# C2Or1B-01: Development of a Helium Recondensing Cryostat

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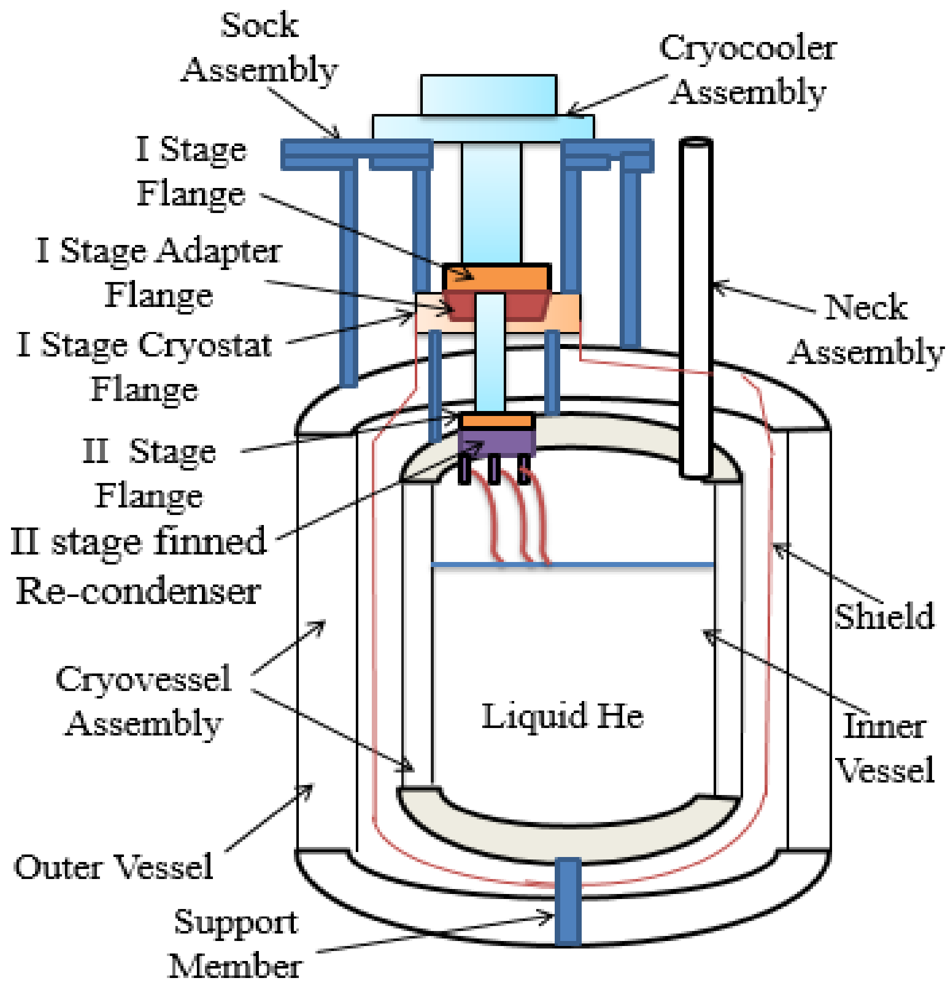
# Development of a Helium Recondensing Cryostat

- **Demerits of conventional Helium cryostats:**
- Disruption in operation and loss of liquid Helium due to periodic refilling.
- Require Helium recovery system, liquefaction plant.
- **Present work:** A step towards conservation of liquid Helium with an objective to develope an **"in-situ"** recondensing Helium cryostat.

# Development of a Helium Recondensing Cryostat

- **Mechanical and thermal design:**

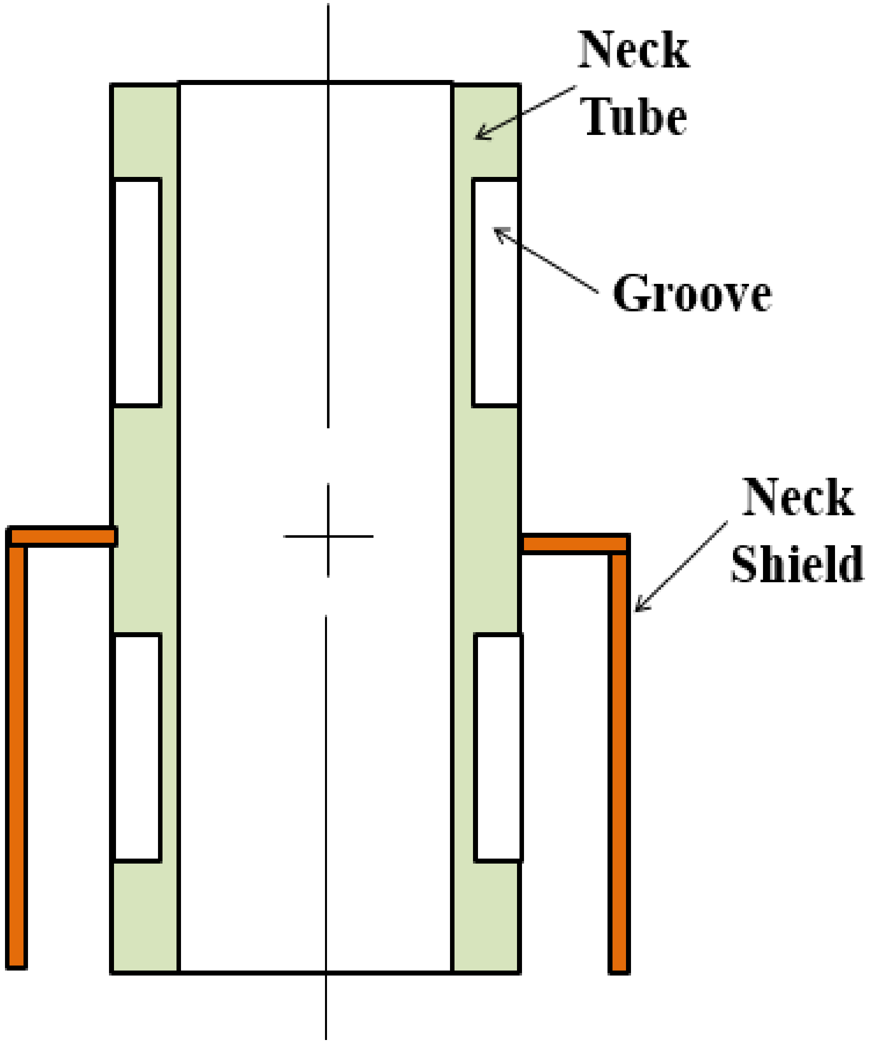



**“In-situ” Helium recondensing cryostat**

**Design specifications of Helium recondensing cryostat**

| Design Parameter | Design Specification |
|---|---|
| LHe storage capacity | 100 litre |
| Ullage volume | 6% of liquid voulme |
| Design presure | 6 bar |
| Length to inside diameter ratio ($l/d$) | 0.9 |
| Normal permissible boil-off rate | 1% per day |
| GM Cryocooler | 40 W at 43 K – I stage<br>1 W at 4.2 K- II stage |

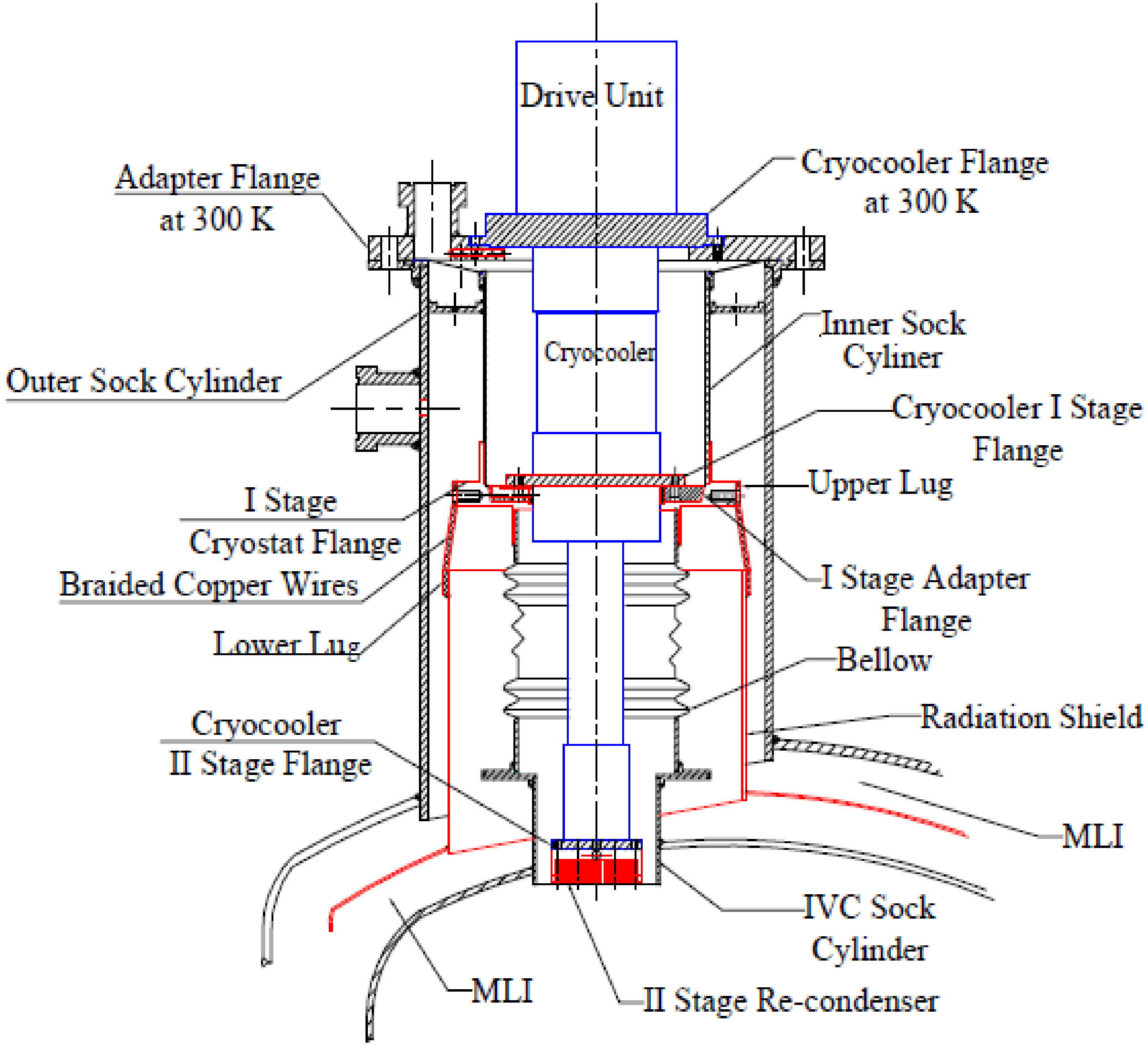
- **Mechanical and thermal Design:**
- Radiation shield- Perforated, 1.5 mm thick, Material- ETP Copper,
- Multilayer insulation- 0.006 mm Aluminum foil and 0.15 mm fiberglass paper.
- Neck Tube – SS 304.
- Radiation shield brazed to neck tube.
- Neck thermal load transferred to I stage of cryocooler.




Neck tube

# Development of a Helium Recondensing Cryostat

- **Sock assembly:** For smooth insertion and proper positioning of cryocooler for **“in-situ”** recondensation .
- Encloses adapter flange and cryostat flange of I stage for transfer of cooling effect at I stage of cryocooler to radiation shield through braided copper wires.




**Sock assembly**

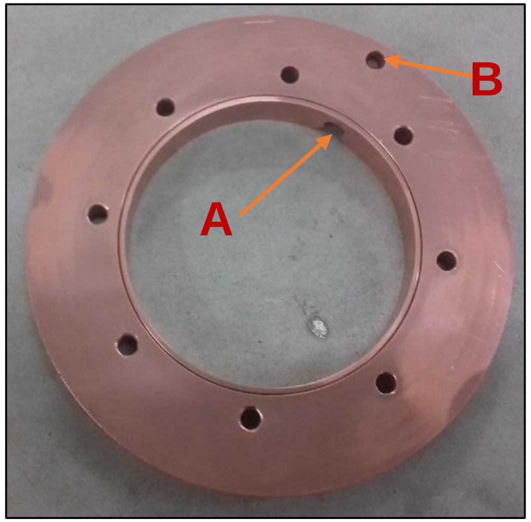
# Development of a Helium Recondensing Cryostat

- **I Stage adapter flange** of OFHC Copper is mounted on intergral cryocooler flange at I stage.
- Internal cross hole **(A)** and hole **(B)** are provided in it for passage of lead wires of Silicon diode and heater mounted at II stage re-condenser.
- **I Stage cryostat flange** of ETP Copper is connected to shiled through braided copper wires.
- **H6h6** precison location rotational sliding fit.

  Perfect thermal coupling.

  Minimum contact thermal resistance.

  Minimum loss during transfer of cold generated at I stage of cryocooler to radiation shield.




I stage Adapter flange

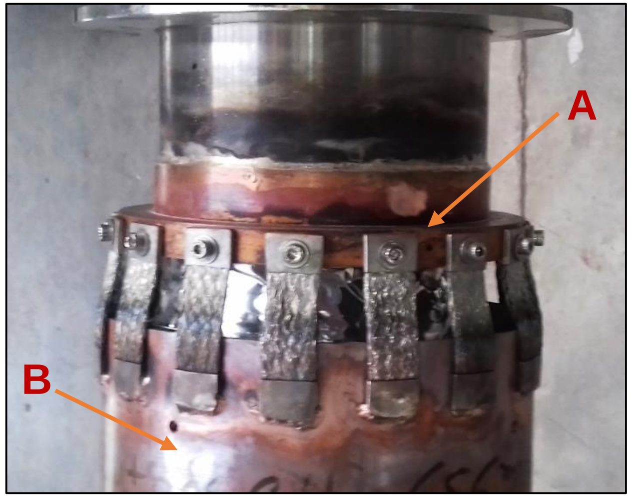
I stage cryostat flange

Fitment of both I stage flanges

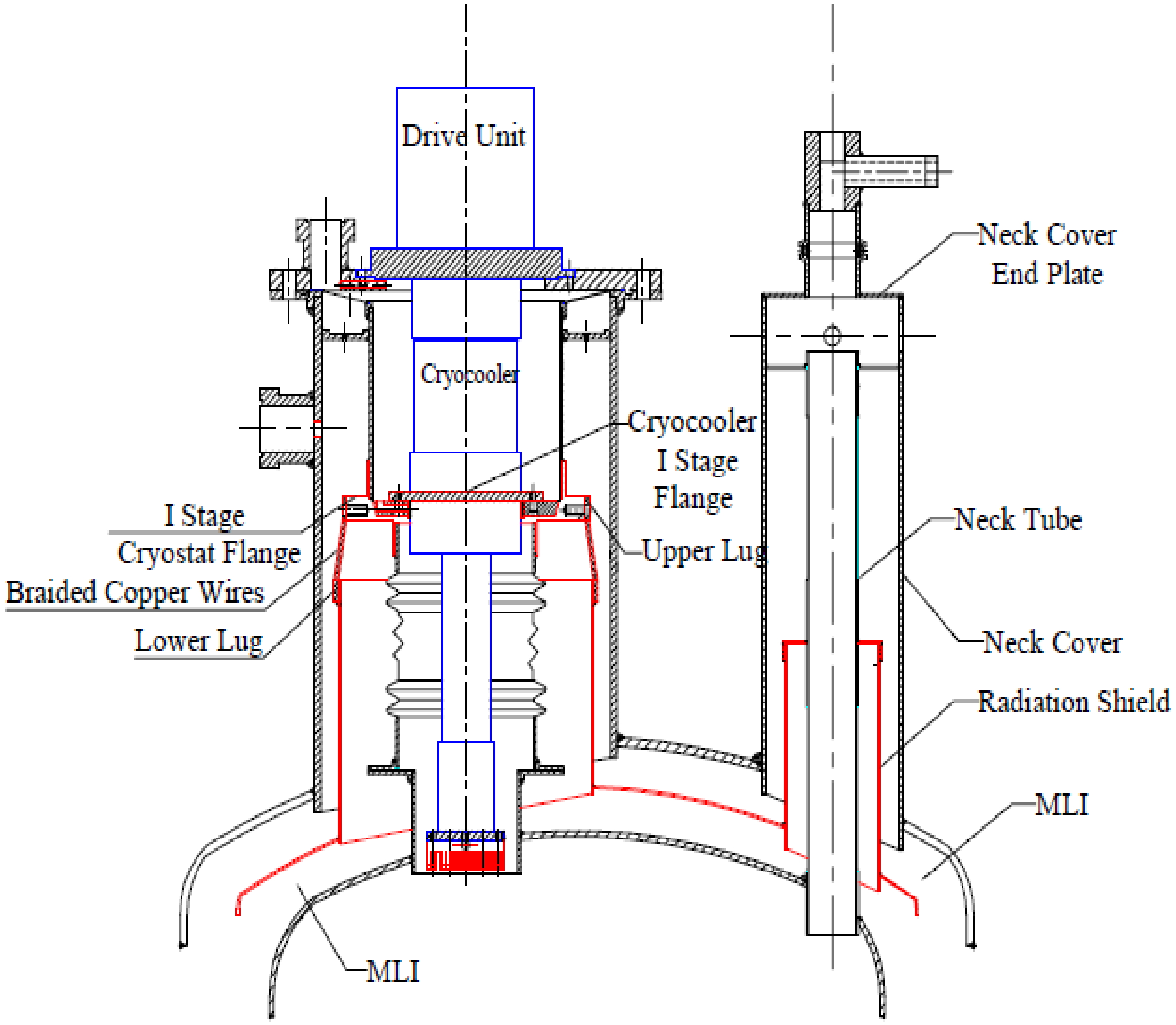
# Development of a Helium Recondensing Cryostat

- **Braided Copper wires with lugs:** 16 sets of 80 mm long, 32 x 30 x 0.2/1.0 mm, each with 02 No. ETP Copper lugs provide thermal linkage for transfer of cooling effect from I stage cryostat flange **(A)** to radiation shield **(B)**.

**Braided Copper wires with lugs**



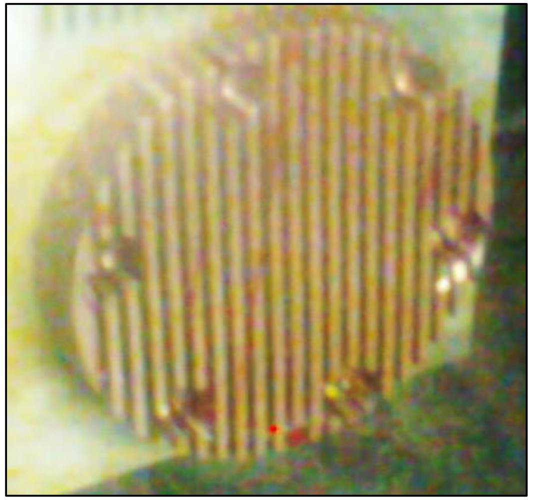

**Thermal linkage of I stage cryostat flange to shield**



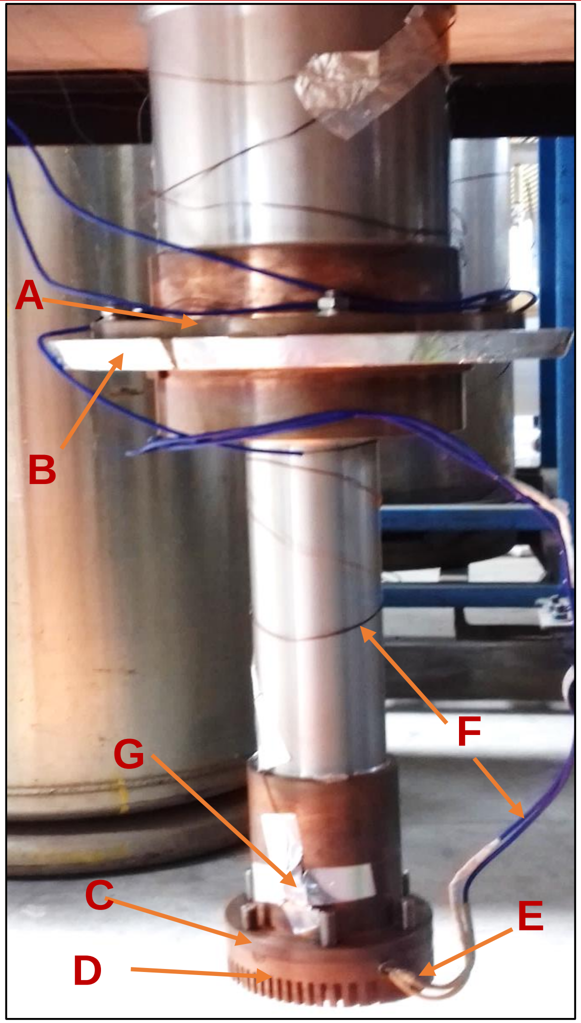

**Thermal linkage of neck tube to cryocooler**

# Development of a Helium Recondensing Cryostat

- **II stage Re-condenser (D)** made of OFHC Copper is mounted on integral II stage flange **(C)** of cryocooler for **“in-situ”** recondensation.
- 19 No. straight rectangular integral fins each of thickness 1.5 mm, height 10 mm with 1.5 mm gap between two fins are cut on an **inclined blank** of varying thickness of 20.7 mm at one edge and 17.5 mm at diametrically opposite edge.
- This ensures that condensed liquid Helium will collate at one end of fin and drop from there.



**Finned re-condenser (C)**




**I Stage adapter flange B and II stage re-condenser D mounted on integral cryocooler flanges A and C; Heater E, Lead wires F, Silicon diode G at II Stage**

# Development of a Helium Recondensing Cryostat

- **Manufacturing processes involved:** Forming, Machining, Joining, MLI application.

**Inner vessel**

**Integration of inner vessel with middle Copper shield**

**Application of MLI on Copper shield assembly**

**Integration with outer vessel**


**Cryocooler mounted on re-condensing cryostat**

- **Quality tests conducted:** Pneumatic and hydrostatic pressure tests, MSLD test using Helium gas.

  As per ASME Code, Section VIII, Division I.

# Development of a Helium Recondensing Cryostat

- Continuous trials conducted separately on Sumitomo Heavy Industries (SHI), Japan make two stage GM Cryocooler in a specially fabricated vacuum jacket.
- **Sensors and Instruments:**

  Silicon diode and Heater-1 No. each at I stage cryostat flange.

  Silicon diode and Heater-1 No. each at II stage re-condenser.

  Silicon diode- 1 No. at shield bottom.

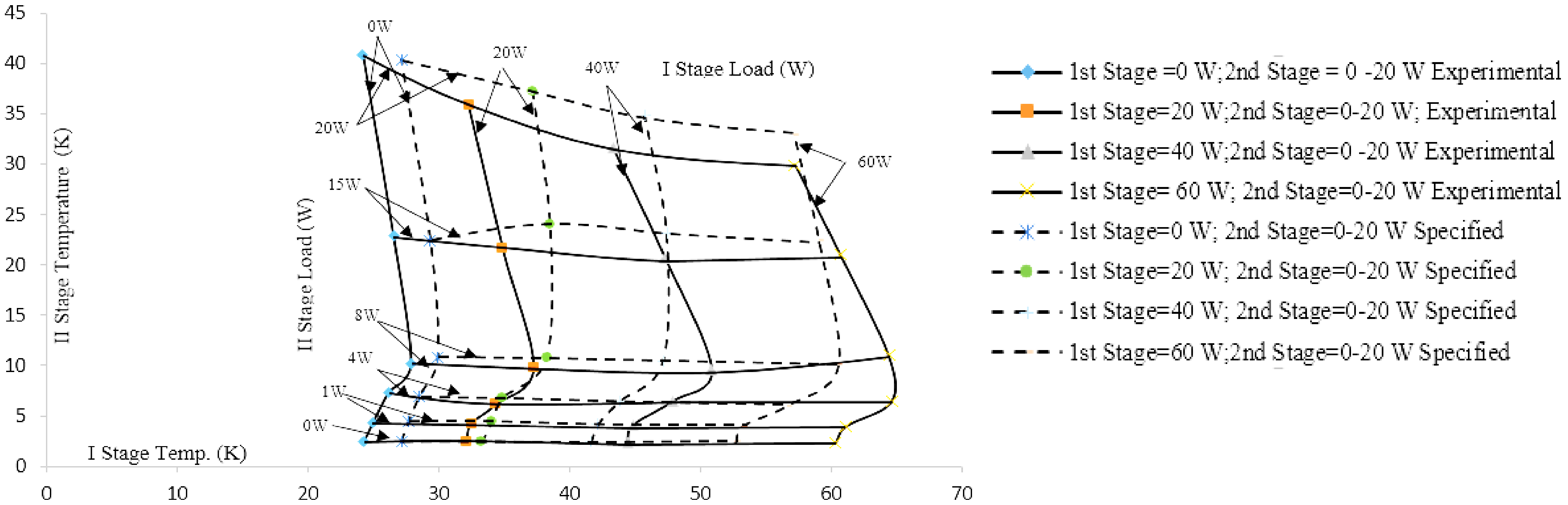
  Temperature indicators- 2 No. for I stage, shield and II stage temperatures.

  0- 60 W D.C. Power source - 1 No. for I and II stage heaters.

- **Results : 40 W** at **40.3 K** - **I Stage** , **1 W** at **4.02 K** - **II Stage.**
- **Cryocooler capacity : 40 W** at **43 K** - **I Stage** , **1 W** at **4.2 K** - **II Stage.**

# Development of a Helium Recondensing Cryostat

- Thermal load map of cryocooler obtained experimentally at various electrical heater loads applied to both stages and compared with thermal load map specified by SHI.




**Comparison of thermal load map of GM cryocooler for experimnental results with specifications by SHI**

- **Conclusion:** Performance of GM cryocooler found **better** than specifications by manufacturer.

# Development of a Helium Recondensing Cryostat

## Parts of sock assembly causing problems in fitment of cryocooler in cryostat

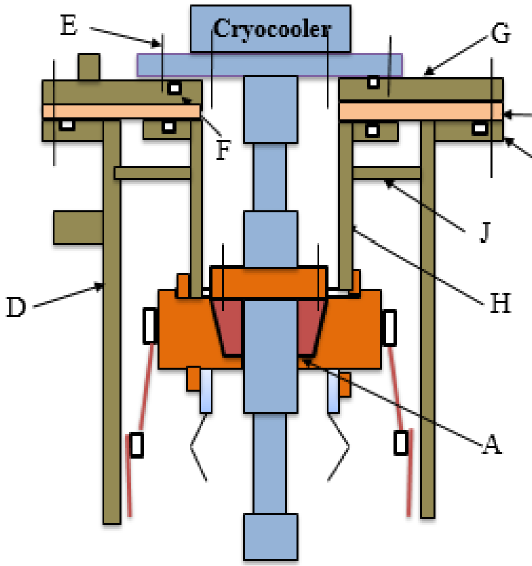
| Part No./Name | Reason of problem | Corrective Measures |
|---|---|---|
| **A-** Face of I stage cryostat flange. | **Waviness** and **gap** at face **(A).** | **Lapping** at face **(A)** using tool developed 'in-house'. |
| **B -** Outer sock cylinder top flange | **Deformation** in outer sock cylinder top flange **(B)** during its **welding** with outer sock cylinder **(D)** resulted in **gap** upto 3 mm with mating face of 7 mm thick intermediate flange **(C).** | Intermeidate Flange **(C)** **discarded** from sock assembly. A **ring of varying thickness** of 7 mm at one edge and 4 mm at diametrically opposite edge **fused** with outer sock cylinder **(D).** |

M-5 x 9 – 08 No. through holes **(E)** - Blinded by about 1 mm from bottom.

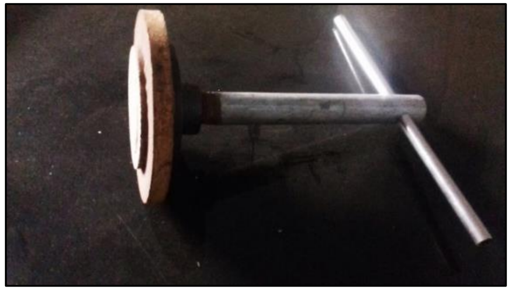
O-Ring **(F)** in outer sock cylinder top flange **(B)** - Changed from Φ 3.5 to Φ 5 mm.

**Vertical alignment** of cryostat- **Ensured.**

**Result:** Cryocooler **fitted properly** in sock assembly of cryostat.




**Parts of sock assembly causing problems in cryocooler fitment;**
**G- 300 K Cryocooler flange,**
**H- Inner sock cylinder**



**Lapping tool**

# Development of a Helium Recondensing Cryostat

- **First trial of cryostat performance test in vacuum:**
- **Results: Unsatisfactory. Heavy condensation** of ambient water vapour on outer surface of outer sock cylinder D.

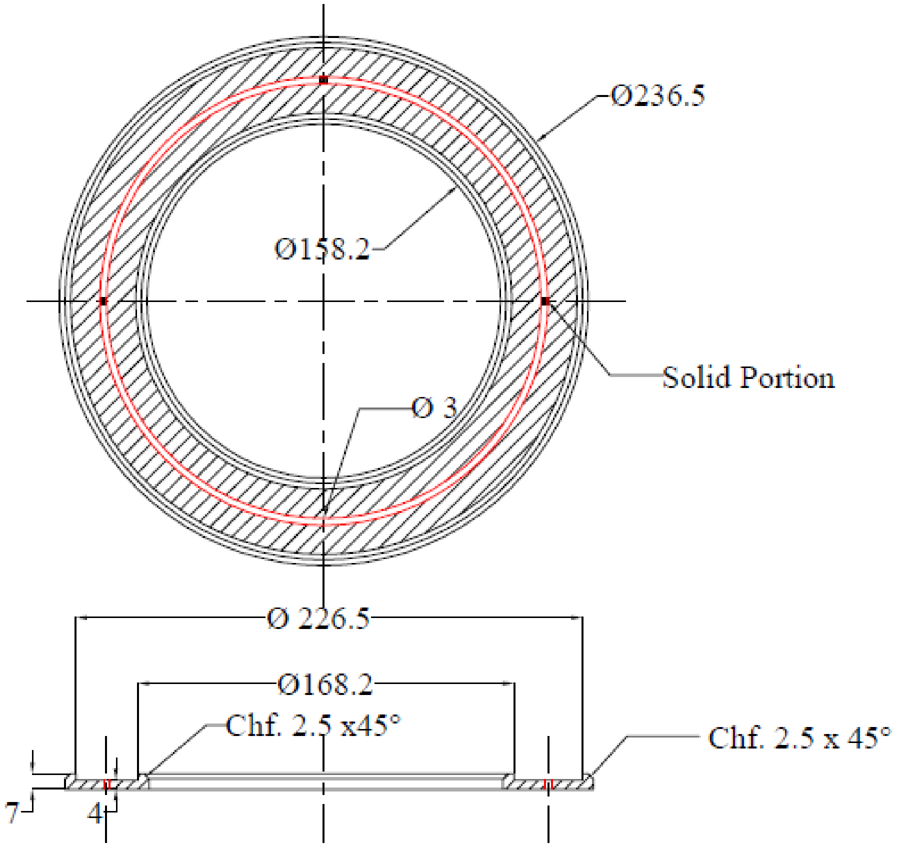
  **High temperatures** of **82.60 K** and **6.47 K** for **I** and **II stage** respectively at no electrical heater load.

  **Reason: High radial conduction heat transfer** from ambient to I stage due to **large thickness** of vacuum arresting plate **(J)**.

  **Corrective action**: ϕ 3 mm **through slot** provided in 4 mm thickness of vacuum arresting plate **(J)** , **retaining 3 mm solid portion** at **3 locations**, 120° apart.

  O- Ring : Φ5 mm neoprene rubber, Sealant: Vacuum clay.

  Vacuum in inner vessel volume and insulation space < $10^{-6}$ mbar.




**Modified vacuum arresting plate**

# Development of a Helium Recondensing Cryostat

- **Results: Unsatisfactory.** With no electrical heater load, **I stage : 51 K, II stage : 5** to **6 K**.

  **Reason:** Cracking of vacuum clay due to **very low temperature**. **Loss of vacuum** on insulation side.

  **Corrective action:** Sealant applied: **Araldite.**

  **Cryocooler trial** with **cryostat** in **vacuum** conducted for **08 Days.**

- **Results: Steady tempertaures** of **50.75 K** and **3.80 K** at **I** and **II stage** respectively **after cooldown.**

  **Satisfactory results** of **51.33 K** at **I stage** and **0.336 W** at **4.21 K** for **II stage** obtained on applying electrical heat load to II stage only.

  **Cracking of araldite and loss of vacuum after the trial, prior to LN2 purging of cryostat.**

  **Reason:** Exposure of araldite to **very low temperatures** and **high vacuum** for **long period** during trial.

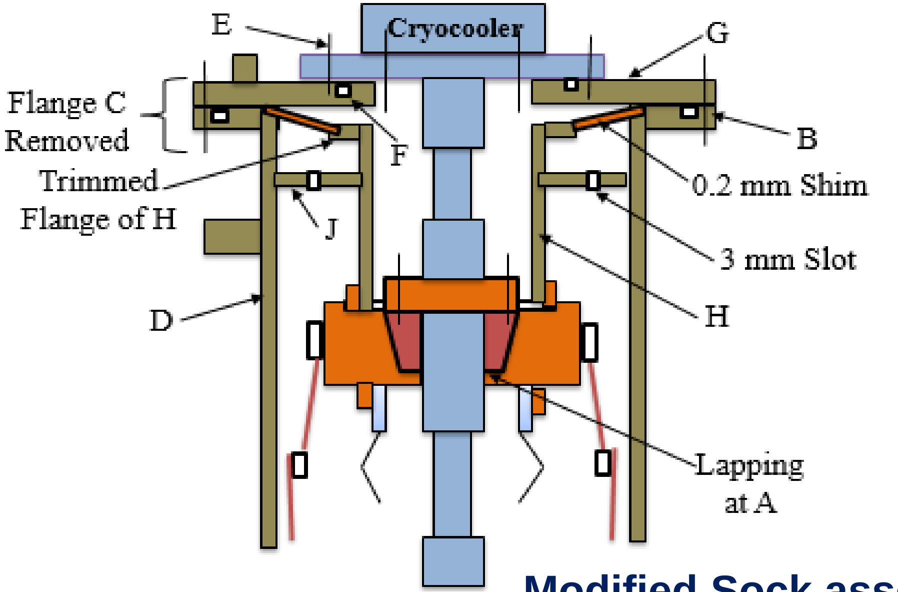
  **Modification: Used 0.2 mm thick SS-304 vacuum arresting shim in sock assembly.**

  Discarded O-ring in slot of modified vacuum arresting plate.

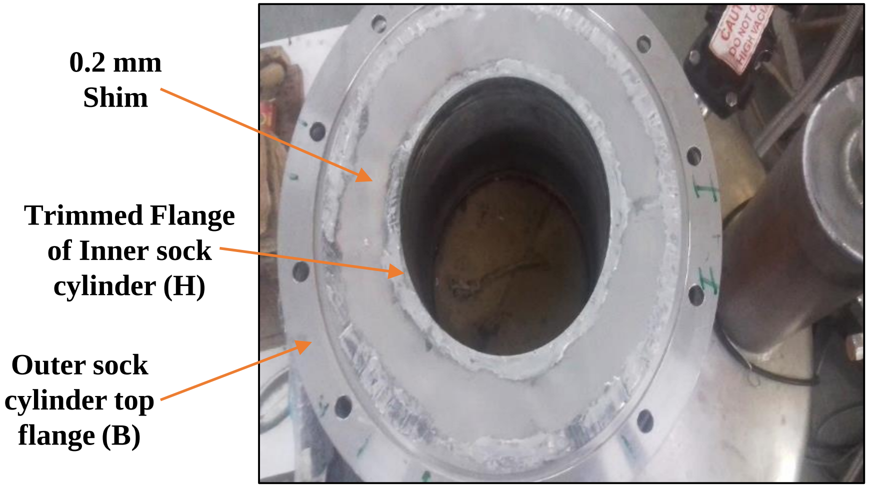
# Development of a Helium Recondensing Cryostat

## Effect of modifications in mechanical design of sock assembly on its themal load due to conduction for I stage

| Arrangement in sock assembly | Solid conduction heat load (W) | | |
|---|---|---|---|
| | Radial | Axial | Total |
| Thick vacuum arresting plate J only | 66.63 | 22.62 | **89.25** |
| Vacuum arresting plate with ϕ 3 mm slot fitted with O-ring and vacuum clay around it. | 16.06 (Includes 0.967 W) | 22.40 | 38.46 |
| Vacuum arresting plate with ϕ 3mm slot, **No O-ring**, **Vacuum arresting shim, 0.2 mm thick SS-304, brazed in sock assembly.** | 5.35 (Vacuum arresting plate: 0.967 W + Vacuum arresting shim: 4.38 W) | 22.40 | **27.75** |




Modified Sock assembly




0.2 mm shim in modified sock assembly

# Development of a Helium Recondensing Cryostat

- **Second trial of cryostat performance test in vacuum:** Carried out after all modifications in sock assembly.
- **Sensors and Instruments:**

  Silicon diode and Heater-1 No. each at I stage cryostat flange.

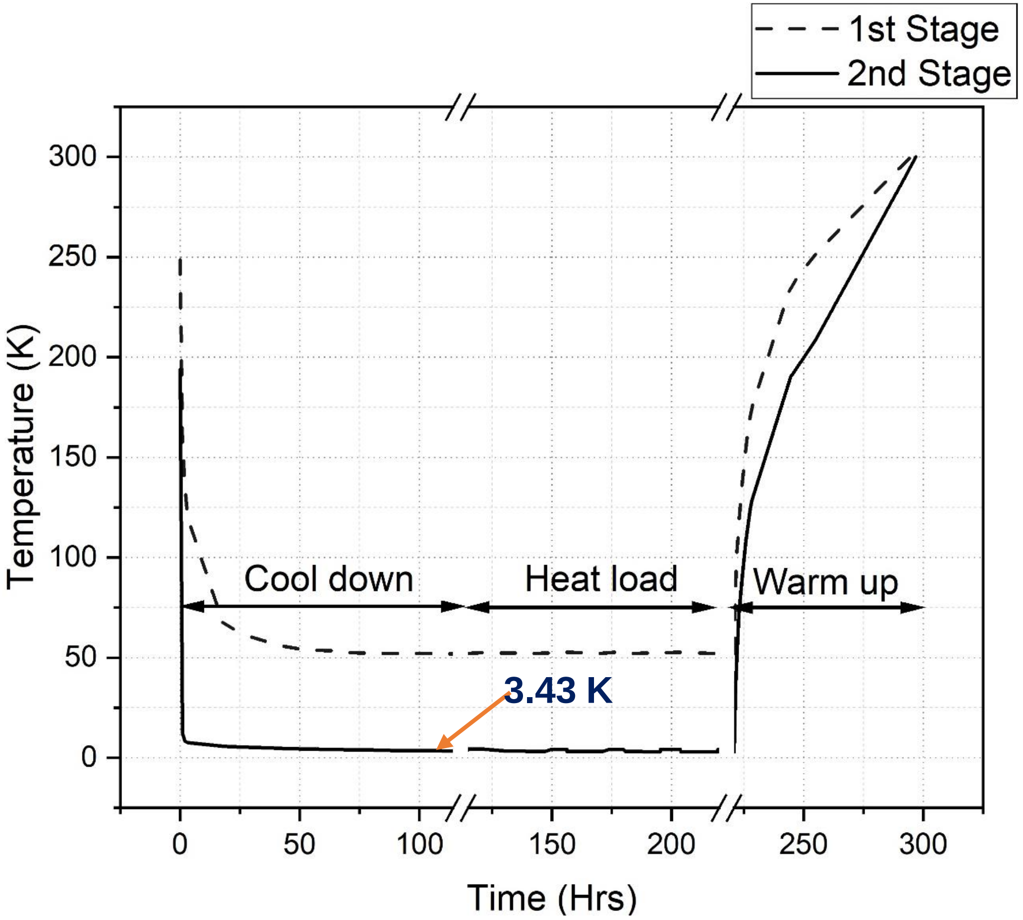
  Silicon diode and Heater-1 No. each at II stage re-condenser.

  Pt 100 – 1 No. each at shield bottom and neck tube joint.

  Temperature indicator- 1 No. for I and II stage temperatures.

  0- 60 W D.C. Power source - 1 No. for I and II stage heaters.

  Ohm meter- 1 No. for shield Pt 100 resistances measurement.
- **Results of cooldown:** Almost **steady state temperatures** of **51.95 K** and **3.43 K** for **I** and **II stage** respectively at no electrical heater load.




**Cool down curve of Helium recondensing cryostat performance test in vacuum**

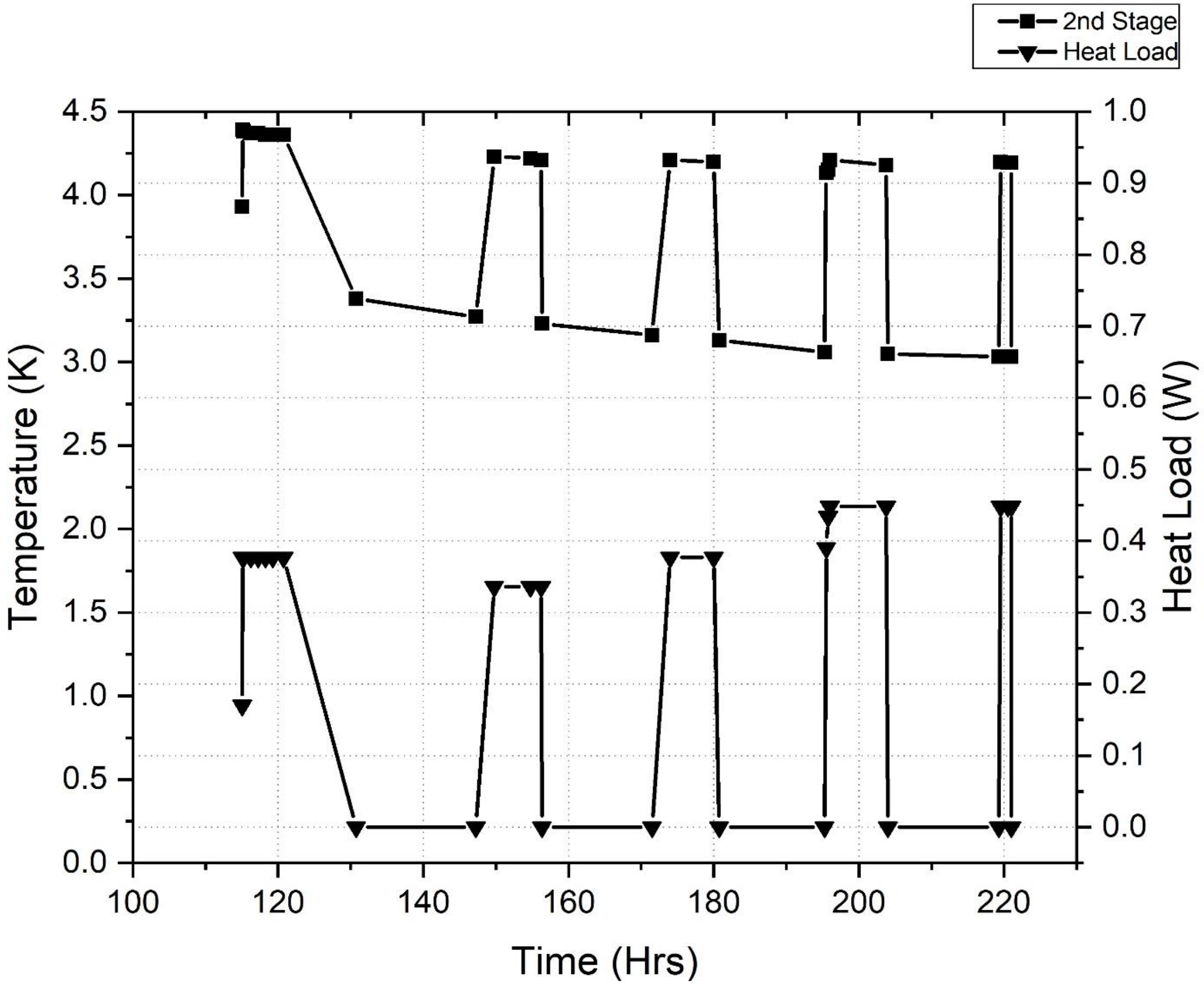
# Development of a Helium Recondensing Cryostat

- **Results of electrical heater load application:**

  **II stage : 0.448 W** at **4.21 K,**

  **I stage : 52.47 K with no electrical heater load.**


**I and II Stage temperatures with applied electrical heater load for cryostat performance test in vacuum**




**Variation of II Stage temperatures and applied electrical heater load for cryostat performance test in vacuum**

- **Test Results: <u>Satisfactory</u>**

# Development of a Helium Recondensing Cryostat

## Results of themal load estimation due to cryostat assembly (after modifications)

| Thermal Load (W) | Cryovessel | | Neck | | Sock | |
|---|---|---|---|---|---|---|
| Stage: | I | II | I | II | I | II |
| 1.Solid Conduction | 2.73 | 0.076 | 1.74 | 0.08 | 27.75 | 0.045 |
| 2.Radiation | 0.67 | $2.23 \times 10^{-4}$ | 0.119 | $2.17 \times 10^{-5}$ | 0.337 | 0.056 |
| 3.Residual Gas Conduction | 0.33 | 0.038 | 0.011 | $2.86 \times 10^{-4}$ | 0.039 | $1.5 \times 10^{-3}$ |
| Total (1+2+3) | 3.73 | 0.114 | 1.87 | 0.08 | 28.13 | 0.103 |

| Stage: | I | II |
|---|---|---|
| Thermal load due to cryovessel, sock and neck assembly: | 33.72 W | 0.298W |
| Conduction load due to sensors/ instruments lead wires: | $6.67 \times 10^{-3}$ | $4.98 \times 10^{-3}$ |
| Total thermal load of cryostat assembly: | **33.73 W** | **0.303 W** |
| Cryocooler Specifications: | **40 W** at **43 K** | **1 W** at **4.2 K** |
| Cryocooler Performance: (our results of second test) | **0 W** at **52.47 K** | **0.448 W** at **4.21K** |

# Development of a Helium Recondensing Cryostat

- **Conclusions:** Excess of thermal load over and above normal boil-off load = **0.4176 W**
  **= (0.448 - 0.0304)**
- Any experiment with **heat load < 0.4176 W** can be conducted using present cryostat,
  with **“in-situ”** recondensation for any length of time,
  without any increase in pressure of cryostat from 1 bar,
  without any need of refilling of LHe in cryostat.
- **Objective** of present work to develope an **“in-situ”** recondensing Helium cryostat is thus **fulfilled.**
- The cryocooler needs to be tested one more time in cryostat filled with LHe.


- **Acknowledgements:** The authors acknowledge financial support from **Board of Research in Nuclear Sciences (BRNS), India** for present research work in area of **“in-situ”** Helium recondensation cryostat.

# Thank you !