and the holes on the 80K shield are closed with the flanges and the Super Insulation.





Laser position monitors for measuring the GRP positions

Cool-down of Module-A by STF cryogenic system



Cooling was performed during the normal working time:

1. **The first step of cool-down of the Module-A with four cavities**
   - **In the first two days, four cavities and the GRP were cooled to 200 K by helium gas at 90 K.**
   - **The total mass flow rate was 1.0 g/s, and the typical cooling speed of the cavities was 7.3 K/h.**
2. **Cool-down from 200 K to 4K**
   - **Liquid helium at 4 K was directly transferred from the liquid helium Dewar of 2000 L on the ground level to the cryomodule in the tunnel.**
   - **In the cooling process, the cooling speed of cavities was 12.5 K/h.**
   - **The total time for cooling four cavities from room temperature to 4K was 49 hours.**

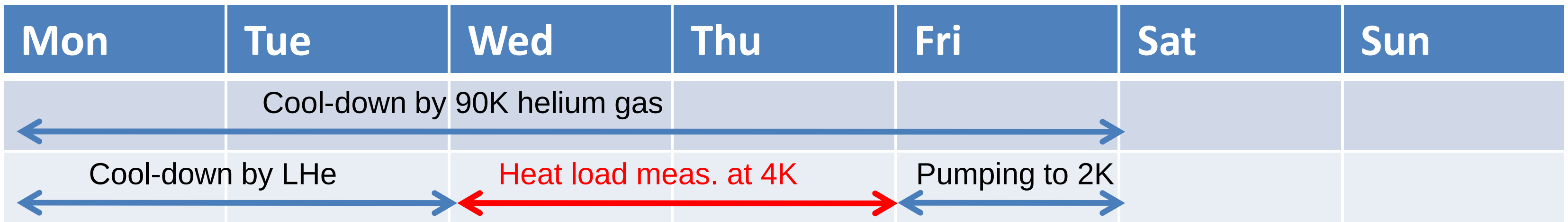
During the thermal tests of S1-G cryomodules:

- **Cooling 80 K thermal shields will be kept for 24 hours.**
- **Supplying and pumping LHe will be performed from 8:00 to 22:00 or for 24 hours.**

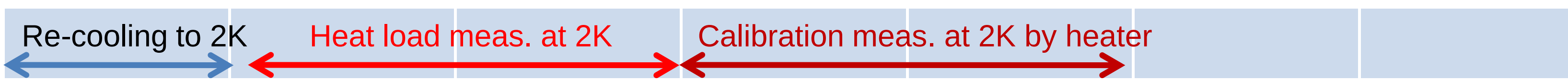
Time schedule for the thermal test of S1-G modules

In the first test term

Cool-down and thermal test at 4K



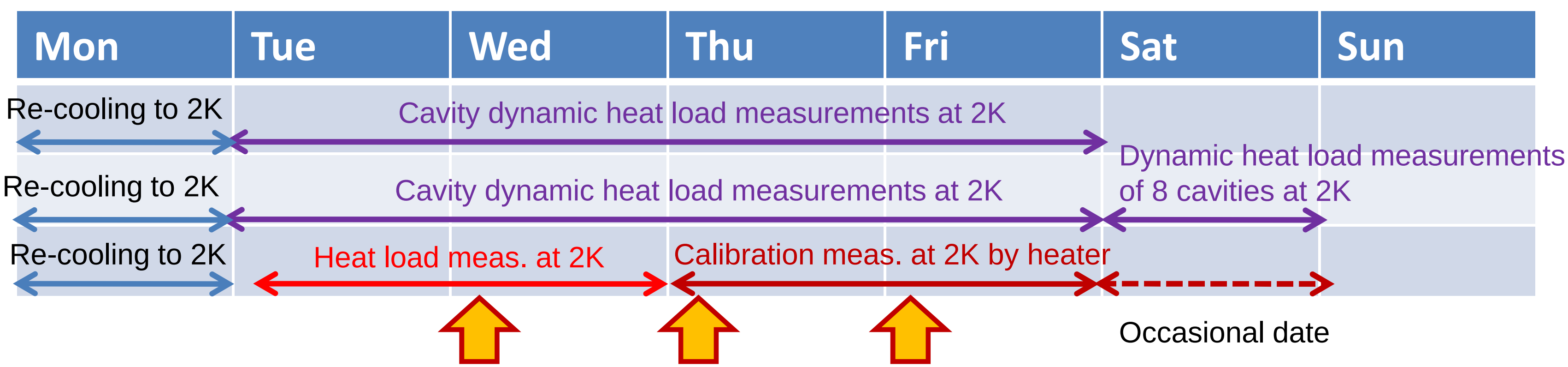
Thermal test at 2K



In the second test term

Cool-down and thermal test at 4K are same as in the first term

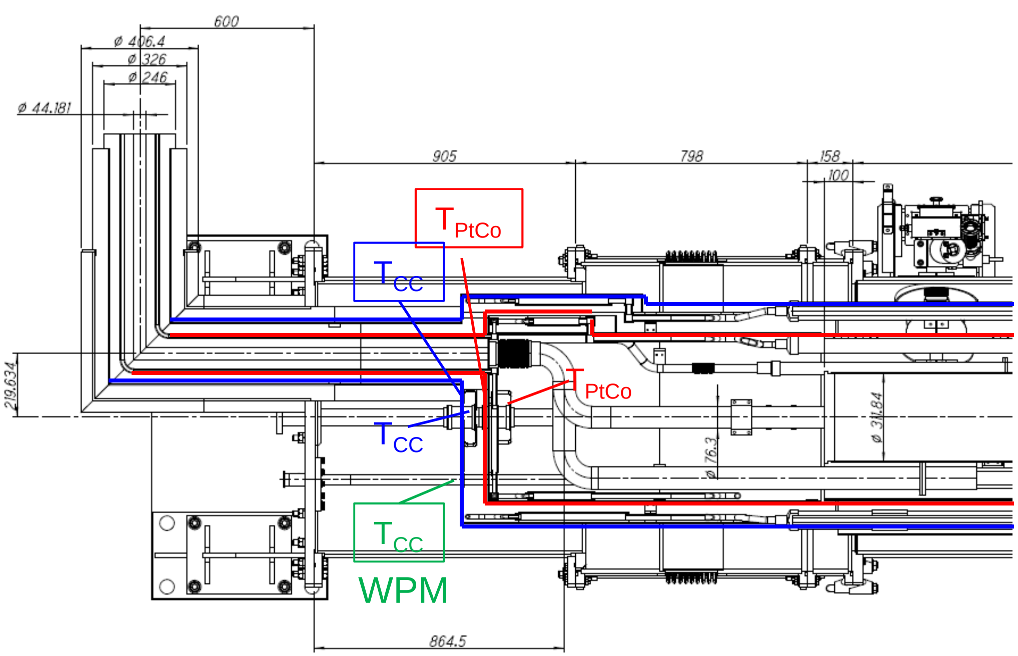
Thermal test at 2K



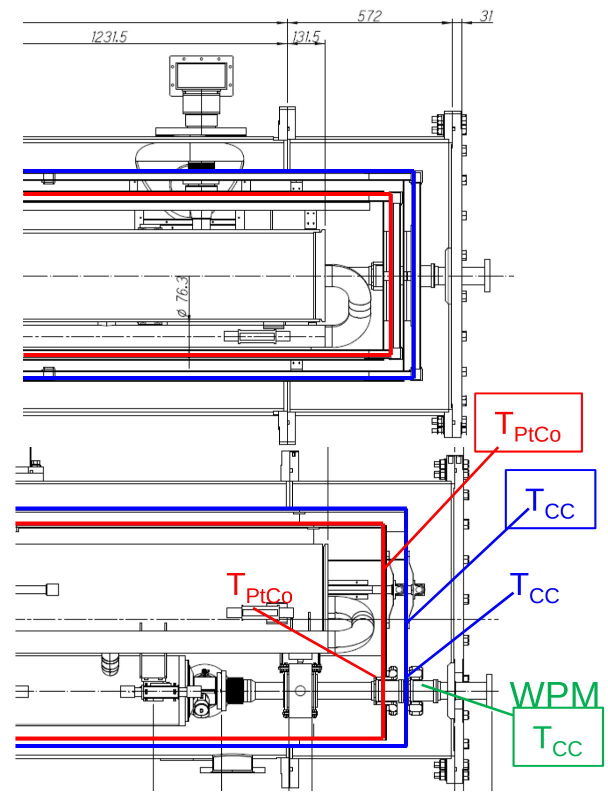
Heat load measurement at 2.5K in the process of pumping.
Steady state condition should be attained at 2.5K.

Discussions: comments from Tom Peterson

1. As we have discussed, end effects are always a source of an uncertain amount of additional heat in a thermal test. My experience with magnets is that end effects will typically add a few Watts at each end. This may create some uncertainty in the static heat load data, however, dynamic heat loads should still provide a clear signal on top of the static baseline. As Jim mentioned in the meeting today, instrumentation in the end boxes can help to untangle some of those questions about end effects.



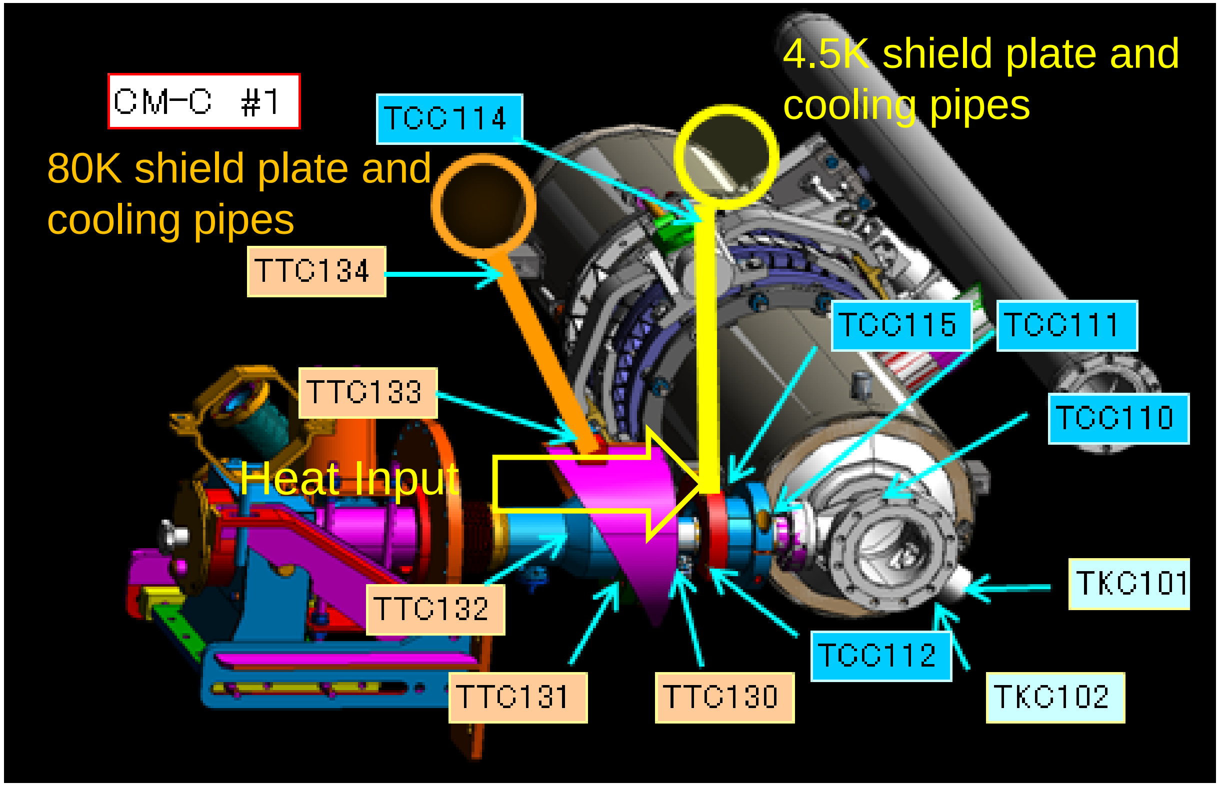
Module-C end



Module-A end

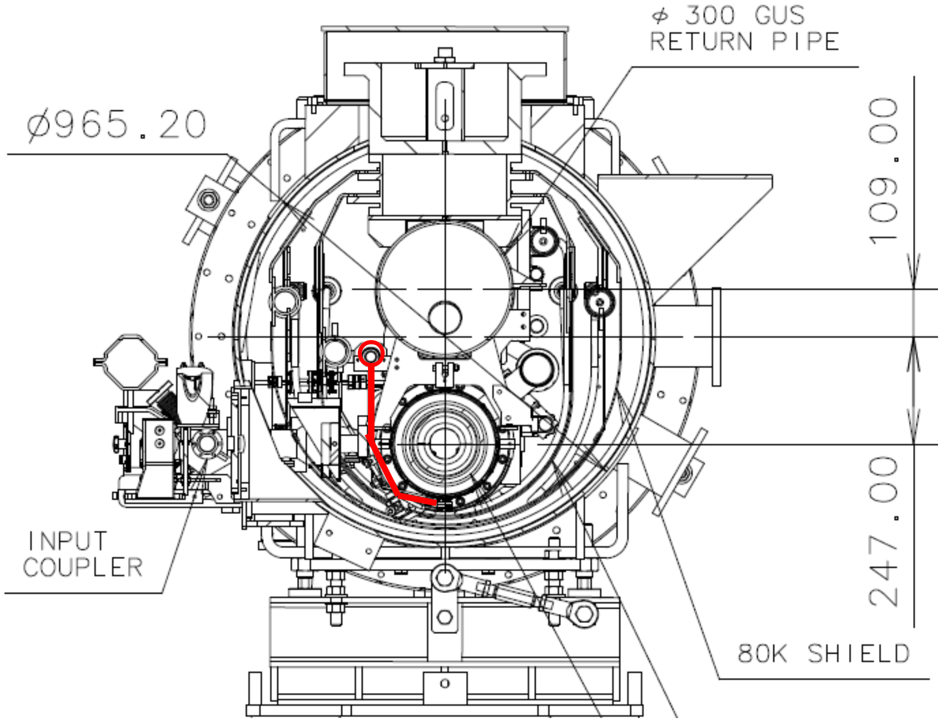
2. 4.5 K heat load measurement. This heat load measurement should provide an interesting comparison to the 2 K heat load. If your 4.5 K thermal shield cooling is at the same temperature as the helium vessels, in theory the static heat load on the helium vessels at 4.5 K would be zero. Deviation from zero will tell you how much heat is getting past the 4.5 K thermal intercepts and thermal radiation shield.

4.5K heat loads of Module-A and –C are measured all together.
The heat load of each module will be separated from the measured temperature profiles of the components.



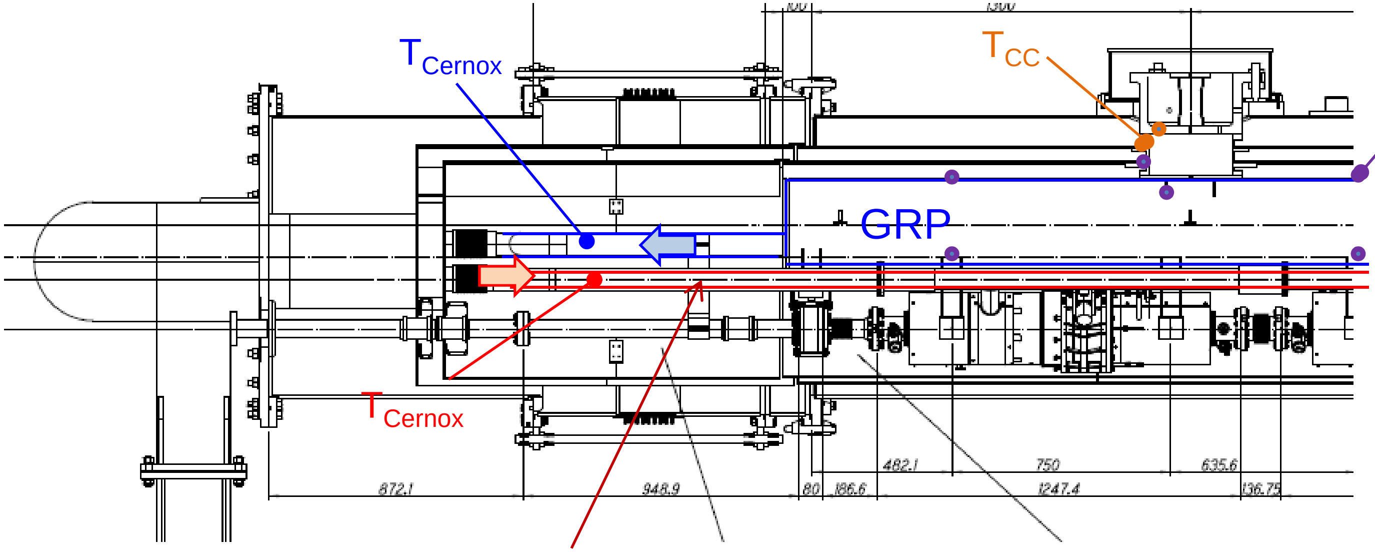
Temperature sensors on the input coupler for the FNAL cavity.
The configuration of the sensors for input coupler is same for the KEK cavity.

3. If you see more heat at 2.0 K than expected, a heat load measurement at 2.5 K can tell you whether the additional heat is at all related to superfluid heat transport, such as heat transport into the system via a cooldown line or vent line which contains superfluid.

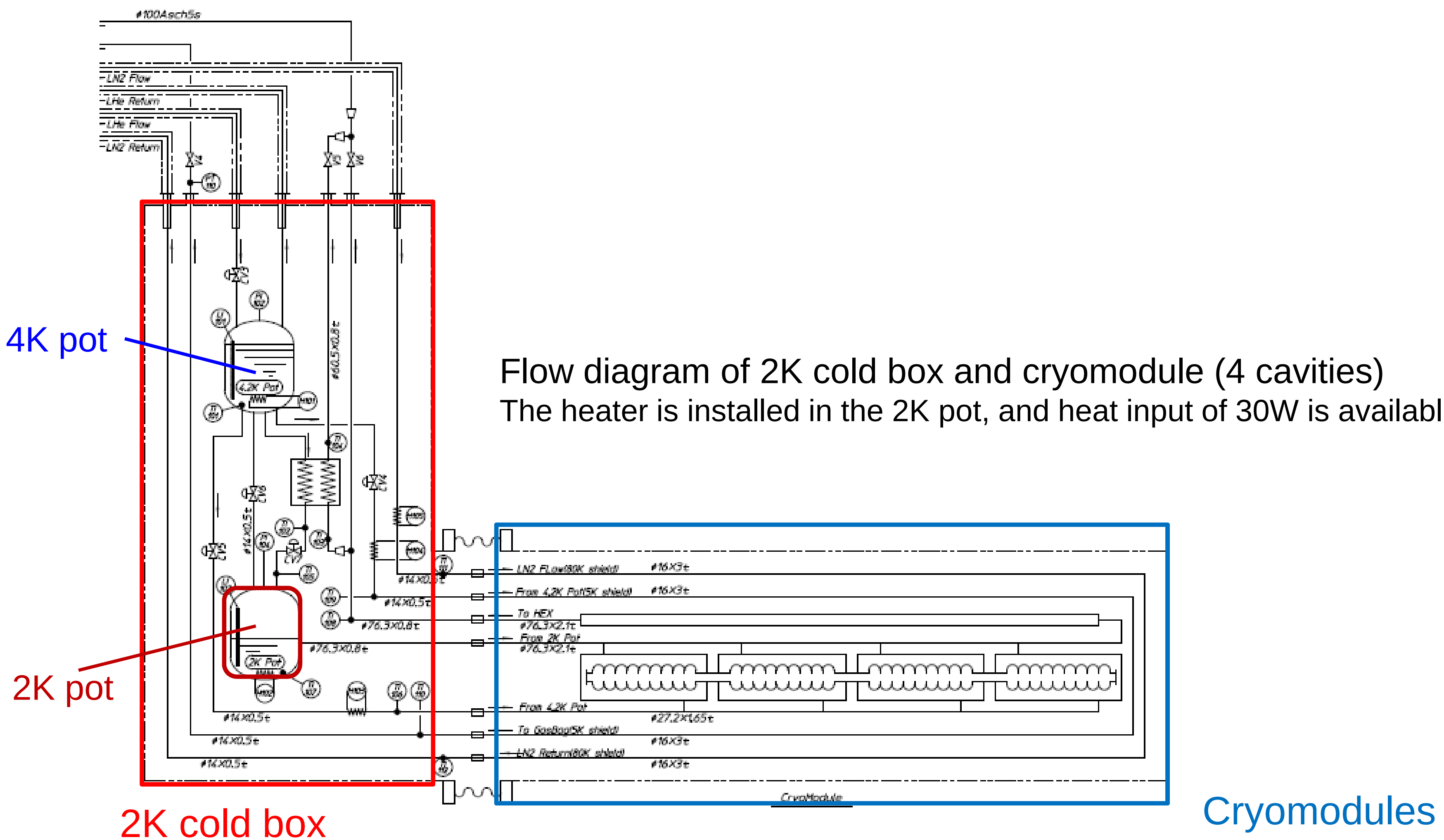


4. A significant portion of 2 K heat may be in the gas return pipe. It receives heat from the support posts, and it has a surface area comparable to the total of the helium vessels. But the boiloff test with liquid will not see the heat in the 2 K gas return pipe. The temperature profile on the 2 K gas pipe will be interesting and may provide some indication of heating of the 2 K pipe, but helium flow rate will be very low. With higher flow rates (such as during a dynamic heating test) the better heat transfer within the 2 K pipe may result in somewhat better interception of heat to the gas, so one may see some cooling of the gas return pipe with dynamic heating in the cavities. This could, in turn, slightly reduce static cavity heat load. This will all be challenging to interpret, but worth a try. Your very thorough instrumentation will be a great help to understand this.

The higher flow rate will be gotten by the heater in the 2K pot in the 2K cold box.
The measurement of heat load at the GRP could be measured by the T sensor in the return line.



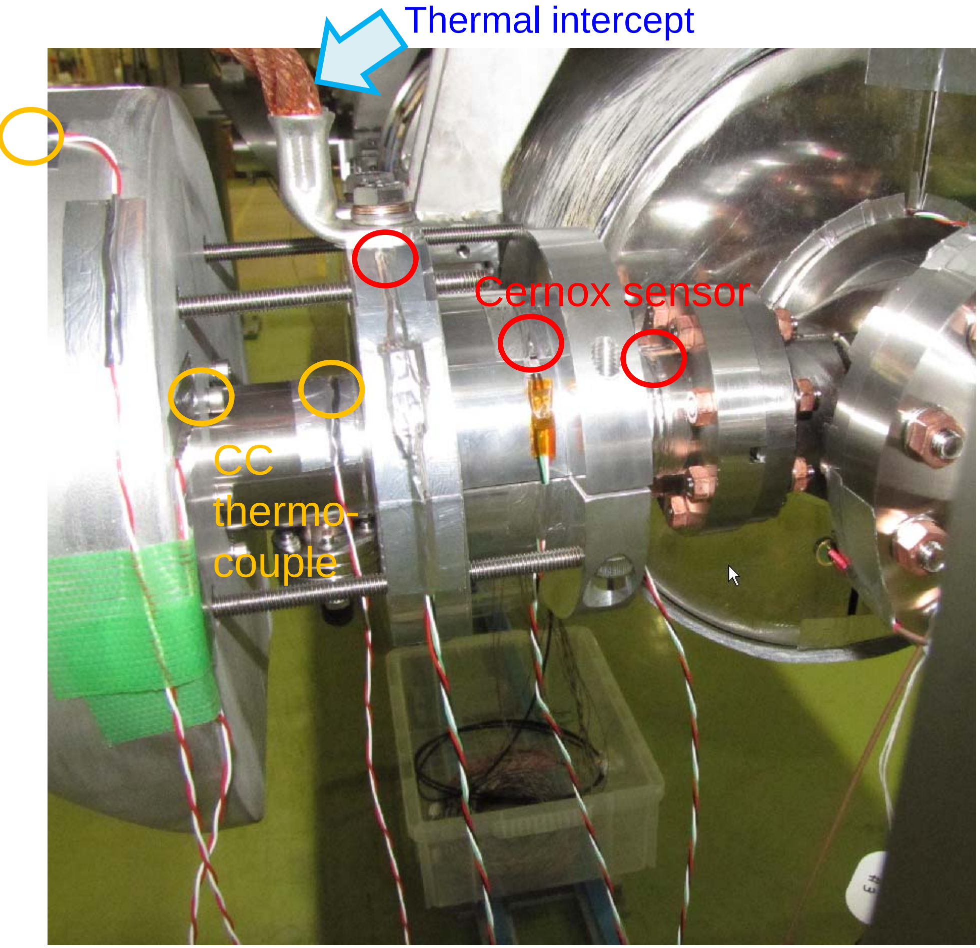
5. What will be the power of the calibration heaters? Calibration heaters which add heat loads comparable to the total dynamic heating (say 10 W to 15 W) could help to understand any non-linearity in heat appearing at the cavities (as a function of heater power) due to the issue described in #4 above.



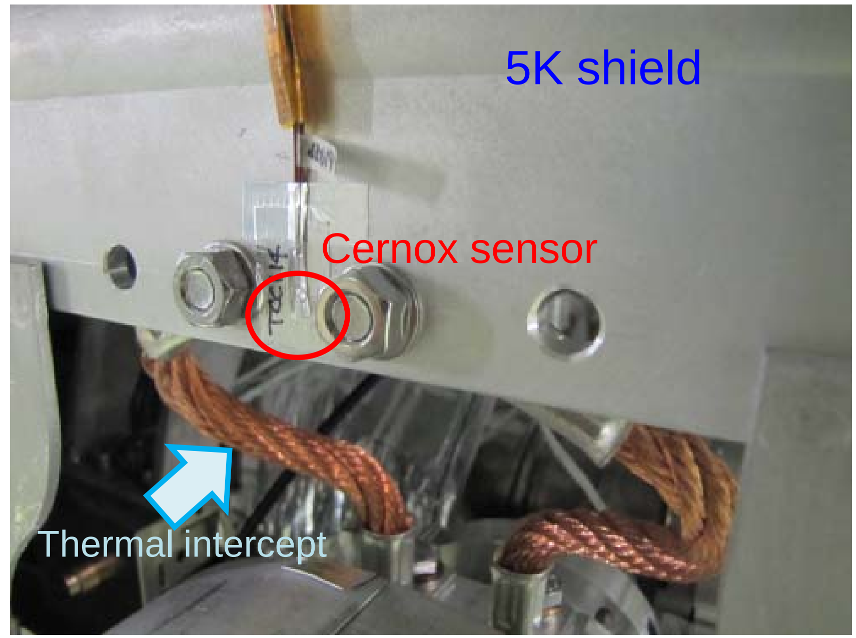
Flow diagram of 2K cold box and cryomodule (4 cavities)

The heater is installed in the 2K pot, and heat input of 30W is available.

6. Temperature differences from one end of a thermal strap to the other end should provide some nice indications of heat loads at thermal intercepts, such as on the input couplers, etc. Again, these data should be quite interesting.



T-sensors on the input coupler



Connection of 5K thermal intercepts to 5 K shield.
Indium sheet was sandwiched. T-sensor is Cernox.

7. You mentioned an overnight pause of cryogenics, then pumping back down to 2 K in the morning. We did the same thing for our US-LHC magnet tests at 2 K. We occasionally had problems with air in-leaks after pumps were shut off but the system remained at 2 K, subatmospheric. I think that our pump seals leaked when the pumps were no longer rotating, and unfortunately we did not have double-seals. You probably already have experience with how to prevent such leaks. The result for us was also typically to test starting at about noon, and testing continued into the evening. Your comment about a 2-hour wait for equilibrium and the time for doing these tests all seem about right to me, based on our experienceng.