External review (KAGRA Cryogenics) on April 2012

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This chapter separates into two sections. The first half of the chapter (written by Toshikazu Suzuki) describes about the cooling system that contains cryostats, cryocoolers and shield ducts. In the second half (written by Kazuhiro Yamamoto), it describes about cryogenic payload.

Cooling system

1 Overview

1.1 Definition and scope of the subsystem

The following equipments belong to the category of Cryogenics subsystem.

- Cryostat (Cryochamber)
- 4K Cryocooler unit (Double stage PTC with vibration isolation structure)
- Shield duct
- 80K Cryocooler unit (Single stage PTC with vibration isolation structure)
- Instruments for monitoring cryogenic equipments
- Cryogenic Payload

The function of the Cryogenic subsystem is to carry out the following items for the categorized equipments.

- Design

- Prototype test (if possible)
- Manufacture
- Inspection
- Storage and Transportation
- Installation
- Adjustment

1.2 Important interface

1.2.1 Vacuum

- Low outgassing specifications.
  - Polishing inner wall of chambers and shields.
  - Selection of materials, thin SI film.
- Leakage, accumulation of condensable gas.

1.2.2 Vibration Isolation

- Chamber connection to SAS-A chamber at the top flange cryostat.
- Cryopayload is suspended from the 300K part of type-A SAS.

1.2.3 Layout

- Distance to gate valve flange.
- Anchor against atmospheric pressure.

1.2.4 Tunnel

- Transport through arm tunnel.
- Layout in laboratory room, piping pits, gas piping and the target position of installation.
- Crane or machine for loading/unloading of heavy components.
- Waste heat from compressors.
- Soundproofing area for compressors.

1.2.5 Mirror

- Absorption of 1064nm light.
- Scattering of main beam.

1.2.6 Auxiliary Optics

- Optical monitor of test mass/mirror
  - View ports
  - Optical levers.
  - CCD camera (?), Fiber scope (?)
- Baffles with vibration isolation.

1.2.7 Interferometer

- Aperture of thermal radiation baffles.
- Edge scattering of baffles.

1.2.8 Analog electronics

- Thermometer monitor.
- Driver signal of rotary valves.
- Grounding.

1.2.9 Digital system

Logging data from devices and instruments.

- Thermometers per unit
  - Cryostat
    - Si diode 28
    - PtCo 26
    - Heater 2
    - Spare wiring 6
  - Low vibration 4K cryocooler unit
    - Si diode 11
    - PtCo 4

    * Heater 2
  - Compressor
    * 6 channels for monitoring compressor status.

- Pressure monitor
  - Vacuum in cryostat.
  - Supply and return pressure of Helium gas in compressor.

1.2.10 Data acquisition

- Regular maintenance
  - Compressor: Every 3×10^4 hours. The interruption can be minimized by replacing the compressor unit if we have spares.
  - Cryocooler Cold Head: Every 2×10^4 hours. Contents are in the followings.
    1. Replace filter unit.
    2. Replace a sliding parts of the rotary valve unit.
    3. Exchange the enclosed He gas in the cold head.

    It does not take much time for replacements if we have spare parts. The gas exchange on the site is an issue of consideration.

1.2.11 Clean environment

- Assembling in JIS class 7 (US 10000)
  - Cryostat
  - Cryocooler unit
  - Shield Duct
- Assembling/Installation in JIS class 7 (US 10000)
  - Cryopayload

1.3 Design phase

1.3.1 Cryostat

Design of the cryostat that includes cryochamber and double radiation shield has basically finished. Manufacturing contract made with Toshiba in 2011fy. Components of the cryostat are under manufacturing.
Preparation of bidding in 2012fy is in progress.

1.3.2 Low vibration 4K cryocooler unit

Based on the CLIO cryocooler, a prototype was designed and experimentally tested in the summer of 2011. After the prototype test, the contract has made with Jecc Torisha in 2011fy. Assembling seven cryocooler units are in progress.
Preparation of bidding in 2012fy is also in progress.

1.3.3 Shield duct

Basic studies for protection of thermal radiation have performed. An optimal configuration of thermal radiation baffles has calculated. A design of prototype is in progress.

1.3.4 Low vibration 80K cryocooler unit

Preliminary vibration test of bare PTC was performed in the summer of 2011.

1.3.5 Cryopayload

Details are described in another chapter of the document.

2 iKAGRA

2.1 Target specifications

2.1.1 Cryostat

Two cryostats will be installed in the center room. They will work as 300K vacuum chambers for test masses. Another two cryostats will be installed in both end rooms and separated from another part of the vacuum space by the gate valves in the iKAGRA phase. So the function of the cryostats in the end rooms will be independent of iKAGRA operation.

Important specification for the cryostat in the center room

- Shape and sizes: Drawings are shown in Fig.1 and Fig.2.
- Material of the chamber: Stainless steel 304
- Inner surface of the chamber : ECB finish (same as other vacuum chambers)
- Tolerance of machining: According to JIS B0405 standards
- Tolerable limit of leak rate : $\dot{Q} \leq 1\times10^{-10}$ Pa·m^{3}sec^{-1} of He at 300K.

- Accuracy of installation: Within ±2 mm from the target position on the local horizontal plane. The position standards of the installation should be marked before starting installation by an appropriate surveying.

2.1.2 Low vibration 4K cryocooler unit

The cryocooler units in the center room will not operate during the iKAGRA phase. Those will work as 300K vacuum chambers. The main specifications are same as that of cryostat. Drawing is shown in the Fig.5.

2.1.3 Shield ducts and Low vibration 80K cryocooler units

Those apparatus are not equipped to the cryostats in the center room during the iKAGRA.

2.2 Final design

2.2.1 Cryostats and low vibration 4K cryocooler units

Design process of those equipments followed the instructions of the vacuum subsystem. Drawings of cryostat are shown in Fig.1 and Fig.2.
Selection of MLI was based on the measurement of outgassing rate. A new type of SI film have been used for MLI of KAGRA cryo-equipments. Out gassing rate of the SI film decreases to almost the same that of stainless steel surface after 200 hours of pumping. Auxiliary materials that are used for three dimensional fabrication of MLI were also selected by outgassing measurements.
Deformation of the cryostat under atmospheric pressure was analyzed by FEM. The result shows that the maximum deformation of 1.7 mm was occurred at the center of the bottom plate. (Fig.3)
Also buckling was analyzed by FEM. The result show that coefficients of buckling were larger than 17 for the lowest six modes under atmospheric pressure and the weight of 500 kg on the top cap. (Fig.4) Low vibration 4K cryocooler units will not operate in the iKAGRA period. The specifications were determined as vacuum chambers. Part of the design process was the same as that of the cryostat.

2.3 Schedule

In the 2011fy, manufacturing is in progress as shown in the former section. The manufacturing of four cryostats and sixteen cryocooler units will finish In the end of 2012fy if biddings and contracts will be successful.

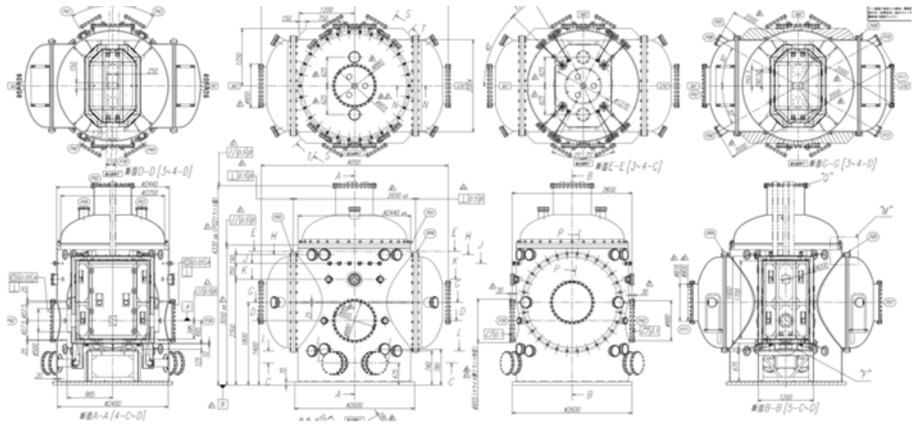

Figure 1: Cryostat (Cryochamber) Drawing: TOSHIBA

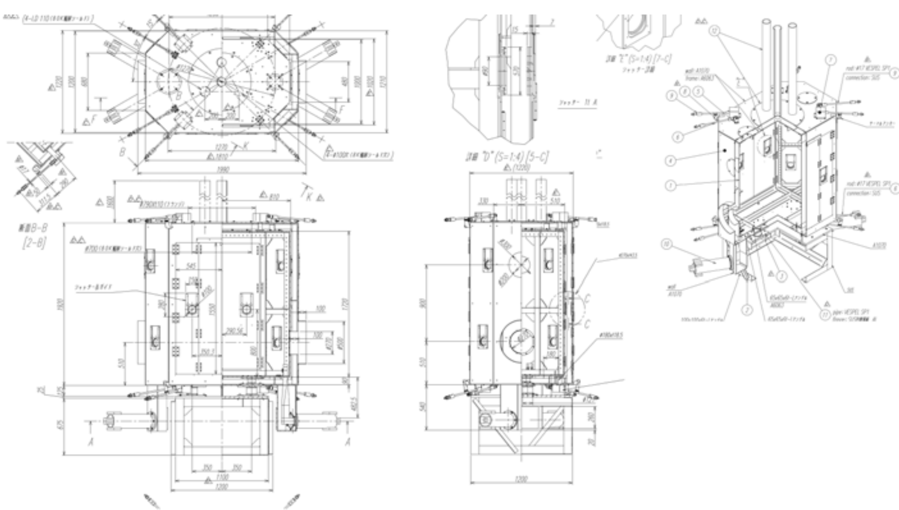

Figure 2: Cryostat (Radiation Shields) Drawing: TOSHIBA

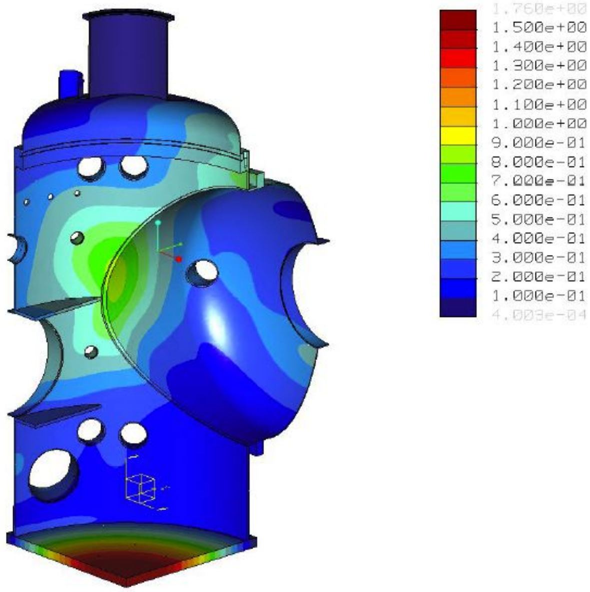

Figure 3: Deformation of cryochamber under atmospheric pressure. Maximum deformation of 1.7 mm was occurred at the center of the bottom plate. Plotting: TOSHIBA

2.4 Quality assurance

- Before the bidding, we had meetings for explaining the conceptual and the fundamental design of KAGRA cryogenics with candidates of manufacturer.
- After the contract, detail design and simulation were performed by the manufacturer with KAGRA members.
- Inspection of the factory has been performed.

2.5 Installation scenario

Installation will start on 2014. The process will be synchronized to the schedule of vacuum chambers and ducts.

2.6 Risk management

2.6.1 Transportation through arm tunnel

- Passing test by dummy model with the same size of the cryostat.
- Correct the narrow paths if exist.

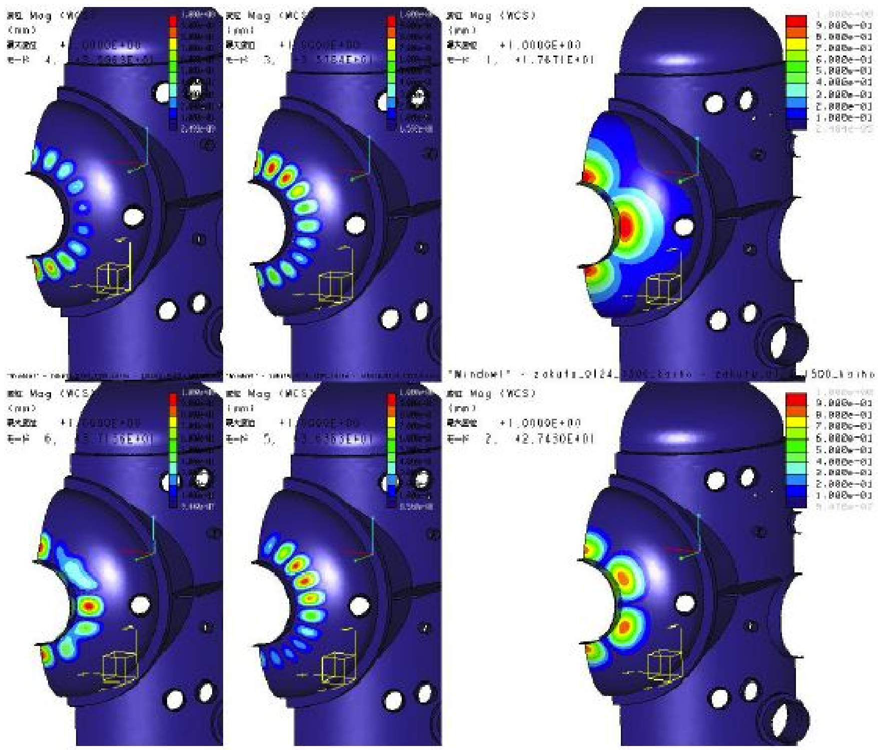

Figure 4: Buckling mode of cryochamber under atmospheric pressure and the weight of 500 kg on the top cap. The lowest six modes are shown. The coefficients of buckling are larger than 17 for those modes. Plotting: TOSHIBA

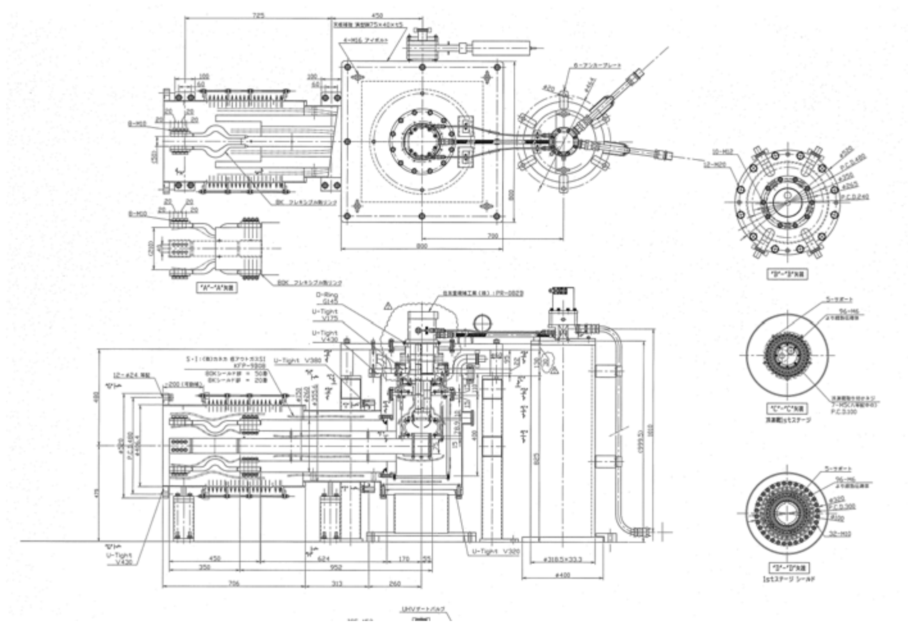

Figure 5: Low vibration 4K cryocooler unit. Drawing: JECC TORISHA

2.6.2 Leakage

Same as 300K vacuum chambers and components.

3 bKAGRA

3.1 Requirements

Cool test masses down to 20K and keep the temperature during operation. Some features are listed in the followings.

Cryostat

A sketch is shown in Fig.6

- Diameter ϕ2400 mm, height 4330 mm (from the bottom to the connection to SAS) , mass 11.7 ton (include cryochamber and double radiation shields).
- Four cryocooler units are connected to each cryostat.
- Two way of 8K-cooling paths. (inner heat conductors)
  - Two of cooling path made of 5N8 aluminum bar is used to cool the cryopayload.
  - Another two paths cool the inner shield.

- Four of 80K cooling path cool the outer shield. The cooling paths are made of 1070 grade aluminum.
- ϕ900 mm connection flange to SAS-A on the top cap.
- ϕ2400 mm ports on both sides with ϕ800 mm service ports on each side cap.
- Hinged doors on radiation shields.

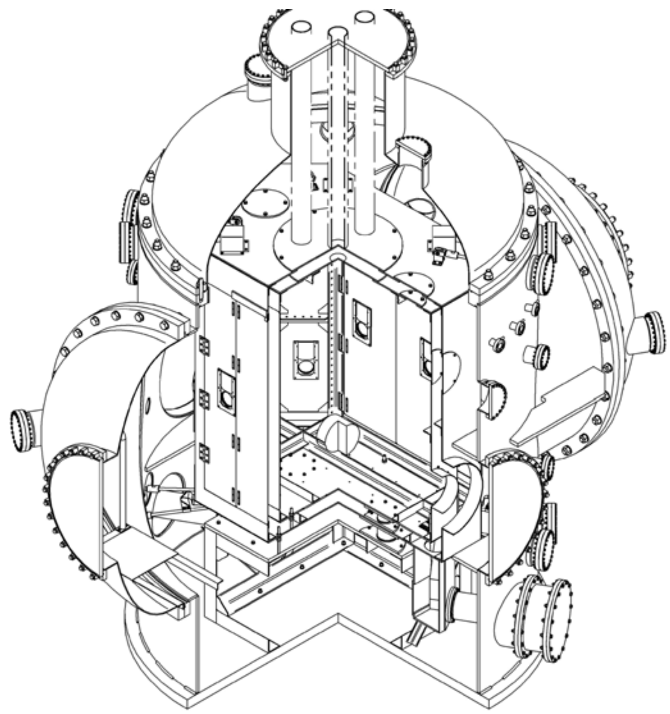

Figure 6: A sketch of the cryostat and radiation shields. The direction of the main beam is supposed to be from the right bottom to the left top on the figure. A test mass is shown in the inner shield. Detail of cryopayload is not shown. Drawing: TOSHIBA

Low vibration 4K cryocooler unit
Drawing is shown in Fig.5.

- Cooling power at the connection to the cryostat.
  - 8K cooling path : 2.5 W or more at 9 K.
  - 80K cooling path : 35 W or more at 70 K.
- Vibration amplitude at the connection point to the cryostat.

- 8K cooling path : 0.1 μm or less.
- 80K cooling path : 0.1 μm or less.

The specifications of cryostats and 4K cryocooler units were basically determined because the manufacturing has already been started.

3.2 Preliminary design

Basic design of the cryostat and the low vibration 4K cryocooler units are the same as described in iKAGRA design. In order to have functions of cryogenic equipments of bKAGRA, the followings are added.

- Extend 8K cooling bar made of 5N8 aluminum with an appropriate shield from a scattered main beam or excess radiation heat.
- Flexible heat links from the cooling bar to the cryopayload.
- Radiation shields for connecting wires or rods between a part of SAS-A in 300K.
- Shield ducts to stop thermal radiation from the 300K part of the vacuum duct.

3.3 Schedule

Table 1: Schedule

2011fy	Purchase and machining of components of cryostat. A partial assembling included. Assembling seven of low vibration 4K cryocooler units. Performance test of cryocooler units.
2012fy	Assembling four cryostats and nine cryocooler units. Performance test of cryostats and cryocooler units. Design and trial manufacture for a prototype shield duct.
2013fy	Store cryostats and cryocooler units for waiting for installation. Performance test of shield duct by the prototype. Design and manufacture shield ducts.
2014fy	Start carry in the tunnel and installation. Two cryostats install to the center room. Other two install to each end room.

3.4 Prototype test

A prototype of 4K cryocooler unit was manufactured and tested its performance in June and July 2011. The drawing of the prototype is shown in Fig.7. From the results of the

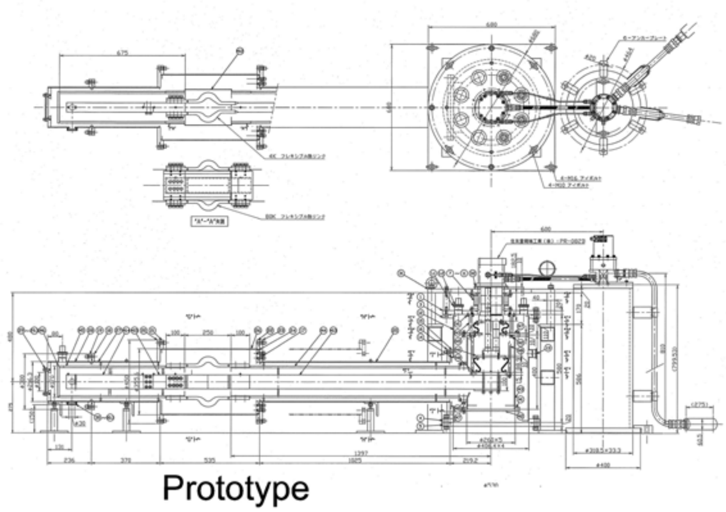

Figure 7: A prototype of low vibration 4K cryocooler unit. Drawing: JECC TORISHA

performance test, the design of cryocooler unit was modified in the followings.

- Thicker 80K conductor (Al 1070).
- Fix connection hoses.
- Thicker upper flange.
- Increase number of bolts for conductor connection.
- Shorter conduction paths.
- Strengthen support legs.

For development of cryopayload, a test cryostat with a single cryocooler unit is planed. Purpose of the test cryostat is in the following.

- Scale model experiments of shield duct.
- Cooling experiment of cryopayload by a dummy test mass.

In the period of iKAGRA, cryostats in end rooms are separated from other part of main apparatus by gate valves. A cryostat in an end room is useable as a test facility for installation and performance test of cryopayload under a clean environment with real scale.

3.5 Quality assurance

Same process as used in iKAGRA.

3.6 Installation scenario

Same scenario as supposed in iKAGRA for cryostats and 4K cryocooler units.
For shield ducts, it is not clear because a manufacturing period depends on a budget condition.

3.7 Risk management

Supposed risk factors are listed in the followings.

- Budget request for manufacturing shield ducts.
- Maintenance expenses.
- Business withdrawal by the company that produces necessary components.
- Excess heat loads.
- Excess vibrations on the inner shield and cooling path of the cryopayload.
- Dust control failure.
- Leakage in cryogenic operation.
- Life/maintenance period shortening of instruments in humid environment.
- Long time constant of large cryogenic system.

Appendix-A : Design changes that have been made with the suggestions in the 1st external review

A design adopts the radiation heat transfer for boosting initial cooling of the cryopayload including test mass.

Appendix-B: Items that have been reduced in cost

Suppose a mechanical buffing with #400 mesh as a preliminary polish, a specification of final polishing method of the inner wall of the cryostat was changed from ECB to CP.

Appendix-C : Abbreviations

Table 2: Abbreviations used in this section

Abbreviation	Description
CP	Chemical Polish
ECB	Electro-Chemical Buffing
FEM	Finite Element Method
MLI	Multi-Layer Insulator or Insulation
PTC	Pulse Tube Cryocooler
SI	Super Insulator

Cryogenic payload

4 Overview

4.1 Definition and scope of the subsystem

The cryogenic payload means the suspension systems for the cooled mirrors of the main Fabry-Perot cavity. They are suspended from the vibration isolation system called Type-A and surrounded by the radiation shield. The heat links between the masses of the payloads and the shield (or heat path near the radiation shield) belong to the cryogenic payload. Therefore, the cryogenic payload is on the border between the vibration isolation and cryogenics. Other items which are in the radiation shield (for example, the baffle to prevent from the propagation of the scattered light) are also included in the cryogenic payload.

4.2 Important interface

As the explanation in the previous sub section, the cryogenic payload is on the border between the vibration isolation (Type-A; development, installation, commissioning) and cryogenics (heat links and cryocoolers). Therefore, the interfaces with these subgroups are extremely important.

The sapphire mirrors are provided by the mirror subgroup. Our subgroup should discuss how to suspend the sapphire mirrors using the sapphire fibers. The measurement of the coating mechanical loss is also managed by the both groups. The clean room should be discussed by the subgroups of the mirror, facility, and ours.

The control and monitor of the positions and angles of the mirrors and payloads are an important issue. Our subgroup considers it in cooperation with the subgroups of Main Interferometer (scheme of the interferometer control) and Digital Control and Electronics (control and monitor).

Auxiliary Optics and our subgroups design the baffle in the cryostat for the (large angle) scattered light by the sapphire mirror and other monitors.

4.3 Design phase

In iKAGRA phase, no cryogenic payload is necessary because the room temperature interferometer will be constructed in this phase. Therefore, all items in cryogenic payload are for bKAGRA, not iKAGRA. Nevertheless, there should be progress in the iKAGRA phase because it takes time for development and so on. Some cryogenic payload will be installed in iKAGRA phase (before the observation of iKAGRA).

5 iKAGRA

Since the room temperature interferometer will be constructed in iKAGRA phase, nothing is mentioned here. However, it must be note that the cryogenic payload will be made and some of them will be installed in iKAGRA phase.

6 bKAGRA

6.1 Requirement

The cryogenic payload should be installed in safe and clean environment within the short period. The procedure should be considered and investigated carefully.

The sapphire mirrors should be enough cooled. The mirror temperature should be below 20 K with hear load by the light absorption in the mirrors (about 1 W). The initial cooling time must be as short as one month.

The control (and damping) for the angle and position of the mirrors and the other masses are necessary and they must work well at cryogenic temperature.

The thermal noise, the external vibration via heat links, and control noise are should be smaller than the sensitivity of bKAGRA ($1.4 \times 10^{-22} \times (10\ \mathrm{Hz}/f)^{2.5} [\mathrm{m}/\sqrt{\mathrm{Hz}}]$ between 10 Hz and 100 Hz).

6.2 Preliminary design

The cryogenic payload is the triple pendulum and is suspended from the Type-A SAS (Figures 8,9 are schematic views.). It is enclosed by the double radiation shields. The mirror (23 kg) and recoil mass (about 30 kg) are suspended from the intermediate mass (about 60 kg). The distance between the centers of mirror and the intermediate mass is 30 cm. The intermediate mass and its recoil mass (about 60 kg) are suspended from the platform (about 120 kg). The distance between the centers of the intermediate mass and platform is 40 cm. The heat links are between the inner radiation shield and payload. The radiation shield is cooled by pulse tube cryocoolers. For one sapphire mirror, 4 cryocoolers are necessary.

How to assemble and install, control and damping system will be considered. The thermal noise should be evaluated. The initial cooling time (Fig. 10) and mirror temperature with absorption of laser (Fig. 11) are evaluated by Y. Sakakibara and seismic motion (Fig. 12) is calculated by T. Sekiguchi. Noise of control and damping system should be estimated.

We need the baffle in cryostat in order to reduce the effect of the large angle scattered light (on the mirror surface). The design of baffle itself is proposed by Mike Smith (LIGO, Caltech). He also has already evaluated the scattered light noise and it is much smaller than the sensitivity of bKAGRA. However, he recommended that this baffle should be suspended (he is afraid that the resonance peak of this baffle itself appears above the floor level of the sensitivity). It is suspended in cryostat and is inside main Fabry-Perot cavity.

6.3 Schedule

In iKAGRA phase, our subgroup will prepare the actual cryogenic payload to install in Kamioka mine. Therefore, we should check the cryogenic payload performance before the installation. Moreover, some components of cryogenic payload also must be investigated.

In order to check the cryogenic payload performance, the 1/4 (quarter) cryocooler in the second research complex of Kashiwa campus, the University of Tokyo will be used. Quarter implies that number of the cryocooler is quarter of the actual one (4 cryocoolers), not the size of the cryostat. In this experiment, we can check and confirm how to assemble and install, the initial cooling time, the control and damping systems. Although the payload in 1/4 cryostat is similar to the bKAGRA payload, it is not the same (for example, the mirror and its fibers could be not made from sapphire).

Some components of the cryogenic payload, for example, sapphire fibers to suspend the sapphire mirrors, should be investigated.

After these experiments, we will procure and install the four cryogenic payloads.

The details of the timeline are as follows;

- March 2013 : 1/4 cryostat will arrive at Kashiwa campus.
- April 2013 - September 2014 : Experiment of 1/4 cryostat
  - April 2013 - May 2013 : Vacuum and cooling test without payload, assembling the payload
  - June 2013 : Installation of payload and cooling test
  - July 2013 - September 2014 : Cooling test, control and damping test
- - September 2014 : Other R&D items (sapphire fibers and so on)
- September 2014 : The final design of cryogenic payload will be fixed.
- July 2014 - March 2015 : Procurement of cryogenic payload
- June 2015 - September 2016 : Type-A (including cryogenic payload) installation and commissioning for end mirrors
- November 2015 - December 2016 : Type-A (including cryogenic payload) installation and commissioning for front mirrors

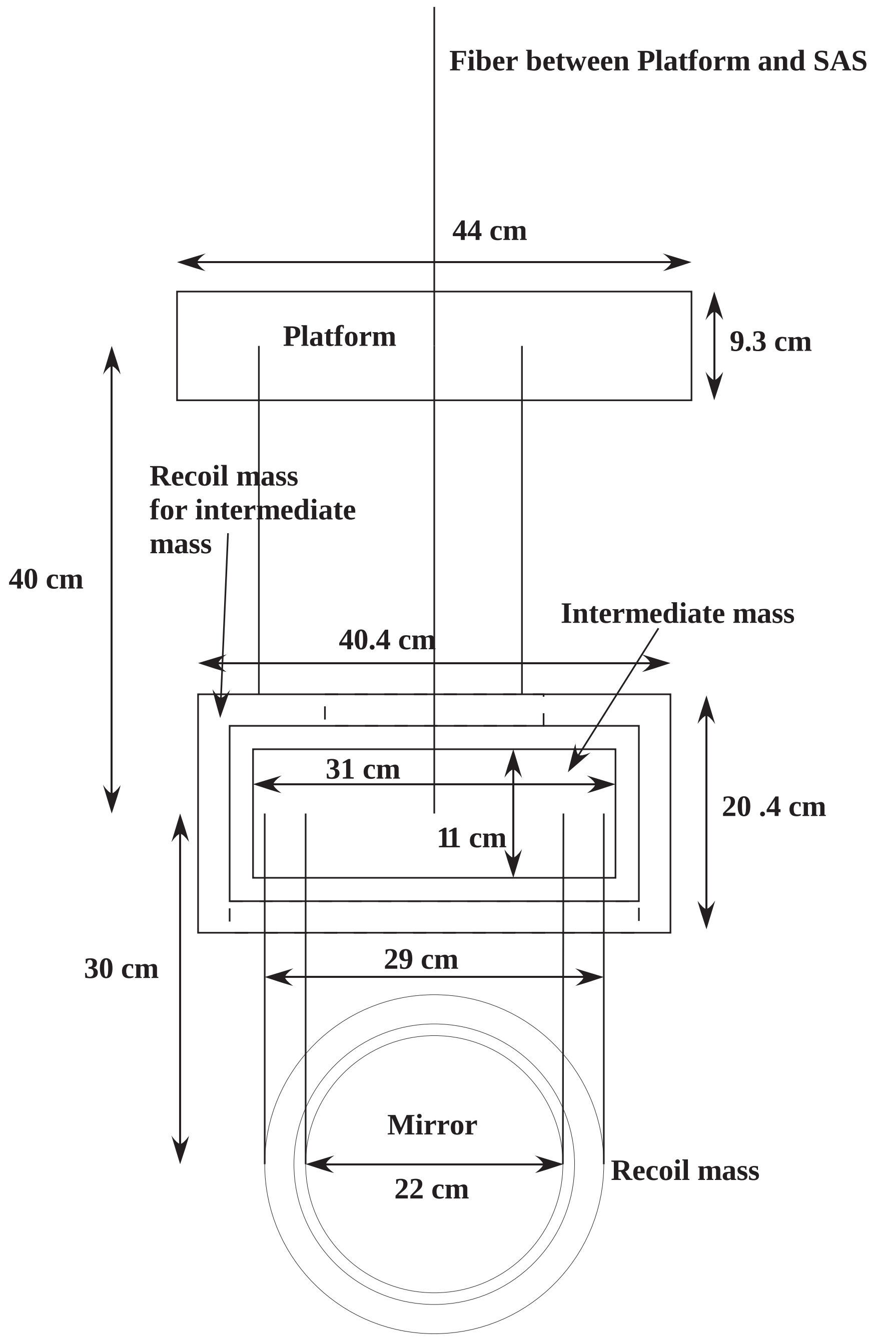

Figure 8: Schematic view of cryogenic payload (from optical axis)

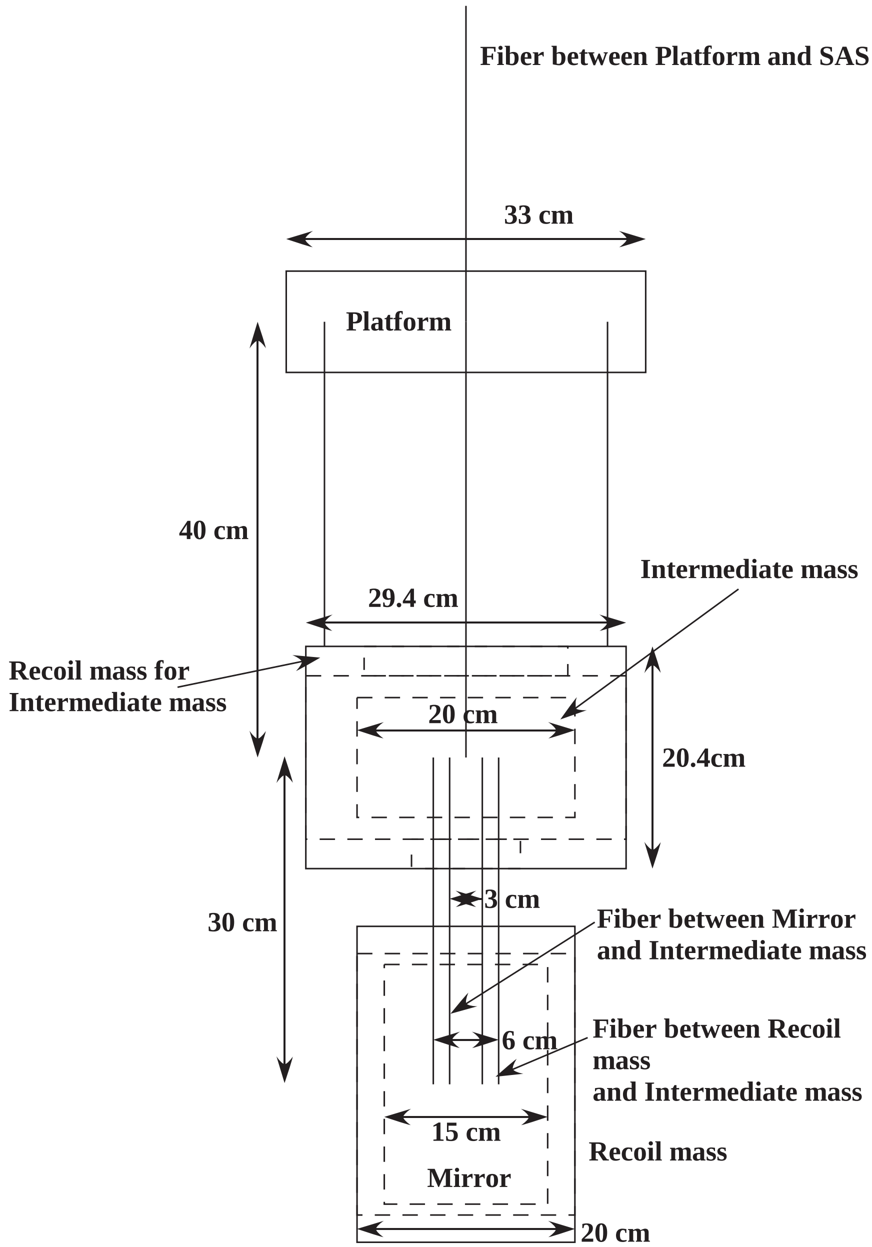

Figure 9: Schematic view of cryogenic payload (from other horizontal axis)

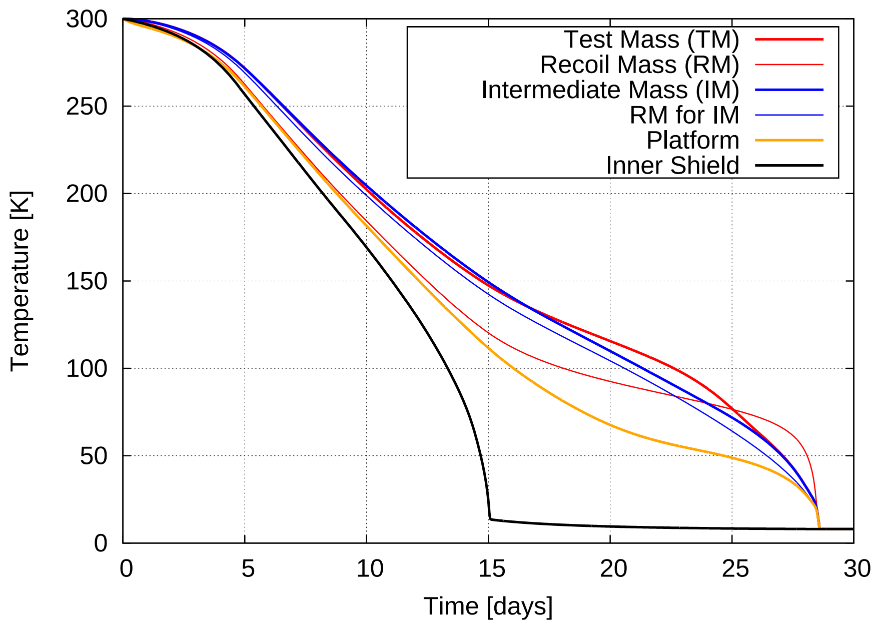

Figure 10: Simulation of the initial cooling time of the cryogenic payload by Y. Sakakibara. The result shows that the initial cooling time is about 1 month.

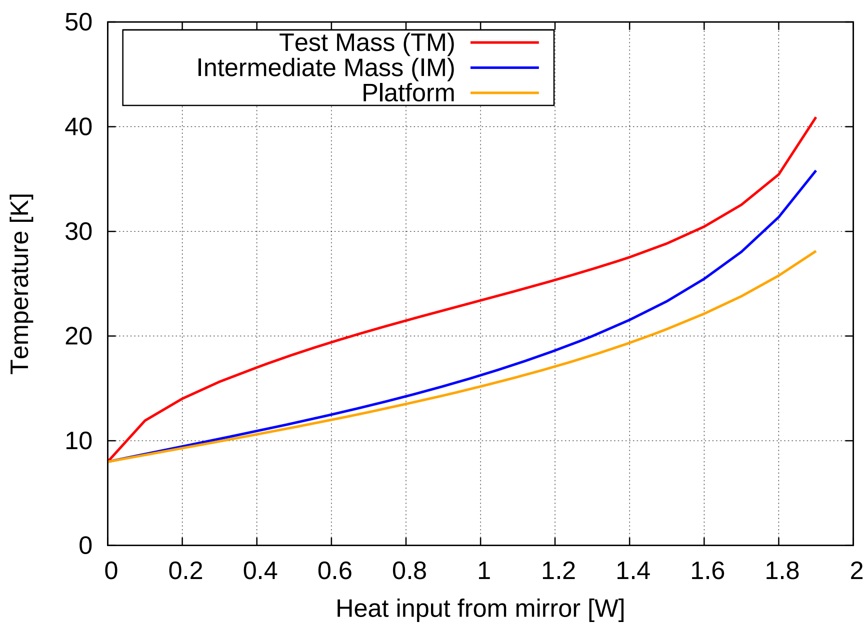

Figure 11: Temperature of the masses of the cryogenic payload (Y. Sakakibara). The horizontal axis represents the heat load on the mirror.

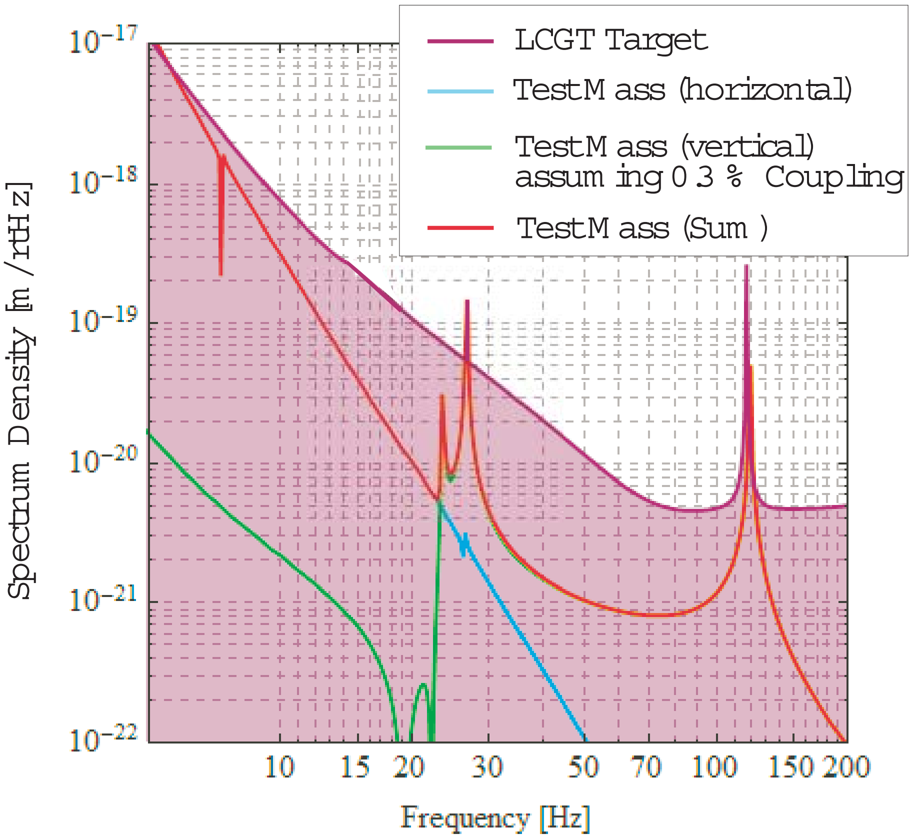

Figure 12: The seismic noise (including the vibration via heat links) of KAGRA (T. Sekiguchi)

6.4 Prototype test

1/4 cryostat is the prototype test for the cryogenic payload for bKAGRA. We will make the prototype payload and install in the 1/4 cryostat. We will check these items.

- How to assemble and install
- Cooling test : Initial cooling time is calculated (Y. Sakakibara and S. Koike). Measurement of reflection of Diamond Like Carbon (DLC) (Y. Sakakibara).
- Control and damping (including the parametric instability) : Simulation of mechanical response (T. Sekiguchi and S. Koike)

Here, the other R&D items are also explained.

- Sapphire fibers: Measurement of thermal conductivity, mechanical Q-values, and tensile strength. How to make thick ends and to connect to the mirror and the intermediate mass (bonding) (K. Shibata, T. Ushiba, T. Suzuki)
- Material of mass and wires (except for sapphire fibers and mirror): Measurement of thermal and electrical conductivity, Q-values, and tensile strength (C. Tokoku)
- Measurement of mechanical Q of coating : Although we measured the loss of the JAE coating, JAE does not provide coating. We measure the coating for KAGRA. (E. Hirose, K. Yamamoto)
- Vertical spring in cryostat: Design and measurement of resonant frequency and Q-values at cryogenic temperature. Temperature dependence. (H. Ishizaki, T. Sekiguchi)
- Development and test of sensors, actuators, motors in cryostat
- External vibration via heat links
  - Transfer function of heat link : Simulation (Y. Aso) and measurement
  - Vibration measurement of radiation shield : Measurement and simulation
- Thermal noise evaluation : (T. Sekiguchi and K. Yamamoto)
- Baffles for scattered light : Design of baffle itself and suspension and damping systems (M. Smith and T. Akutsu)

Based on the result of the experiment, the final design will be fixed. Human resources are shown in Appendix C.

6.5 Quality assurance

First of all, we should confirm the items in 1/4 cryostat and the other R&D. Before procurement, we select the material for cryogenic payload. Each parts in cryostat should be tested in 1/4 cryostat and so on.

After procurement, if possible, we check parts in Kashiwa (or KEK (Tsukuba) or Kamioka site). Especially, the test of the sapphire fibers is important. Since we cannot use the sapphire fibers which we test, we pick up some fibers for test (thermal conductivity, mechanical Q value, strength) and the remains are installed in cryostat in Kamioka mine.

6.6 Installation scenario

- 2015 Jun - 2016 Sep : X-End mirror
  - June 2015 - July 2015 : Type-A installation
  - July 2015 - December 2015: Cryogenic payload installation and test with fixed Type-A
  - January 2016 - July 2016 : Type-A + Cryogenic payload test
  - July 2016 - September 2016 : Mirrors are replaced by sapphire ones.
- July 2015 Jul - September 2016 : Y-end mirror
  - July 2015 - August 2015 : Type-A installation
  - August 2015 - February 2016 : Type-A test with dummy load
  - February 2016 - July 2016 : Cryogenic payload installation and test
  - July 2016 - September 2016 : Mirrors are replaced by sapphire ones.
- November 2015 - December 2016 : Front mirrors
  - November 2015 - May 2016 : Type-A installation and commissioning
  - September 2016 - December 2016 : cryogenic payload installation and commissioning

Human resources are discussed in Appendix C.

6.7 Risk management

- Sapphire fibers (P= 2, S=3, R= 6) : Sufficient investigation and tests (or silicon ?)
- Vibration via heat link (P=2, S=2, R=4) : Measurement and simulation of shield vibration and heat link transfer function and design

- Vertical spring in cryostat (P=2, S=2, R=4) : Development should be in progress.
- Budget after 2013 March (P=2, S=3, R= 6) : Cryogenic payload, Duct shields (for end mirrors), Delay of budget may change schedule and make process of development complicate. We must win budget!
- Clean room for mirrors, payload, cryostat, SAS (P=1, S=3, R=3) : We (or new associate professor of ICRR ?) should prepare clean room.
- Short installation time for front mirrors (3 months) (P=2, S=2, R=4) : We should learn many lessons about end mirrors (or adjust the schedule of DRMI).
- Operation of Type-A with cryogenic payload (P=2, S=3, R=4) : No test outside the mine (Installation and commissioning of Type-A and B are parallel). We should learn many lessons in R&D (1/4 cryostat and Type-B) and some tests at Kamioka site.
- Some troubles in cryogenic (P=2, S=2, R=4): Serious delay. We should learn many lessons about 1/4 cryostat. If there are small cryostats, they are useful.
- Assembling of payload (P=2, S=2, R=4): It is not so easy to handle huge masses. 1/4 cryostat is useful to check the procedure of the installation. Mock up is also useful.
- Sapphire mirror installation (P=2, S=2, R=4) : Short installation term. We should learn many lessons in R&D.
- Baffle in cryostat (P=2, S=2, R=4): The most serious problem is how to suspend it. We should check whether the suppression of scattered light effect is enough or not (at least, using simulation system).
- Control and damping (including parametric instability) (P=2, S=2, R=4): We should prepare the design based on the current best knowledge.
- Human resources (P=2, S=3, R=6): The details are described in Appendix C.

7 Appendix A: Design changes that have been made with the suggestions in the 1st external review

On the first external review, the cryogenic payload is not discussed. Thus, there are no changes.

8 Appendix B: Items that have been reduced in cost

On the first external review, the cryogenic payload is not discussed. Thus, there are no changes.

9 Appendix C: Human resources

Before installation (until September 2014)

In this phase, researchers (or graduate students) are necessary.

- 1/4 cryostat : 3 persons
- 6 items of R&D : 7 persons

Cryogenic experiment apparatus for R&D

- KEK : two ? small vacuum flask for liquid helium
- ICRR : 1/4 cryostat, CLIK, a small cryocooler from Mio lab

In installation (after June 2015)

In this phase, the technical staffs are necessary. Probably, 3 persons are necessary for the installation for a cryogenic payload. Therefore, 3 (6) persons must work for cryogenic payloads between July 2015 (February 2016) and February 2016 (December 2016). If persons for Type-A SAS (Type-A (SAS) does not includes the cryogenic payload) are taken into account, 12 persons should work from November 2015 to May 2016 for Type-A SAS and cryogenic payload. The timeline is as follows.

- (June 2015 - July 2015 : 3 persons for Type-A installation at X-End)
- July 2015 - October 2015 : 3 persons for cryogenic payload at X-End (and 3 persons for Type-A installation and commission at Y-End)
- November 2015 - February 2016 : 3 persons for cryogenic payload at X-End (and 9 persons for Type-A installation and commission at Y-End and X-Front and Y-Front)
- February 2016 - May 2016 : 6 persons for cryogenic payloads at X-End and Y-End (and 6 persons for Type-A installation and commission at X-Front and Y-Front)
- June 2016 - September 2016 : 6 persons for cryogenic payloads at X-End and Y-End
- September 2016 - December 2016 : 6 persons for cryogenic payloads at X-Front and Y-Front