

CRYOREFRIGERATOR PUMP TEMPERATURE PROFILING & TRANSIENT LOG

|                                                      |                                           |                                       |
|------------------------------------------------------|-------------------------------------------|---------------------------------------|
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| Created By: Kadeem Manning                           | Role / Title: Tier II Facility Technician | Review Cycle: Annual (12 Months)      |
| Target Equipment: Leybold COOLVAC 1500-60000 iSL/iBL | Compressor Unit: COOLPAK 2000i / 5000i    | Controller: COOL.DRIVE i / CRYOVISION |

1. Purpose, Scope & Cryogenic Thermal Operating Parameters

This protocol defines the standardized procedure for logging, verifying, and evaluating the transient cool-down performance, steady-state thermal equilibrium, and regeneration thermal response curves for gaseous helium-refrigerated cryopumps (Leybold COOLVAC series with two-stage Gifford/McMahon COOLPOWER cold heads). Accurate temperature profiling ensures that the **1st Stage Radiation Shield / Baffle (T<sub>1</sub>: 45 K to 80 K)** effectively freezes out water vapor (H<sub>2</sub>O) and carbon oxides (CO<sub>2</sub>), while the **2nd Stage Cryopanel Array (T<sub>2</sub>: 10 K to 20 K)** maintains sufficient cryocondensation capacity for N<sub>2</sub>, O<sub>2</sub>, Ar and cryosorption capacity via activated charcoal for light non-condensable gases (H<sub>2</sub>, Ne, He).

| Thermal Stage / Parameter  | Operating Temperature Range         | Primary Gas Entrapment Mechanism                                                          | Critical Thermal Limit / Threshold                                        |
|----------------------------|-------------------------------------|-------------------------------------------------------------------------------------------|---------------------------------------------------------------------------|
| 1st Stage (Shield/Baffle)  | 45.0 K to 80.0 K (-228°C to -193°C) | Cryotrapping / Cryocondensation of H <sub>2</sub> O, CO <sub>2</sub> , heavy hydrocarbons | T <sub>1</sub> > 85.0 K causes H <sub>2</sub> O outgassing into 2nd stage |
| 2nd Stage (Cryopanel)      | 10.0 K to 20.0 K (-263°C to -253°C) | Cryocondensation of N <sub>2</sub> , O <sub>2</sub> , Ar, CO, CH <sub>4</sub>             | T <sub>2</sub> > 20.0 K causes argon/nitrogen thermal capacity overload   |
| 2nd Stage Charcoal Array   | 10.0 K to 15.0 K (-263°C to -258°C) | Cryosorption of H <sub>2</sub> , Ne, He into coconut-shell activated charcoal             | T <sub>2</sub> > 15.0 K causes rapid desorption of hydrogen spikes        |
| High Vacuum Crossover Load | Max 250 to 500 mbar·L burst         | Transient gas burst during main gate valve opening                                        | T <sub>2</sub> transient spike must remain below 22.0 K                   |

2. Transient Cool-Down Performance Profiling Log (Ambient 293 K to Base 12 K)

**Pre-Cool-Down Requirements:** Vessel pre-evacuated to p ≤ 1.0 × 10<sup>-1</sup> mbar (100 mTorr); COOLPAK compressor static helium pressure verified at 16.5 bar(g); cooling water flow verified at 5.5 L/min. Log T<sub>1</sub> (1st stage diode) and T<sub>2</sub> (2nd stage diode) every 15 minutes during the 90-minute cool-down cycle.

| Time (min)     | 1st Stage T <sub>1</sub> (K) | 2nd Stage T <sub>2</sub> (K) | Compressor HP (bar) | Compressor LP (bar) | Vacuum (mbar)          | Operational Status / Phase Milestone                                         |
|----------------|------------------------------|------------------------------|---------------------|---------------------|------------------------|------------------------------------------------------------------------------|
| 0 min          | 293.2 K                      | 293.1 K                      | 16.5 bar            | 16.5 bar            | 4.5 × 10 <sup>-2</sup> | Compressor START; G-M cold head pulsing initiated                            |
| 15 min         | 185.4 K                      | 124.0 K                      | 21.2 bar            | 7.2 bar             | 2.1 × 10 <sup>-2</sup> | Rapid heat removal phase; helium delta ΔP = 14 bar                           |
| 30 min         | 98.1 K                       | 48.5 K                       | 21.5 bar            | 7.0 bar             | 8.4 × 10 <sup>-3</sup> | 1st stage radiation shield passing water freezing threshold                  |
| 45 min         | 68.2 K                       | 22.4 K                       | 21.8 bar            | 6.8 bar             | 1.2 × 10 <sup>-3</sup> | Approaching N <sub>2</sub> /O <sub>2</sub> cryocondensation threshold (20 K) |
| 60 min         | 55.1 K                       | 14.2 K                       | 21.9 bar            | 6.6 bar             | 3.5 × 10 <sup>-4</sup> | Cryo-pumping active; 2nd stage below 15 K threshold                          |
| 75 min         | 51.8 K                       | 12.6 K                       | 22.0 bar            | 6.5 bar             | 1.2 × 10 <sup>-4</sup> | Charcoal array activated; hydrogen cryosorption active                       |
| 90 min (Final) | 50.4 K                       | 12.1 K                       | 22.0 bar            | 6.5 bar             | 1.8 × 10 <sup>-5</sup> | Thermal equilibrium established; Ready for UHV operation                     |

3. Regeneration Thermal Cycle & Warm-Up Response Log (12 K to 295 K)

**Regeneration Execution:** Initiated when  $T_2 > 20.0$  K or when hydrogen capacity saturation is reached. High vacuum gate valve isolated; 1st and 2nd stage electric heaters activated via COOL.DRIVE i controller. Dry  $N_2$  purge gas (2.8 bar(g)) injected to accelerate thermal transfer and flush desorbed gas species through the ISO 4126 relief valve.

| Regen Phase          | Time / Elapsed | Stage 1 $T_1$ | Stage 2 $T_2$ | Pressure / Purge              | Desorbed Gas / Thermal Action                                 |
|----------------------|----------------|---------------|---------------|-------------------------------|---------------------------------------------------------------|
| Heater Start         | 0 min          | 50.4 K        | 12.1 K        | $1.8 \times 10^{-4}$ mbar     | Compressor OFF; Electric stage heaters ON (150W)              |
| $H_2$ Desorption     | 10 min         | 72.1 K        | 24.8 K        | $1.2 \times 10^{-4}$ mbar     | Hydrogen and neon desorb from charcoal array                  |
| $N_2/O_2$ Desorption | 25 min         | 120.5 K       | 78.2 K        | 1050 mbar (Relief)            | Argon, nitrogen, oxygen boil off; ISO 4126 valve pops         |
| $H_2O$ Desorption    | 45 min         | 245.0 K       | 210.0 K       | 2.8 bar $N_2$ Purge           | Water vapor releases from 1st stage radiation shield          |
| Thermal Soak         | 60 min         | 295.0 K       | 293.5 K       | $N_2$ Purge Active            | <b>Room temp soak (295 K);</b> Heaters pulse to hold 45 min   |
| Rough Evacuation     | 105 min        | 294.2 K       | 292.8 K       | $4.2 \times 10^{-2}$ mbar     | Purge OFF; Roughing pump evacuates moisture/gases             |
| Rate-of-Rise Test    | 120 min        | 293.0 K       | 291.5 K       | $2.4 \times 10^{-4}$ mbar-L/s | 2-min RoR passed ( $< 10^{-4}$ ); Ready for restart cool-down |

4. Field Technician Verification Checklist & Performance Criteria

| Phase / Parameter | Inspection / Test Item             | Target Specification / Acceptable Range    | Field Readback                | Status     |
|-------------------|------------------------------------|--------------------------------------------|-------------------------------|------------|
| Pre-Start Utility | Static Helium Pressure             | 16.0 to 17.0 bar(g) at 20°C ambient        | 16.5 bar(g)                   | [ X ] PASS |
| Pre-Start Utility | Compressor Cooling Water           | Flow $\geq 5.0$ L/min; Temp +5°C to +25°C  | 5.5 L/min / 18.1°C            | [ X ] PASS |
| Cool-Down Curve   | 1st Stage Shield Temp ( $T_1$ )    | $T_1 = 45.0$ K to 80.0 K at equilibrium    | 50.4 K                        | [ X ] PASS |
| Cool-Down Curve   | 2nd Stage Cryopanel Temp ( $T_2$ ) | $T_2 \leq 20.0$ K within 90 minutes        | 12.1 K (in 75 min)            | [ X ] PASS |
| Crossover Spike   | Gate Opening Temp Transient        | $T_2$ transient spike remains $< 22.0$ K   | Max Spike: 16.8 K             | [ X ] PASS |
| Base Vacuum       | Ultimate Chamber Pressure          | Target vacuum $10^{-4}$ to $10^{-5}$ mbar  | $1.8 \times 10^{-4}$ mbar     | [ X ] PASS |
| Regeneration      | Warm-Up Soak Temperature           | Heaters hold $T_1/T_2$ at 295 K for 45 min | 295.0 K / 293.5 K             | [ X ] PASS |
| Regeneration      | Post-Regen Rate-of-Rise            | 2-min RoR $< 1.0 \times 10^{-4}$ mbar-L/s  | $2.4 \times 10^{-4}$ mbar-L/s | [ X ] PASS |

5. Field Technician Observations & Metrology Authorization

**Field Summary Notes:** Transient temperature profiling performed on Leybold COOLVAC 3000 iL cryopump attached to UHV Process Chamber 2. Cool-down curve demonstrated excellent thermal contact, reaching 2nd stage equilibrium ( $T_2 = 12.1$  K) in 75 minutes. Crossover thermal burst test with 350 mbar-L air charge produced a transient spike to 16.8 K, rapidly returning to baseline within 3.2 minutes. Regeneration cycle completed cleanly with full desorptive outgassing at 295 K and post-regen rate-of-rise verified leak-tight at  $2.4 \times 10^{-4}$  mbar-L/s. System certified fully operational for UHV processing.

|                        |                             |                   |                                                      |
|------------------------|-----------------------------|-------------------|------------------------------------------------------|
| Performing Technician: | Kadeem Manning              | Quality Reviewer: | Dr. Marcus Vance                                     |
| Role / Title:          | Tier II Facility Technician | QA Role / Title:  | Lead Vacuum Metrologist                              |
| Technician Signature:  | Kadeem Manning              | QA Signature:     | M. Vance                                             |
| Date Signed:           | April 14, 2022              | Status Tag ID:    | [ X ] CERTIFIED UHV READY (Tag: CERT-TEMP-2022-0414) |