Helsinki University of Technology

Metrology Research Institute

Instruction Manual for

Cryogenic Radiometer

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1. Definitions

1.1. Scope

This Instruction Manual describes the principle and operation of the cryogenic absolute radiometer as the primary standard of optical power. It also includes the quidelines for the calibration of the reference trap detectors with the cryogenic radiometer and comparison of working standard traps with the reference traps.

1.2. Object and field of application

Cryogenic absolute radiometer: Primary standard for optical power measurements. Abreviation “cryo” is also used in the text.

Trap detectors: Transfer standards of optical power measurements. Abreviation “trap” is also used in the text.

Reference standard trap detector: Trap detector that is calibrated against cryo and used to transfer the unit to the working standard traps.

Working standard trap detector: Trap detector that is compared with reference standard trap detectors and used to transfer the optical power unit to other measurements.

1.3. Features

The cryogenic absolute radiometer allows accurate and traceable calibration of photodetectors as transfer standards. The calibration of the detector is made by comparing the response of the radiometer and the detector, illuminated by the same stable light source. The relative standard uncertainty of the calibration of trap detectors is typically 2.5×10^{-4} (1σ) at the wavelengths of 458.1 – 633.0 nm and with power level of appr. 0.1 mW.

1.4. Principle of the primary standard

In calibration of optical power at Metrology Research Institute (MRI), the radiant power of a laser is detected by a cryogenic absolute radiometer based on the principle of electrical substitution radiometry (ESR) [1]. In ESR the temperature of a heat sink is measured during alternate radiant and electrical heating cycles. By adjusting the electrical heating power so that the detected temperature is the same for both types of input heating, the optical power can be equated to the measured electrical power.

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[1] J. E. Martin, N. P. Fox and P.J. Key, “A Cryogenic Radiometer for Absolute Radiometric Measurements,” *Metrologia* **21**, 147-155 (1985).

2. Equipment

2.1. Equipment used in measurements with the absolute cryogenic radiometer

The devices that are used to calibrate optical power are listed in Table 2.1. Additional devices that are used for comparison of traps are listed in **Table 2.2**.

Table 2.1. List of devices used in measurements with the cryogenic radiometer.

Description	Quantity	Identification
A. Radiometer		
1. Detector part of the cryogenic radiometer	1	
2. Electronics of the cryogenic radiometer	1	
B. Vacuum system		
1. Helium dewar	1	
2. Nitrogen container	1	
3. Vessel for cooling with Nitrogen	1	
4. Vacuum pump	1	
5. Pressure sensor	1	
6. Return pipe for used Helium	1	
7. Aluminium post to fix under the cryo cavity during N cooling	1	
C. Light source		
1. Optical power stabilizer	1	
2. Spatial filter	1	
3. Linear polarizer	1	
4. 633.0 nm power and frequency stabilized He-Ne laser	1	
5. AR$^+$ laser with selectable wavelengths of 458.1, 465.9, 472.8, 476.6, 488.1, 496.6, 501.9, 514.7 nm	1	
D. Control and data acquisition		
1. OPM6.exe, measurement program	1	
2. Digital multimeter, HP3458A	2	
3. Detector carriage and electronics	1	
4. Power supply for the carriage electronics	1	
5. Frequency synthesizer, HP8904A	1	MD101

Table 2.2. Additional equipment used for trap calibration and comparison

Description	Quantity	Identification
A. Trap detectors		
1. Trap detector made from windowless silicon Hamamatsu photodiodes (type S1337-11)	At least 1	E.g. MRI9910, MRI9402, MRI9503
B. Measurement and data acquisition		
1. Digital multimeter, HP3458A	1	

3. Measurement traceability and calibration

3.1. Traceability chain of optical power

The optical power measured by the cryogenic radiometer is traceable to the electrical power. The electrical power is measured with calibrated HP3458A multimeters. The meter used should have direct traceability to MIKES, and the calibration should not be older than 1 year. The calibrations of the multimeters are traceable to the national standards of voltage and current.

3.2. Uncertainty components

3.2.1. Uncertainty of the primary standard and corrections

An estimate of the uncertainty of the optical power measurement performed with the cryogenic radiometer is given in **Table 3.1**. More information is available in References [2] and [3].

The relative standard uncertainty of the window transmission is 0.5×10^{-4} when transmission loss is 3×10^{-4}. Tranmission loss is measured by placing a trap detector alternately in front of the window and behind it and comparing the response to a reference detector. The entrance window is carefully cleaned before each calibration.

Table 3.1. The uncertainty budget of trap calibration with cryogenic radiometer (k=1).

Component	Standard uncertainty / 10^{-4}	
Window transmittance	0.5	(A)
Repeatability of results	1.5	(A)
Beam scatter and divergence	0.7	(B)
Uncertainty of the DVMs	0.4	(B)
Nonuniformity of the trap	1.2	(B)
Cavity absorptivity	2.0	(B)
Combined standard uncertainty	3.25	

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[2] T. Varpula, H. Seppä and J.-M. Saari, "Optical Power Calibrator Based on a Stabilized Green He-Ne Laser and a Cryogenic Absolute Radiometer," *IEEE Transactions on Instrumentation and Measurements* **38,** 558-564 (1989).

[3] P. Kärhä, A. Lassila, H. Ludvigsen, F. Manoochehri, H. Fagerlund and E. Ikonen, "Optical Power and Transmittance Measurements and Their Use in Realization of the Luminous Intensity Scale," *Optical Engineering* **34**, 2611-2618 (1995).

The repeatability of successive measurements is 1.5×10^{-4} due to the noise mechanisms like changes in the backround radiation, noise in the temperature sensors and preamplifiers, and laser power instability. The contribution of the beam divergence and scatter to the uncertainty was determined to be smaller than 1×10^{-4} by measuring the beam power at different heights. The uncertainty arising from the current and voltage measurements is 0.4×10^{-4}.

Corrections

The relative corrections applied to the measured readings of the cryogenic radiometer are typically $+3\times10^{-4}$ for the window transmittance and $+0.2\times10^{-4}$ for the cavity absorptivity. The transmission loss has to be measured at least twice during each measurement session and the measured values shall be used as an actual correction term.

3.2.2. Uncertainty of comparison of trap detectors

The uncertainty budget for the comparison of trap detectors are summarized in Table **3.2**. More thorough representation may be found in Reference [3].

Table 3.2. The uncertainty budget of the comparison of trap detectors.

Component	Standard uncertainty / 10^{-4}
Calibration with cryo (Table 3.1)	3.25
Current measurement	0.4
Spatial nonuniformity	1.2
Repeatability	1.5
Combined uncertainty	3.8

The uniformity of the sensitivity over the active surface of the detector is a typical value that has been measured by scanning a laser beam 2 mm in diameter ($1/e^2$ points) across the active area of the detector.

4. Setup installation

4.1. Preparations

List of devices which have to be loaned and reserved in advance:

- Liquid He has to be ordered one week earlier from the Nesteydin at the Physics department.
- The vacuum pump must be loaned from the atom trap setup
- The dewar for nitrogen has to be loaned from microsystems group
- HP8904 frequency synthesizer has to be loaned from the students' lab
- Use of the HP multimeters, the traps and the optical power laboratory has to be agreed within the radiometry group.

4.2. Cleaning of the laboratory

The laboratory must be carefully cleaned before the measurements. There are two possible causes of the unreliable measurement results due to the presence of the dust.

1. During the calibration, the traps are mounted vertically and kept open for long time, so the dust in the air can cause serious and permanent damage if it settles on the diodes of the traps.
2. The dust particles that settle on the surfaces of the lenses, the polarizer and the Brewster window of the cryo can cause additional divergence of the light and change in the window transmittance. If it happens during the measurement session, the results may become unreliable.

4.3. Cleaning of the components

All optical components have to be carefully cleaned before installation. Aceton and paper tissues can be used. It is useful do keep a laser on because all possible dust particles, that remain on the surfaces can be easily detected in the intense laser light.

The window of the cryo should be cleaned last. The cryo should be installed in the rack, and the laser alligned approximately in the center of the entrance window. The lower side of the window should be cleaned first and then the window should be installed back to the cryo. The upper surface of the window is cleaned last. The intensity of the scattered laser light indicates the cleanliness of the surfaces.

4.4. Installation of the lasers

HeNe laser and Argon laser are installed on the top of the rack. Grey plastic plates are used under the lasers to adjust the height and the screwholes. Some of the screws are not metric.

Before the allignment of the mirrors, the optical power stabilizer is installed on the optical rail. Magnetic mount can be used under the stabilizer as it has suitable height and it makes it easy to remove the stabilizer if needed during the alignment process.

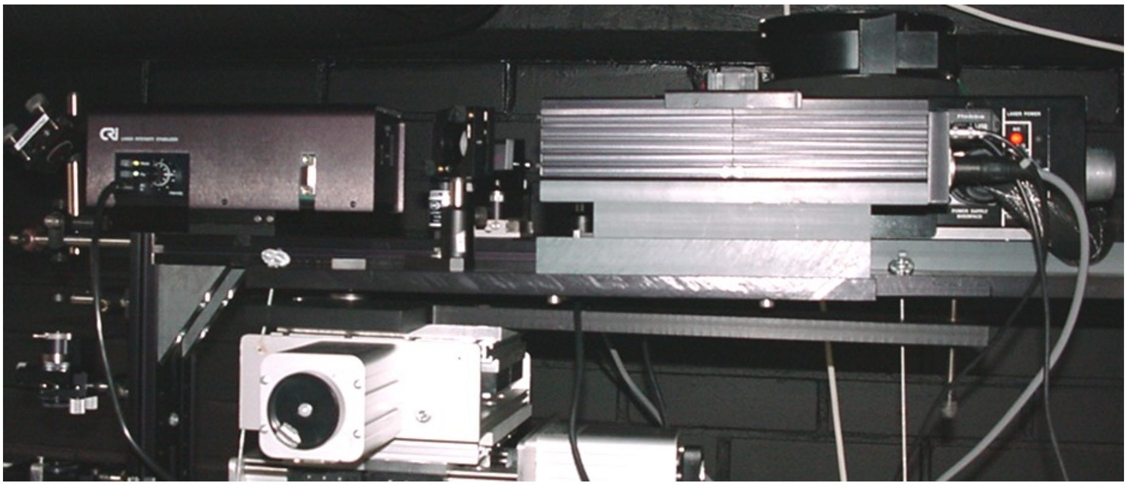


Figure 4.1. HeNe laser and optical power stabilizer installed on the upper plate of the cryo setup.

First the upper plate of the rack should be aligned approximately in the horizontal position. Then one of the laser beams is aligned through the stabiliser and redirected with a mirror vertically down. **NB! The laser beam should remain at a certain distance from the vertical optical rail, approximately 10 cm, so that the spatial filter can be mounted on the rail.** Two iris diaphragms are installed on the vertical rail so that the beam goes throug the irises.

Beam of the second laser is aligned through the stabilizer in such a way that it passes through the two irishes installed on the vertical rail.

4.5. Installation and alignment of other components

There are following components to be installed on the upper plate:

- Lasers
- Mirrors for redirecting the laser beams
- Variable neutral density filter (used with Argon laser only)
- Optical power stabilizer

On the vertical rail:

- Linear polarizer
- Spatial filter with collimating lense
- Two irises
- A baffle to reduce the stray light

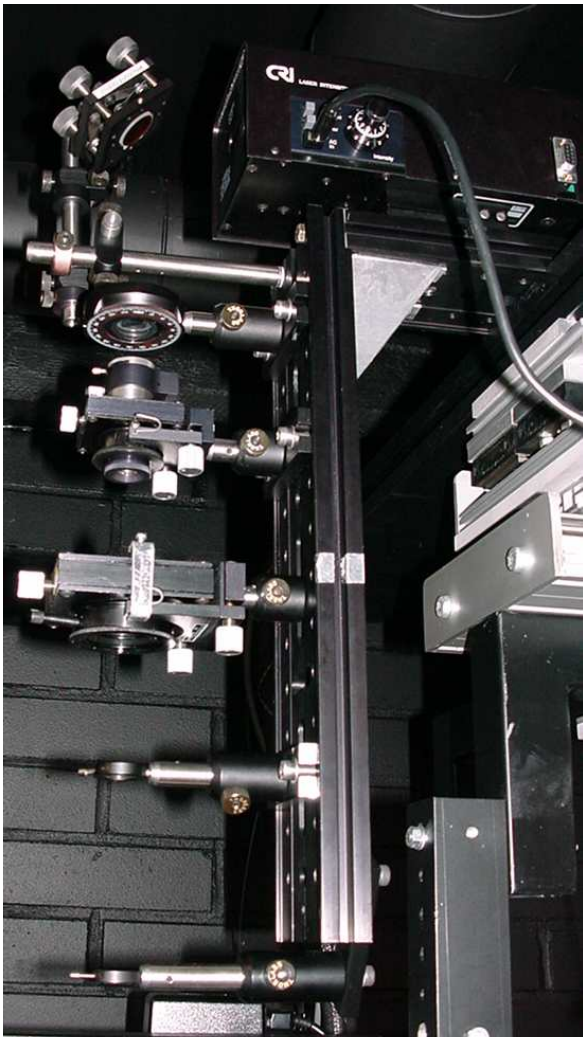


Figure 4.2. Components on the vertical rail.

There are a few tips about the alignment of the components on the vertical rail:

- Linear polarizer should be aligned before the spatial filter is installed and it should be aligned to the maximum throughput position for both lasers. A laser power meter should be used. It is very difficult to align the polarizer after the installation of the spatial filter as the rotation of it slightly changes the beam position, that results in different transmittance of the spatial filter.
- Spatial filter is aligned in such a way that the beam will go through the irises.
- The collimating lens is installed at suitable distance for collimating both laser beams. **NB! The geometry is slightly different for different laser beams.**
- The bafflele can be installed later, after the alignment of the beam into the cryo cavity.

4.6. Preliminary installation of the cryo

The cryogenic radiometer is installed into the rack first without the cooling and the following procedures are done:

- Laser beam is directed to the center of the window
- The entrance window is cleaned. **NB! Before opening the cryo, check that the cavity valve is closed!**
- A trap detector is installed under the window and the angle of the window is aligned to maximize the transmittance; trap is removed after the measurements
- Pressure sensor of the vacuum pump is connected
- The vacuum pump is connected and the cryo is vacuumized again
- The cavity valve is opened and the laser beam is aligned to the cavity.

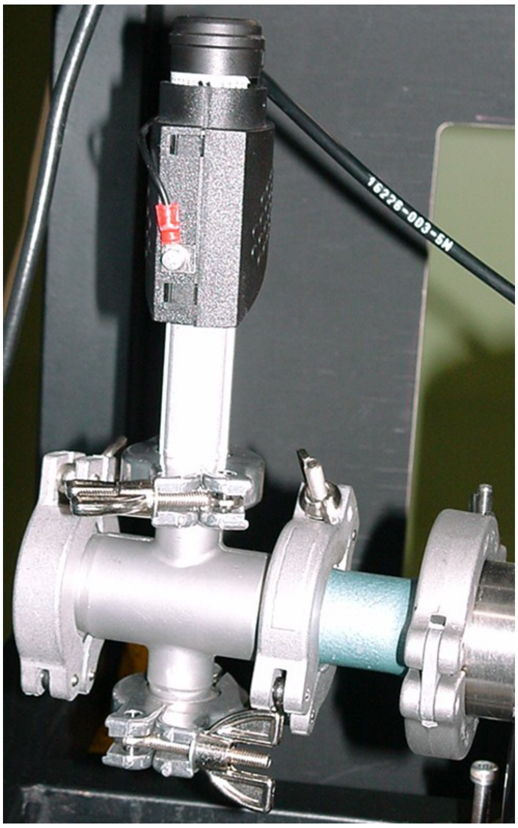


Figure 4.3. Pressure sensor connected to the cryo.

4.7. Vacuum pump

Two stage vacuum pump is used to vacuumize the cryo. It is connected to the cryo with a felxible metal pipe. Special grease can be used with the gasgets.

The first stage is used to reduce the pressure to the level of approximately 5 mbar. Then the second stage is started, which reduces the pressure lower than 10^{-3} mbar. This is the limit of the range of the pressure sensor and the reading of the pump display is set to 10^{-9} mbar.

There is a copper screw to ventilate the pump before disconnecting from the hose. The pump can be on continuously.

Figure 4.4. Vacuum pump. The switch of the first stage is on the blue engine. The upper display is for the pressure sensor. The lower unit has the controls of the second stage. Normal working frequency is around 860 Hz.

4.8. Connections with measurement electronics

There are some general connections that are common for all measurements with the cryo:

- The cable of the cryo is connected with the cryo electronics.
- 12 V power suply is connected to the carriage control unit of the cryo electronics.
- Cable from the electronics unit is connected to the computer LPT1 port.
- Two HP multimeters are connected to the computer via GPIP cable.

Figure 4.5. Power supply of the trap carriage.

4.9. Software OPM6

The control program of the cryo is named OPM6 and it is located in the computer of the optical power laboratory in the directory

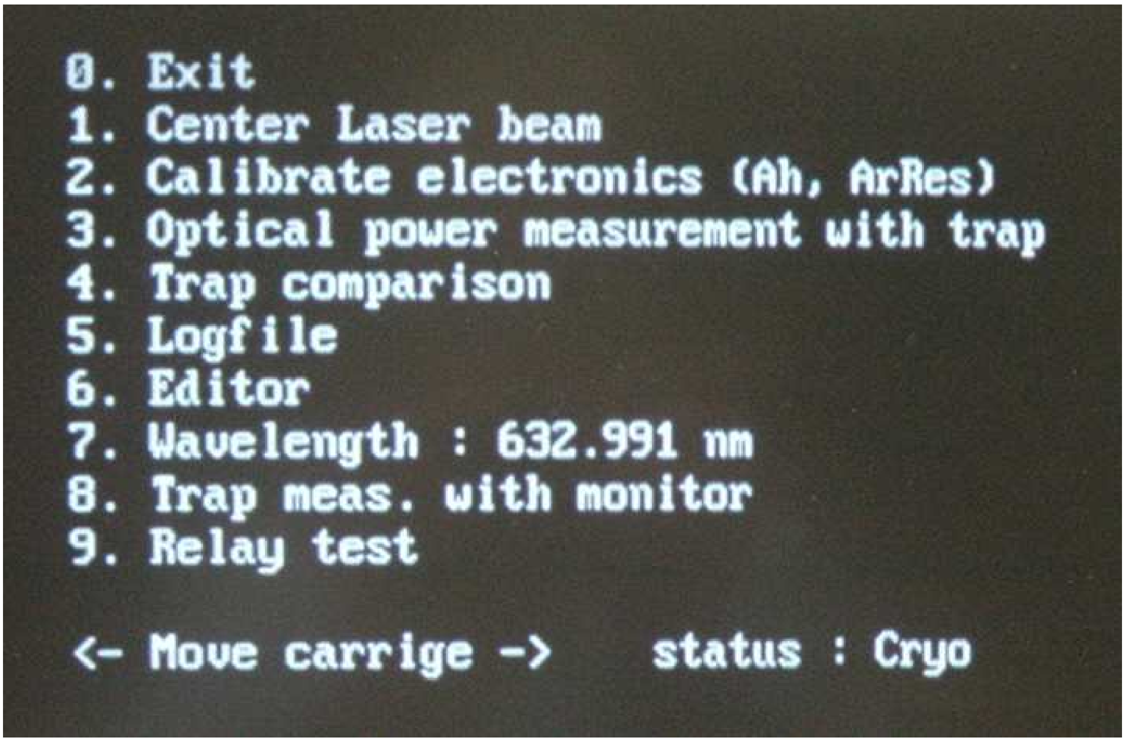
C:\TP7\OPM5

The working directory of the program, where all data files and the logfile are saved, is

C:\TP7\OPM5\DATA

There are list of subprograms and functions in the start menu. All performed opperations are recorded in the file called logfile.log. The measurement data are saved separately also in *.rap files.

NB! The program can not control the trap carriage unless the switch of carriages is in the middle position.



```
0. Exit
1. Center Laser beam
2. Calibrate electronics (Ah, ArRes)
3. Optical power measurement with trap
4. Trap comparison
5. Logfile
6. Editor
7. Wavelength : 632.991 nm
8. Trap meas. with monitor
9. Relay test

<- Move carrige ->    status : Cryo
```

Figure 4.6. The main menue of the OPM6 software.

4.10. Autocalibration of the cryo electronics

Autocalibration procedure is performed before measurements. In addition to the two HP multimeters, HP8904A frequency syntheziser is used as a reference signal source. The aim of the autocalibration is to calibrate the resistances of some cryo resistors. If the calibration is not performed, the values of the resistances from the last calibration are used.

The Cal switch of the cryo electronics must be set on “cal” position (lower position). Another switch has to be in H1 position.

The following connections are made:

- Cable from $U_{1,IN}$ to $U_{sen,H1}$ (U_{ref} ends of the cable remain not connected)
- Signal High from the HP8904A is connected to HP that is measuring the current (look at the message on the HP display)
- Signal Low from the HP8904A is connected to the I_{low} end of the DVM cable from the cryo electronics
- I_{high} end of the DVM cable from the cryo electronics is connected to the HP that measures current

- U_{high} and U_{low} ends of the DVM cable from the cryo electronics are connected to the HP that measures voltage

NB! The HP multimeters have to be themselves autocalibrated before the cryo autocalibration.

The autocalibration procedure can stop and show an error message. That might be a result of a wrong connection.

The expected values of the resistances are approximately

Ah=1.000317, ArResV=0.999967 and Res=1.000035

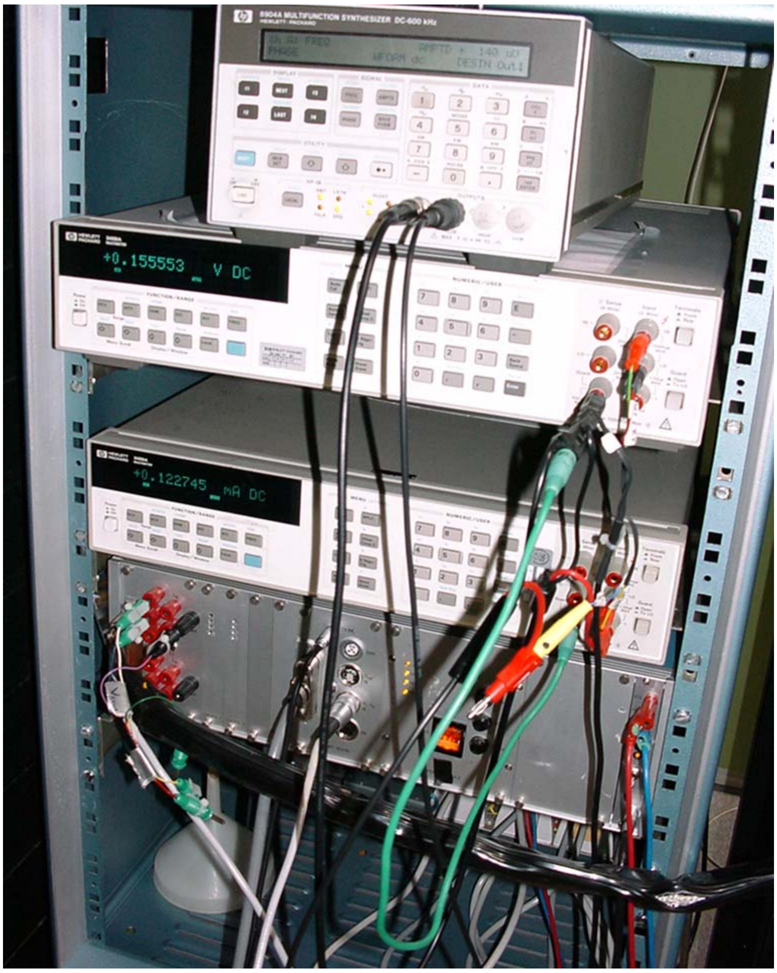


Figure 4.7. Cable connections during the autocalibration procedure.

4.11. Test alignment of the beam into the cavity

The alignment of the laser beam into the cavity can be tested if the cryo is vacuumized. However, the total power reading is meaningless if the measurtements are done at the room temperature.

Changing the position and direction of the laser beam

1. The alignment of the components on the optical rail should not be touched.
2. The beam position can be changed by adjusting the position of the translators under the plate that carries the lasers and the optical rail.
3. The beam can be tilted by tilting the plate.

The alignment procedure

1. Connect the H1 U_{sen} connectors of the cryo electronics to the HP that shows “sensitivity” message on its display.
2. The voltage cables from the DVM cable of the cryo electronics are connected to another HP.
3. There are 8 alignment diodes in the cavity of the cryo. Four of them are close to the bottom of the cavity and another four close to the top of the cavity.
4. Beam alignment procedure of the OPM6 software reads the photocurrents from the diodes and shows the readings graphically.
5. The beam should be aligned in such a way that the readings of all diodes at the same level are similar. There might remain difference between the signal levels for the different set of diodes.
6. The complete alignment can not be done without cooling, because the full power reading is necessary.

NB! The baffel which blocks the stray light on the optical rail does not move together with other setup during the alignment. The laser beam can touch the edge of the baffle and so disturb the alignment. It is suggested to remove the baffle beforehand.

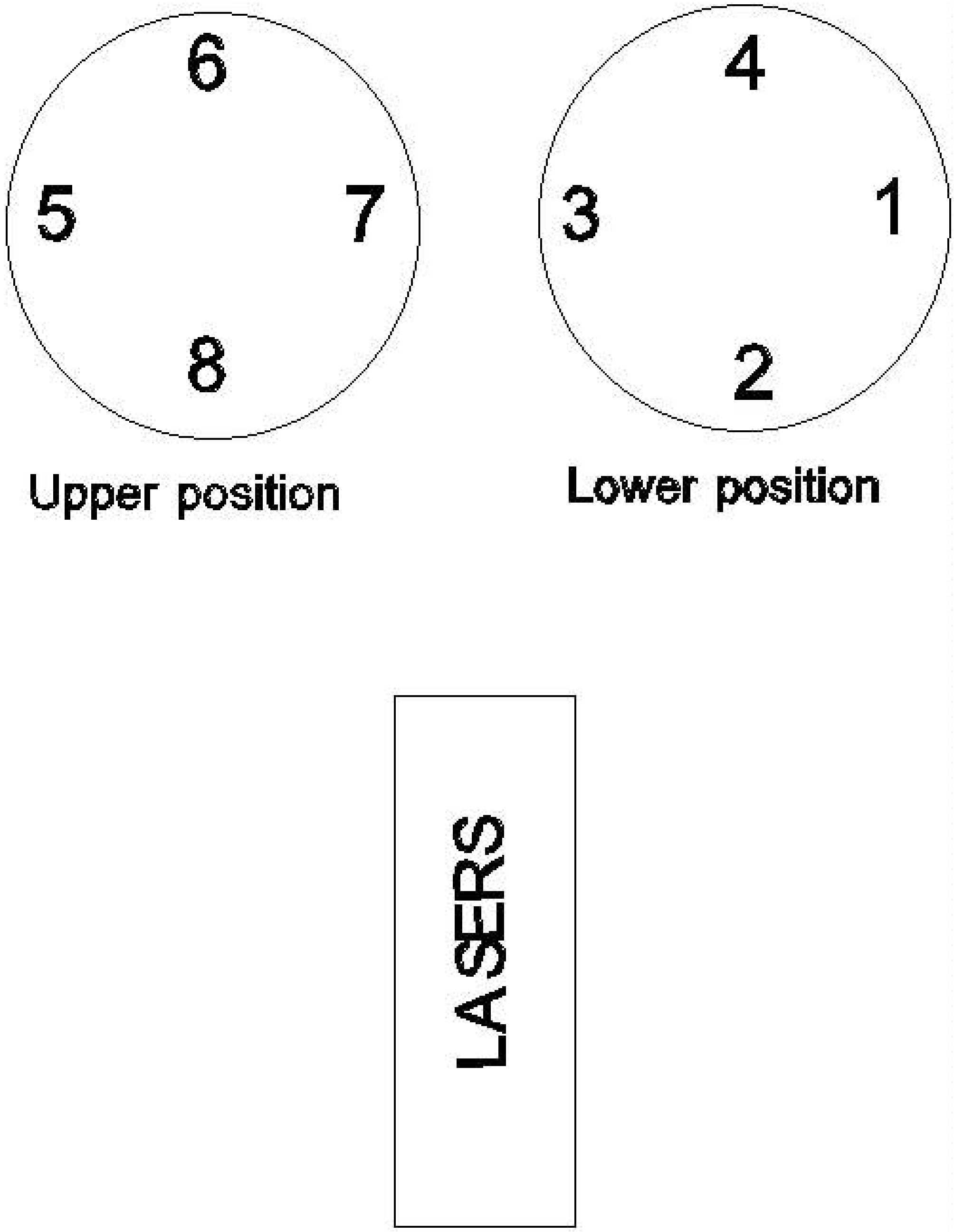


Figure 4.8. Configuration of the alignment diodes of the cryo cavity. The figure size is appropriate to be clearly seen from a distance of more than 1.5 meters during the actual alignment procedure.

4.12. Cooling

Cooling of the cryo is done in two steps. First it is cooled with liquid nitrogen and after that with liquid helium.

Preparations

1. Order the Helium from Nesteytin one week earlier. Make sure, that a dewar with 50 mm neck will be supplied. It is called just “the big neck”.
2. Borrow dewar for nitrogen from atom optics group.
3. Fix the special post under the cryo cavity. The aluminium post is located in the drawer next to the cryo setup. The post is used only during the nitrogen cooling, then it is removed.
4. Prepare the lifting rope that will be used to hang cryo over the helium dewar. The rope can be hanged over the steel wire under the ceiling. The other end of the rope can be fixed to the supporting construction of the optical table.
5. Record the reading of the gas meter that is located in the workshop.
6. Air is pumped out of the cryo during the night before the cooling.
7. Measure the resistances of the cryo cavity resistors.

Cooling with nitrogen

1. Pump is disconnected. Cavity valve is closed. The pressure sensor can remain attached to the cryo. Be careful with the cable of the sensor!
2. Cryo is fixed on its holder on the wall.
3. A few centimetres of nitrogen is poured on the bottom of a steel vessel, which is located next to the cryo setup.
4. The steel vessel is mounted under the cryo so that the post remains a few centimetres higher from the level of the liquid.
5. Fifteen minutes later the vessel is lifted so that the post slightly touches the nitrogen. A catalog book was used under the vessel.
6. Fifteen minutes later the nitrogen is added so that the post is ½ in the nitrogen.
7. In 15 minutes the nitrogen is added so that the copper slightly touches the nitrogen.

8. Half an hour later the nitrogen is added so that the copper is ½ in the nitrogen.

9. One hour later the nitrogen is added so that the copper is completely in the nitrogen.

10. Wait for the stabilization of the cavity temperature. It takes around 1½ hour.

Figure 4.9. Cryo in Nitrogen. There should be a rag around the cryo cavity to reduce the ice formation. It was forgotten during the 2003 measurement session.

Figure 4.10. Cryo is slowly sunk into the He.

Cooling with helium:

1. The helium pipe is connected to the dewar.

2. The carriage with the wheels is removed from under the He dewar.

3. The valve of the helium pipe is opened in the workshop. Check the reading!

4. Cryo is lifted out of nitrogen and the post is removed.

5. **NB! The ice has to be removed from the outer surface of the cavity!**

6. Cryo is hanged with a rope on the construction in the ceiling.
7. The dewar is placed under the cryo.
8. The cryo is slowly immersed into the helium. The total time of the process is approximately 30 minutes.
9. The ring on the cryo is used to close the dewar. It should be closed during the immersion process to avoid the escape of helium.
10. The cryo and the dewar are moved into the measurement setup
11. The pump is connected and the cryo is vacuumized again. The cavity valve can be opened.
12. The control resistances are measured.
13. By next day the resistances should become stabile. That means the temperature of the cryo cavity has stabilized.

Figure 4.11. Cryogenic radiometer in the measurement setup. The entrance window should remain covered whenever measurements are not conducted.

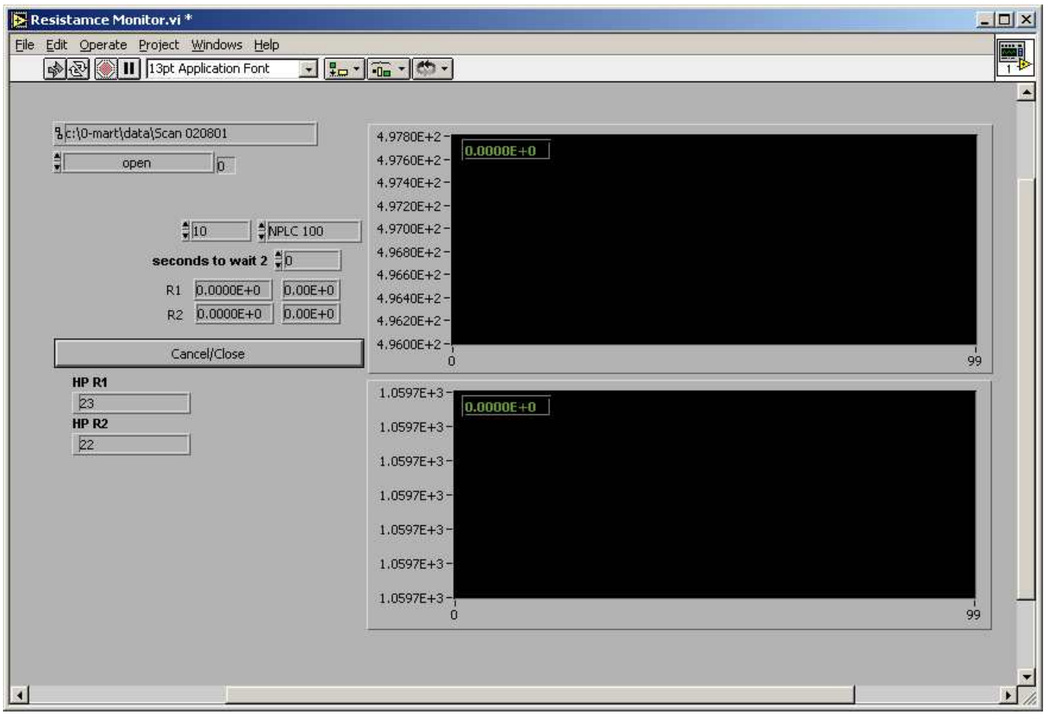
4.13. Measurement of the resistances

Resistances of some resistors in the cavity can be used to determine if the temperature of the cavity is stable. The resistances are stable at the room temperature or if the temperature has stabilized to the temperature of the liquid Nitrogen or Helium.

Contact pins of the cryo cable		Resistance at 20 °C (Ω)	Resistance at 4 K (Ω)
24	8	457	664
24	17	432	465
24	16	87	544
8	17	429	464
8	16	429	467
18	39	38	35.7
18	13	1291	1059
18	34	1290	1059
13	34	45	33.7
13	39	1291	1059
39	34	1290	1059
29	42	1202	1036

Table 4.1. Pin numbers of the cryo cable and the corresponding resistances before and after the cooling.

There is a LabView program called ResistanceMonitor.vi developed for the on-line monitoring of the resistances during the cooling. The program is stored and runs on the Toshiba laptop computer that has to be connected with both HP multimeters. The resistances between pin pairs 24-16 and 18-13 are suitable for monitoring.



Resistamce Monitor.vi *

c:\0-mart\data\Scan 020801

open 0

10 NPLC 100

seconds to wait 2 0

R1 0.0000E+0 0.00E+0

R2 0.0000E+0 0.00E+0

HP R1 23

HP R2 22

Figure 4.12. The control window of the resistance monitoring software in LabView, the Resistance Monitor.vi

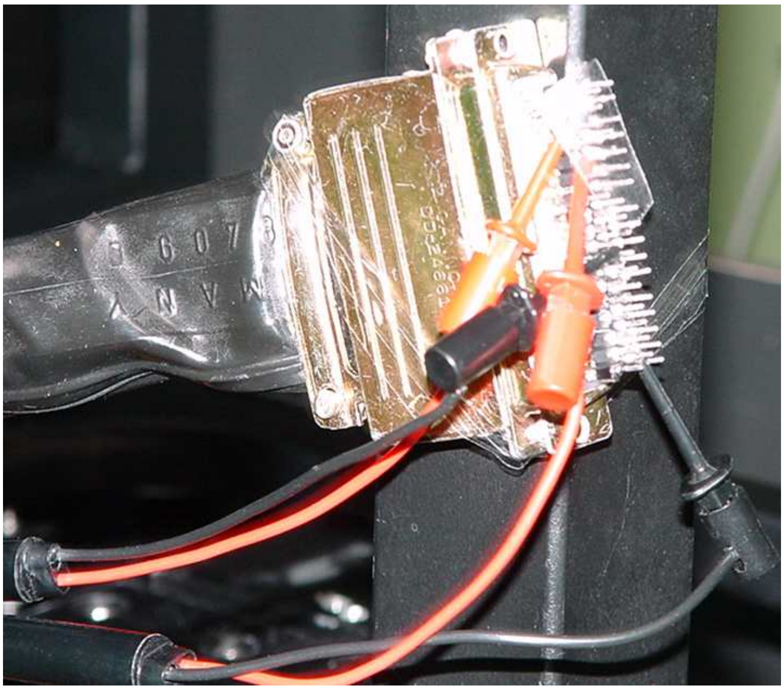
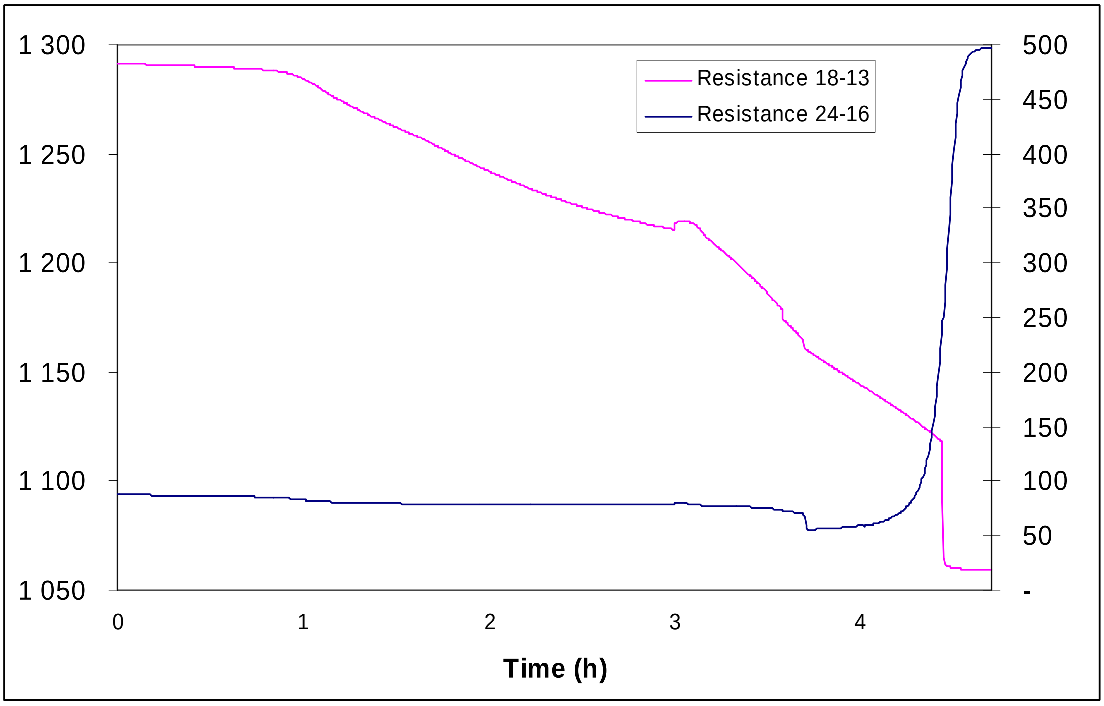


Figure 4.13. Connections for the resistance measurements. An additional connector is used with the cryo cabel to connect the measurement cables.



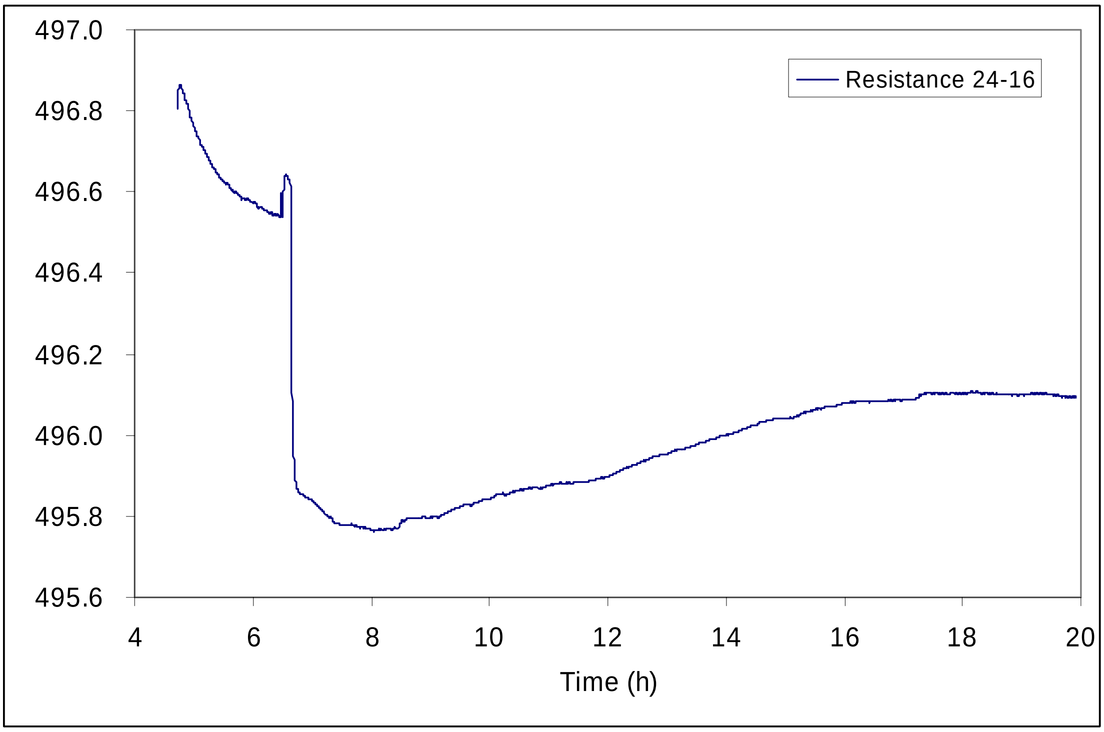


Figure 4.14. Change of the resistances. First 4.5 hours was the cooling with Nitrogen. Fast change region from 4.5 to 5 hours corresponds to the sinking the cryo into the He. The resistance between the pins 24-16 stabilised fast but 24-16 stabilised in 18 hours.

5. Calibration of reference traps

5.1. Setup and connections of the measurement electronics

The basic setup has been descrtibed in the last chapter. There are a few tips about the specific setup:

- Trap under the calibration should be mounted in the trap holder 1 on the carriage.
- The back reflection from the trap is directed to the edge of the iris.
- The trap cable is connected to the HP that measures the current (look at the displays of the HP-s). **NB! Check the polarity! An error message is displayed and the program is halted if the polarity is not correct.**
- The voltage cables from the DVM cable of the cryo are connected to the HP that measures the voltage.

NB! Check that the carriage control switch is in the middle position before the measurements.

5.2. Stability of the laser power

It is crucial to make sure that the optical power stabilizer is working effectivly and in its best power range. For that purpose, the test comparison of two traps should be conducted before the actual calibration with cryo.

In case of HeNe laser, the optimal stabilized output power is around 120 µW, which corresponds to approximately 60 µA photocurrent from the trap detector.

The optimal power for the Argon laser is around 160-200 µW, which corresponds to approximately 80 µA photocurrent from the trap detector. **NB! Variable neutral density filter has to be used before the optical power stabilizer to reduce the laser power to necessary level.**

The standard deviation of the test comparison of the traps should be in the order of 1×10^{-4}.

5.3. Alignment of the laser beam

The basic alignment procedure is described in Chapter 4.11. In addition, the power reading of the cryo has to be maximized. After the alignment, a test trap calibration has to be conducted. Then the realignment and the test measurements should be repeated until it is clear that the power reading of the cryo can not be increased any more with additional improvement of the alignment. The problem is that single power readings of the cryo vary in the order of 1 %. It makes it impossible to find the maximum power position without the test measurements which include total measurement time of over 20 minutes.

Alignment procedure is repeated for each wavelength.

5.4. Trap calibration

NB! Check that the wavelength in the OPM6 program corresponds to the one in use!

NB! Check that the entrance window is clean!

NB! Check that there are no dust particles in the traps!

Before the cryo measurements, the ratios of the reference standard traps should be measured. The agreement between the relative and the absolute calibration is a good indicator to validate the calibration rasults.

Each of the reference trap detectors is calibrated three times with the cryo. The deviations between these measurements should be in the order of 1×10^{-4}. The standard deviation of each measurement should be also in the order of 1×10^{-4}.

Use trap position 1 in the carriage. The time that is normally used for measurements at one laser wavelength is two days.

5.5. Measurement of the window transmittance

After the calibrations at each wavelength, the window transmittance should be measured. The following procedure applies:

- **NB! Close the cryo cavity! Some force is needed for pushing the valve!**
- Stop the stage 2 of the pump. It will take about 5 minutes to stop.
- Stop the stage 1 of the pump
- Open the ventilation screw of the pump.
- Open the cryo
- Mount the Trap 2 under the window
- Measure the ratio with reference trap in position 1 of the carriage.
- Close the cryo; remove it from the setup. Measure the optical power at the same position without the cryo. **NB! Realign the trap!**
- Ratio of the measured ratios gives the transmittance correction.

- Proceed with the beam divergence measurements.

5.6. Measurement of the beam divergence

Beam divergence can be measured before the installation of the cryo. However, it is probable that the beam shape is changed during the beam alignment process. In such a case the divergence measurements have to be repeated after completing the cryo calibrations at that wavelength. The beam divergence has to be measured separately for all used wavelengths.

For the divergence measurements two traps are compared first on the carriage. Then the trap from the position 2 is removed from the carriage and mounted to the lowest position, approximately to the height of the cryo cavity. The trap comparison is repeated and the difference between two measured ratios gives the divergence correction. It is the case because the sizes of the input apertures of the cryo cavity and of the trap detector are approximately equal.

NB! For the measurement in the central carriage position with OPM6, a capital "C " should be typed in before the trap name.

The measured divergence should be in the order of 1×10^{-4} for all wavelengths.

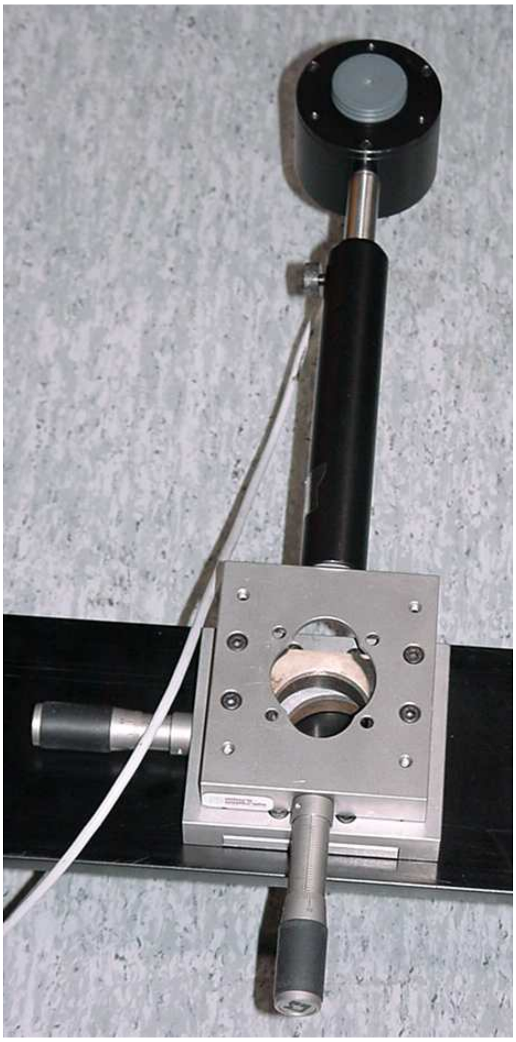


Figure 5.1. Trap at the low position for the beam divergence measurements.

6. Completing the cryo measurements

There are a list of actions that should be followed after the cryo measurements are completed.

1. The reading of the Helium counter is recorded
2. The valve next to the counter is closed
3. The back flow valve of the Helium dewar is closed
4. The emergency pressure valve of the dewar is opened
5. The back flow pipe is disconnected
6. The cryo is removed from the dewar and hanged on the wall.
7. The dewar is closed properly and returned to the Liquidation Center of the physics department
8. All loaned devices are returned.

NB! It is strongly recommended that Helium is not completely used and some of it is left in the dewar.

7. Calibration of the working standard traps

Working standard traps are compared against the reference standard traps when the cryo calibrations at all wavelengths are completed.

The OPM6 software can be used. It has a subprogram called Trap Comparison that can be started from the main menu of OPM6. The program gives guidances about how connect the the traps to the multimeters.

One reference standard trap is used as a reference. Other reference standard traps are included in the calibration among the working standard traps and compared with the reference trap in order to validate the calibration.

The calibration of each trap should be repeated at least twice.

NB! Check the beam shape at each wavelength!

8. Reporting results

Report of the calibration results has to be issued. Following data has to be included in the report:

1. Ambient temperature and humidity.
2. Names of the calibrated traps.
3. Name of the trap that was used as a reference in comparison with working standard traps.
4. Measured external quantum efficiencies.
5. Calculated responsivities.
6. List of used wavelengths with clear notice if these are given in air or in vacuum.
7. Uncertainty budgets.
8. Differences from the previous calibration if available.

The results and the data are stored as follows:

1. The raw measurement data are stored in the computer of Optical Power Laboratory.
2. The MS Excel file with the calculations is stored in the My Documents folder of the computer Mart that is located in room I433.
3. Paper copy of the results is stores in the folder called Calibrations on the bookshelf in room I433.
4. Copy of the data and the calculation file is stored in the Quality folder of MRI server Megamuisti at **\\MEGAMUISTI\public\data\MRI_docs\quality\radiom**
5. Original of the calibration certificate is stored at the green drawer in the meeting room