EUROPEAN LABORATORY FOR NUCLEAR RESEARCH

CERN - LHC DIVISION

LHC-VAC/GS

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In-situ Bakeout for LHC Experimental Chambers
Report on 1 m Test Model

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Table of Annexes:

1. Introduction

The beam pipes of the LHC experiments Alice, Atlas, CMS and LHC-B will have to be either entirely or sectionally heated up in-situ to activate a longitudinal Non Evaporable Getter (NEG) pump in the beam pipe. In-situ in this note means that the bakeout material stays around the beam pipe during machine operation. The baseline temperature for all bakeout material tested was 300°C, which is the temperature to activate the commercially available NEG pump of type St 707. There is a study ongoing with the aim to reduce this temperature to approximately 200 °C. Some test were made at this temperature for comparison. The in-situ bakeout parameters are dependent not only on the bakeout temperature, but also on the power of the electric heating, performance of the thermal insulation and the power of the active cooling possibility required in order to be below the maximum admissible temperature in the detector envelope.
This note describes the different materials tested on a one meter long model to see their suitability, mounting requirements, space constraints and to estimate the heat loss via the thermal insulation. The environment simulated for the bakeout test was similar to the that in the Argon Endcap (AE) detector of the Atlas experiment, the beam pipe diameter chosen for the test set-up was O.D. 48.3 mm.
The potential options will be validated on a 4 m long model.

2. Design Parameters

Table 1: Following parameters were used to simulate the NEG-activation of the beam tube in the AE detector of the Atlas experiment in July 1997:

	Parameter given		Parameters used	
Activation temperature:	300	°C	300 and 200	°C
Radiation resistance:	10	MGray	10	MGray for heaters and insulation, not for adhesive tape
Max. outlet temperature of cooling gas:	100	°C	90	°C
Heat transfer in detector:	0	W		Not achieved
Pipe outside diameter	50	mm	48.3	mm
Thickness of bakeout material	<10	mm radial		various
Gap for air cooling and offsets between beam pipe and detector	15	mm radial		about 7.5 mm
Inside diameter of detector envelope	100	mm		80 mm
Relative magnetic permeability	1.02			Not checked
Transparency		as high as possible		various

It should be noted that the design of the vacuum system has changed since the initial parameters were given, and not all input parameters are still the same.

3. Experimental set-up of 1 m long test model

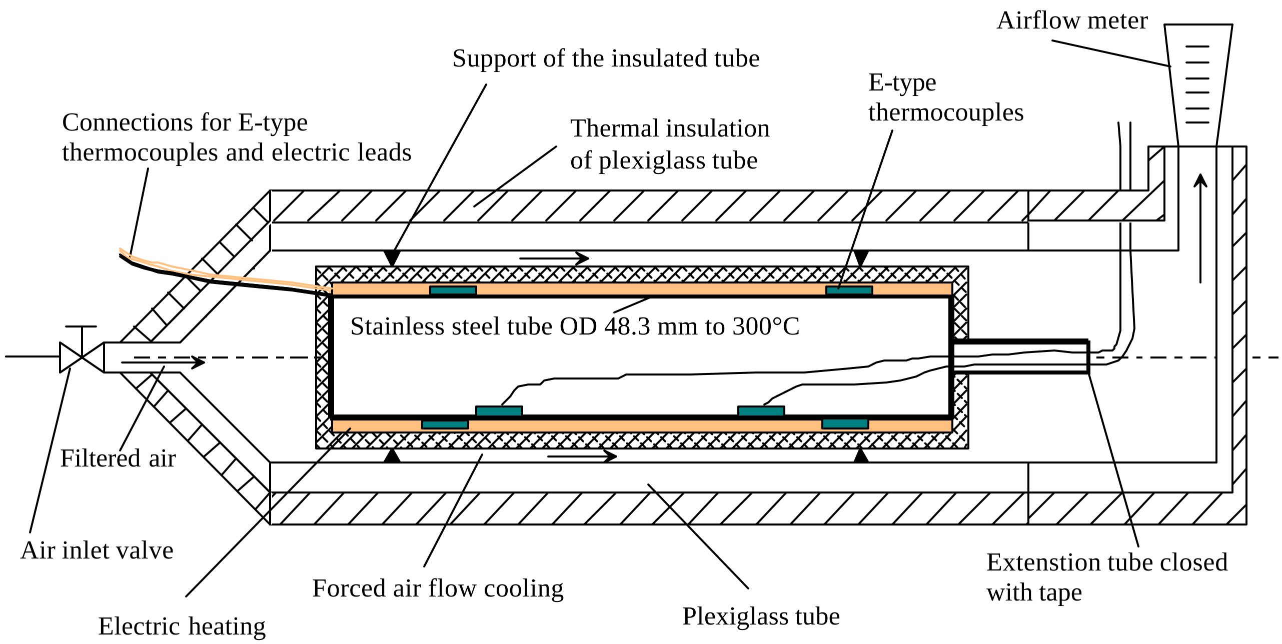

Figure 1: Schematic of experimental set-up for in-situ bakeout test without insulation vacuum

Materials used for the set-up:

Airflow meter: GEMÜ, PP Rotation air flow meter DN25, Type 825 for 1-16 Nm^3calibrated to 80 °C
Plexiglass tube: OD 90 mm, ID 80 mm, 1200 mm long from CERN store
Thermal insulation on plexiglas tube: 10mm thick glass-fibre insulation
Thermocouples: E-type, Chromel / Constantan
Temperature recorder: Philips PM 8237A, 30 Channel Multipoint Data Recorder

The power and temperature were adjusted by changing manually the voltage on a variable potential transformer. The electric heater and a precision resistor were connected in series. The power was calculated via the voltage drop.

4. Heating

A search was made to find the best thermal insulation with the lowest thermal conduction and thin electric heating.
The radiation hardness and the temperature criteria excluded all organic materials with the exception of polyimide and possibly PEEK [1].

4.1 Electric heating

The types of electric heating tested were a co-axial heater, a heater strip, a polyimide foil heater and a "sandwich" heating with spayed ceramic and stainless steel resistor.

[1] H. Schönbacher, M. Tavlet, Compilation of Radiation Damage Test Data, Part 1, 2nd Edition, Halogen free cable-insulating materials, CERN, 1989

4.1.1 Direct/Joule heating

The simplest way to heat up the beam tube would be direct or Joule heating of the beam pipe, which means that a current flows in the resistive beam pipe itself.

Assumptions for a stainless steel tube for the AE detector of the Atlas experiment:

Tube OD	50	mm
Wall thickness	1	mm
Resistivity of 316 stainless steel at 300 °C	0.9	$\Omega \cdot mm^2/m$
Power needed	200	W/m

Hence:

Cross section of the tube	154	mm^2
Resistance per meter tube	5.8	$m\Omega$
Current in beam pipe	185	A

A current of 185A requires a high current source. The beam pipes within the experiments are made of different diameters and different materials besides stainless steel such as aluminium and beryllium. Thin wall bellows have to compensate for thermal expansions and alignment tolerances. Hence, the resistance changes locally which could result in overheating and damage of the beam pipe. If joule heating was chosen, attention would have to be paid that the current does not flow via the beam pipe supports in the detectors.
For these reasons, Joule heating was not considered in this study. Work on this subject is currently ongoing and will be presented in a future report.

4.1.2 Heater Strip

One of the most common devices to heat up circular tubes is a heater strip which is wound in a spiral around the tube. This consists of a flexible resistive element in glass fibre insulator. For the test on the one meter long model, an undulated resistor was chosen, which reduces the risk to be burned during a heating cycle.

Table 2: Dimensions and characteristics of the heater strip tested.

Thickness	2	mm
Width	25	mm
Length	3.6	m
Max. surface temperature	450	°C
Power	1180	W at 240V (for 3.6 m long heater strip)
Heating element		Nickel-Chrome alloy (Magnetic permeability not tested)
Electric insulation		Woven glass fibre cloth
Maximum thickness of tape (at electrical connection)	8	mm
Supplier / Type		WISAG, Switzerland / Type G

The heater strip was mounted with adhesive glass fibre tape.
One heater strip showed an electric short circuit after the strip was mounted to the O.D. 48.3 mm tube, heated up to 300 °C and demounted for 5 times. The failure occurred because the glass fibre cloth was rubbed off locally.

This failure was surprising since heating tape is considered to be reliable. The nickel-chrome alloy resistor could be replaced by a stainless steel one with well defined magnetic characteristics. Tests made with insulation vacuum showed a high contamination of the insulation vacuum pipe with a "sticky yellow film". It is assumed that it is silicone released from the glass fibre fabric insulation of the heating tape. The contamination was reduced with every heating cycle.
The mounting of the heating tape will have to be changed for the real application, since the glue of the adhesive tape will degrade due to radiation.
For applications for which space constrains are not dominating, a heater strip can be considered as a simple solution to heat up the beam pipes.

4.1.3 Co-axial heating cable

Co-axial heating cables are made out of a resistor, usually insulated by a ceramic powder inside a sheath (see *Figure 2*). Two manufacturers of this heating element were found, Alcatel Cable and Philips Thermocoax. The minimum diameter of standard co-axial heating cables is 1 mm. To reduce the risk of overheating the cable locally, a 1.5 mm diameter cable was chosen with a resistance of 2.1 Ω/m. A 0.2 m long cold transition with copper core (0.15 Ω/μ) and OD 1.5 mm was included on both ends of the 4 m long resistive part of the cable to allow for a thermal transition between the heated beam pipe and the electrical connection.

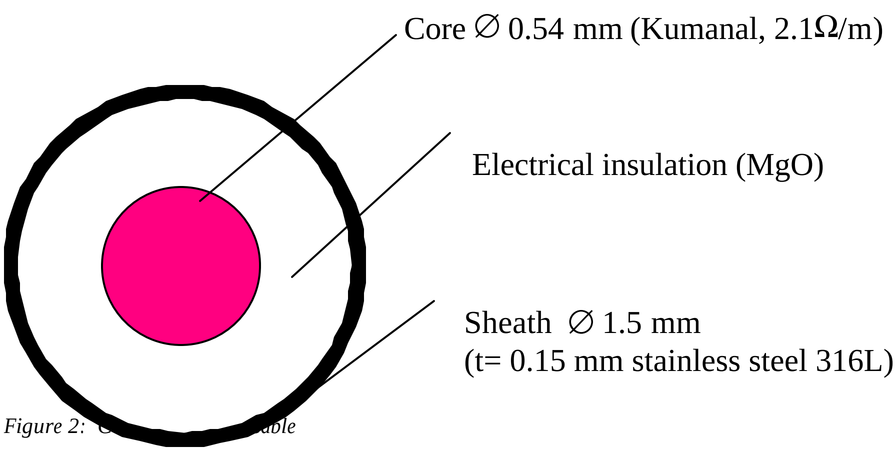

Figure 2: C[illegible]able

The 4 m long cable was mounted in a spiral on the 1 m long beam pipe. The cable was fixed with thin wires for a preliminary test. For further tests, it was induction brazed under vacuum without flux using a CuAgPd (10%Pd) alloy.
The advantages of the co-axial heating cable are the high radiation resistance, the high maximum temperature of up to 700 °C and the small diameter.

4.1.4 Polyimide (Kapton ®) heating foil

Polyimide heating foils are made out of a thin resistive foil circuit laminated between two polyimide foils, see *Figure 3*. The thickness of the heating foil is 0.13 mm. The time dependent degradation of Kapton ® starts at 250 °C in air, the maximum short time temperature is about 420 °C [2]. The maximum temperature is higher under vacuum.

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[2] Data from supplier

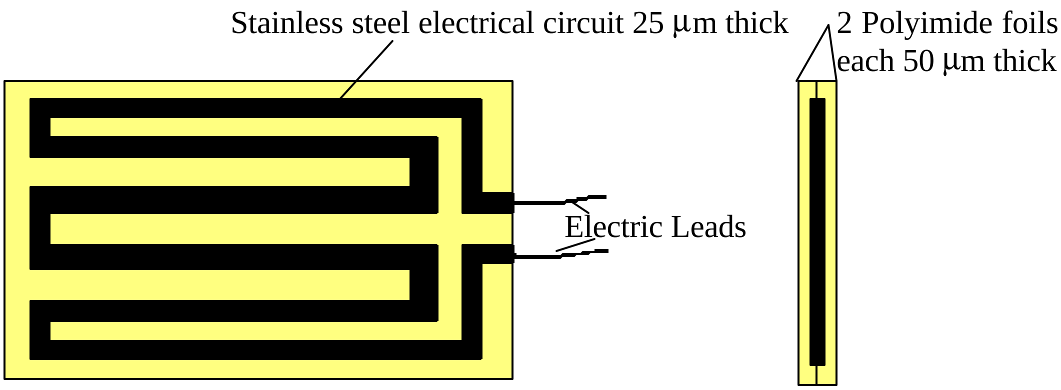


Figure 3: Polyimide heating foil

A number of manufactures were found producing polyimide foil heaters, however, most of them use a glue which is not suitable for the application, e.g. Teflon ® containing. Two manufactures, Minco (F) and Rica (I) were found using a suitable glue. The size of the parts is limited by the bonding press. Rica is limited to 600 mm square, Minco to 430 mm. Rica was given an order for 0.5 m long heaters. A DUPONT Kapton ® KJ thermoplastic polyimide film was used to bond the two layers together.
The two 0.5 m long polyimide heating foils were wrapped around the beam pipe and fixed with adhesive tape.
No degradation of the material could be noticed during the tests at 300 °C for several hours. To qualify this heating method, the degradation of the bonded polyimide foil under radiation and heat would need to be studied in more detail.

4.1.5 Vacuum Plasma Sprayed Heater and insulation EMPA-tube

The heater consists of a sandwich construction of an insulator/conductor/ insulator, which is vacuum plasma sprayed on to the beam tube. This heating system was developed by the Eidgenössische Materialprüfungs- und Forschungsanstalt (EMPA) Thun/CH. The substrate material was the above-mentioned OD 48.3 mm, 2 mm thick wall and 1 m long stainless steel (316LN) tube. A 0.1 mm thick Al_2O_3 ceramic layer was sprayed on to this tube. This ceramic has a good thermal conductance whilst being an electrical insulator. On top of this ceramic were sprayed 16 heating strips of 316L grade stainless steel in a dimension of 5x0.05 mm over 950 mm of the tube. Seven out of the 16 heating strips were used. The final layer was a 0.2 mm thick ZrO_2 ceramic to electrically insulate the heating strips and provide an initial thermal insulation. The tube was sandblasted before coating to obtain a sufficiently rough surface for good adherence. The thickness of 0.05 mm and the width of 5 mm was considered to be minimum to achieve a uniform heat distribution along the tube and to avoid hot spots which could possibly burn the heater. The distance of 5 mm between the heating strips was needed to avoid a cross conductance between heating strips. The interspace between heater strips could be reduced by using a mask technique or protecting the spaces with special tape. This was not considered for this first test since this implied significantly higher cost.

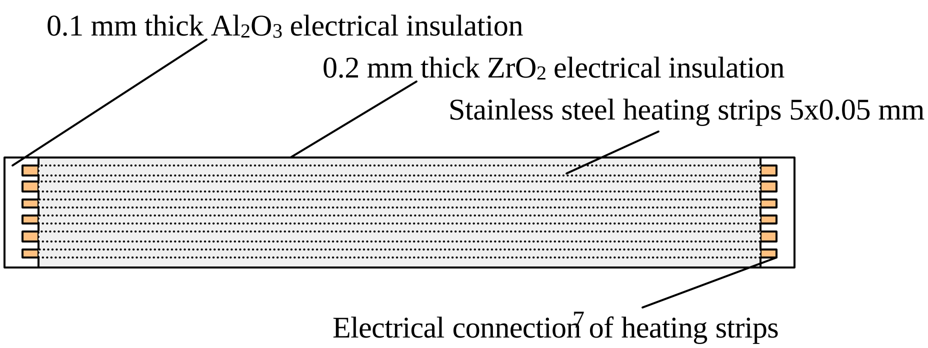


Figure 4: Vacuum plasma sprayed heater, "EMPA" tube

The tube arrived slightly damaged at CERN due to a transport problem. The ceramic at one extremity came partly off. However, the electrical connections could still be made and the tube could be recovered for the bakeout tests. During the 13 bakeout cycles to 200 °C and 300 °C with various thermal insulations no further damage occurred. The ceramic layers seem to be thin and elastic enough to follow the stainless steel tube without cracking. The current EMPA vacuum tank limits the length of the tube to 1 m. Longer tubes up to 2 m could possibly be made by enlarging the vacuum tank. EMPA is looking into alternative spray coating options in the frame of a development contract with CERN. The goal is to develop 1 m and 2 m long tubes with all electrical connections on one side.

5. Thermal insulation

5.1 Active cooling

One of the parameters requested for the in-situ bakeout was that the thermal loss into the detector has to be considered to be zero. Active cooling with air was used to take out the heat generated during the in-situ bakeout (see *Figure 1*). The insulation vacuum tube for the MLI tests (see *Figure 6*) was cooled by natural air convection of the ambient air. With the later option, the active cooling could possibly be suppressed if the thermal loss was low enough and if some heat loss was permitted into the detector.
The strict limit of no heat loss could not be simulated in the 1 m long test set-up, specially when using a cooling airflow with little throughput. There was a considerable amount of heat lost via the plexiglass tube and the airflow meter.

5.2 Ceramic fibre insulation

A market study was made to find the best thermal insulation. The company Microtherm was found producing flexible sheets with extremely good thermal insulation properties. The material used for the bakeout test was a 5 mm thick "semi-matelasse en qualité Super G", sheet with ceramic filling pressed in a glass cloth. This is referred to as Microtherm insulation in this note.

Table 3: Microtherm insulation [3]

Thermal conductivity	0.022 $W \cdot m^{-1} \cdot K^{-1}$	with 300°C hot face temperature in air
Density	240 kg/m^3	
Chemical composition by weight of ceramic filling	SiO_2 65% TiO_2 32% Al_2O_3 2%	

[3] Data from Microtherm catalogue

Chemical composition of glass cloth	SiO_2 54% Al_2O_3 15% CaO_2 17% B_2O_3 8% MgO 5%	
Weight of 1 m long, 5 mm thick sample for diameter 48.3 mm tube	0.32 kg	measured at CERN

The only other company found producing thermal insulation with similar performance is WACKER. Their products "lambda FLEX Wacker WDS " and "Wacker WDS super FLEX" show only limited flexibility without breaking inside the laminate. Preforming the product to a tube would possibly overcome this problem. The product was not tested in this series of measurements.

The insulation was wrapped around the tube using adhesive tape. The insulation could be closed around the tube by sewing with a glass fibre thread. This was not done since the tissue could have been damaged and the ceramic filling could leak out. The manufacturer was positive that with some precautions this could be an option to mount the insulation. A 0.02 mm thick aluminium foil was wrapped around the thermal insulation to avoid that the ceramic powder is blown out of the insulation and to smoothen the surface.
The different thickness of the heaters changed the inner perimeter of the thermal insulation. The tests with the EMPA tube were performed with a insulation which was just fitting around the tube with neither gap nor overlap. For all other heaters, a wider sheet was used which resulted in an overlap of the insulation of 5 to 10 mm, depending on the thickness of the heaters. The thickness of the heaters varied at the electrical connections.
The ends of the tube were insulated with standard thermal insulation with a thermal conductivity which is a factor of 2 higher than that of Microtherm.

5.3 Multi-Layer Insulation (MLI)

Multi-Layer Insulation is the most efficient thermal insulation in a confined space. Aluminium foil or aluminised film reduce losses by thermal radiation and it has little thermal conductance since a spacer material is usually used between the reflectors. Insulation vacuum in the high vacuum range reduces gas convection.
Two different types of MLI were tested.
The first one was an about 9 μm thick aluminium foil with a glass fibre tissue spacer type LYDALL Cryotherm ® 243. An additional 0.03 mm thick aluminium foil was wrapped around to avoid damage to the extremely fragile MLI. The width of the glass fibre tissue was 63 mm with a density of 186 kg/m^3. The width of the aluminium foil was 76 mm, the width of the glass fibre spacer was 88 mm. The strips of MLI were mounted as shown in *Figure 5* using adhesive tape.

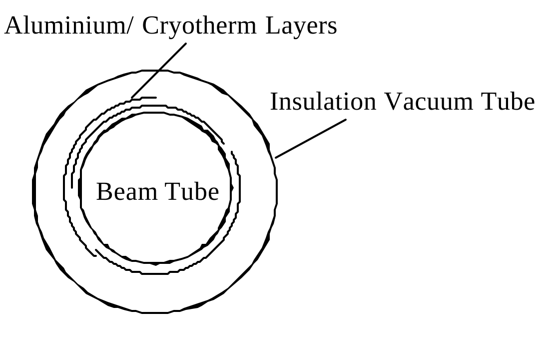
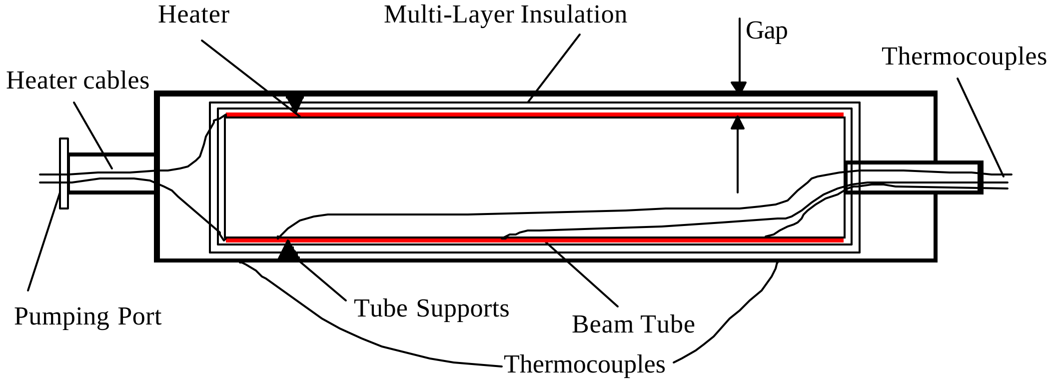


Figure 5: Mounting of Aluminium foil/Cryotherm Ò 243 MLI

The second type of MLI tested was a double sided aluminised Kapton ® (Polyimide) of 25 μm thickness supplied by TRICON. No spacer material was used between the reflector.
The gap between the heated beam tube and the insulation vacuum tube was 2.5 mm, 4 mm or 6 mm. The interspace was filled with 1, 5 or 10 layers of MLI of either type. The insulation vacuum was pumped by a standard LEP-type pumping group (S=150 l/s). The pressure indicated on the pumping group was in the order of 10^{-5} mbar. The conductance between the tube and the pumping group was calculated to be 4.3 l/s. The pressure in the insulation vacuum was therefore estimated to be in the order of 10^{-4} mbar. The outside of the insulation vacuum tube was cooled by natural air convection.

Figure 6: Experimental set-up for MLI tests for 1 m long beam pipe



6. Results

The results are quoted for the 1 m long diameter 48.3 mm stainless steel tube heated to 300 °C. The results in detail are stated in annex 1 to 7. The line through the points are to guide the eye. A table to compare the different heater types can be seen in annex 8, one to compare the different insulations in annex 9.

Table 4: Power generated and temperature increase of cooling air dependent on gas flow using heater strip and 5 mm Microtherm insulation

Airflow	3 m^3/h	6 m^3/h	12 m^3/h	24 m^3/h
Power	151 W	164 W	174 W	199 W
Temperature increase	55 °C	48 °C	33 °C	18 °C

It should be noted that the power lost via the plexiglass tube and the flowmeter did not heat up the air.

Table 5: Power dependence on heater type for 5 mm thick Microtherm insulation at 6 m^3/h air cooling with 10 layers of MLI of aluminium foil/Cryotherm Ò 243 under vacuum and 6 mm gap between beam tube and insulation vacuum tube

	Heater strip	EMPA	Polyimide foil heater	Co-axial cable
5 mm Microtherm	160 W	200 W	170 W	-
10 Layers MLI	33 W	15 W	24 W	14 W

Table 6: Power dependence of the number of layers of the MLI using aluminium foil/Cryotherm Ò 243 under vacuum and 6 mm gap between beam tube and insulation vacuum tube

	No Layer	1 Layer	5 Layers	10 Layers
EMPA tube	196 W	29 W	22 W	15 W

Table 7: Power dependence of gap between beam tube and insulation vacuum tube for 10 layers of MLI using aluminium foil/Cryotherm Ò 243 under vacuum

	6 mm	4 mm	2.5 mm
EMPA tube	15 W	22 W	25 W

7. Discussion of Results

7.1 Heaters with standard 5 mm thick Microtherm insulation

The power to keep the ∅ 48.3 mm tube at 300 °C is between 150 W and 200 W for all heaters, see annexes 1 and 2. The temperature difference over the length of the EMPA-tube is significant. It is assumed that the effect of a non-linear heating due to a change in cross section of the 316L heating strip and the effect of the temperature change of the cooling air flow are superposing each other.
Besides space and transparency constraints, there is no significant advantage of one heating method over the other. The radiation hardness and the long term suitability of polyimide foil heater needs to be tested in the future.
The influence of the airflow can be seen in annex 2. An increased airflow has the tendency to equalize the temperature over the tube and reduces the temperature at the outlet. A typical temperature difference of the air with 6 m^3/h (~1 m/s) cooling airflow over the tube is 40 °C, the tube itself shows a temperature difference of 30°C. For an airflow of 24 m^3/h, both temperature differences are below 20°C. Exception is the EMPA tube, where the temperature differences are significantly higher. A significant amount of the heat is lost via the insulated plexiglass tube and the airflow meter, specially for an airflow below 12 m^3/h. Tests on a 4 m long model will give more information about the temperature increase of the cooling air.

7.2 Heaters with MLI

A comparative test was made for 10 layers of MLI with a 6 mm gap between the beam tube and the insulation vacuum tube, see annex 4. It shows that heaters which are bonded to the tube ensuring thermal conduction (EMPA, brazed co-axial cable) need about 15 W to heat the tube up to 300 °C. The heaters which are only wrapped around the tube (heater strip, polyimide foil heater) have no well defined conduction between the heater and the tube. Hence, the heat transport is made to a larger extent by radiation rather than by conduction, which increases the power needed to between 24 W and 33 W. This radiated power is going to both sides, the tube and the MLI. The effect is less obvious if standard insulation under atmospheric pressure as Microtherm is used, since the heat is transported by conduction, convection as well as radiation.

7.3 Standard 5 mm thick Microtherm insulation

The power needed to heat up the 1 m long and ∅ 48.3 mm beam tube insulated with 5 mm thick Microtherm insulation and air cooling of 3 m^3/h to 12 m^3/h with an air entry temperature of 20 °C is between 150 W and 200 W. A change of the air flow cooling in the limits between 6 m^3/h and 24 m^3/h has little influence concerning the heating power, but makes the tube to have a more uniform temperature and a reduced air outlet temperature (annexes 1 and 2).

7.4 Multilayer insulation

Both the aluminium foil/Cryotherm ® 243 and the double sided aluminized polyimide seem to have similar insulation characteristics (see annex 4).
A power of 196 W for the EMPA heater and 280 W for the heater strip was needed to heat the tube to 300 °C without reflector and insulation vacuum pressure in the order of 10^{-3} mbar (see annex 5). One reflector already brings the power down to about 30 W, depending on the heater. With 5 layers and 6 mm gap between the beam tube and the insulation vacuum tube, the power is in the order of 25 W, with 10 layers it is between 15 W and 25 W, with the exception of the heater strip, which needed 33 W.
The gap for the MLI has a significant influence on the heat loss (see annex 5). The smaller the gap, the more the MLI is compressed which results in a better thermal conduction between the layers. The pressure resulting from thermal outgassing between the layers of MLI can be assumed to be higher if the MLI is more compressed because of a reduced conductance between the layers. Hence the heat loss due to convection would also be higher.

One test has been made to compare the MLI at atmospheric pressure with 5 mm thick Microtherm insulation (see annex 3). The maximum average temperature reached was 280 °C at 280 W using 5 layers of MLI and one layer protective aluminium foil, 6 m3/h cooling air and a heater tape. The average tube temperature of 300 °C could not be reached without damaging the plexiglas tube. This solution could be interesting if transparency and space constraints are dominating over heat into the detectors and maximum temperature. The temperature distribution in the tube has to be verified on a longer model.

7.5 Heating to 200 °C

As noted in the introduction, tests were also made for the possibility of NEG-activation at 200 °C. When the tube was heated up to 200 °C, the power is in the order of 100 W using 5 mm Microtherm insulation and air cooling (see annex 6). If 10 layers of MLI under vacuum are used, the power is about 10 W, depending on the heater and the gap between the beam tube and the insulation vacuum tube (see annex 7).

8. Future work

Adhesive tape was used to mount various parts to the beam tube, such as the heater strip, the polyimide foil heater, the MLI, the Microtherm insulation and the thermocouples. The glue of the adhesive tape used is not radiation resistant, so alternative mounting options using mechanical attachments or radiation resistant glue need to be studied. Mechanical attachments (clamps, adjustable rings) must be space minimised.

CERN has a development contract with EMPA, to study the option of a multilayer sprayed heater in more detail. The aim of the study is to develop a 2 m long tube with this kind of heater.

RICA has produced a polyimide foil heater with a 12 μm thick aluminium foil. This heater with a total thickness of about 0.1 mm would be extremely transparent and would have a very low magnetic permeability. The problems to be solved are how to reduce the thickness of the electrical connectors to a minimum, how to increase the length to more than 0.6 m and how to have a good attachment of the foil to the tube.

The co-axial heater is a commercially available item produced by several companies. The change in length to 4 m should be no problem. The diameter of the heater could be reduced to below 1.5 mm if used with MLI under insulation vacuum.

It must be studied what the implications are to avoid the silicone in the electrical insulation of the heater strip, if this is considered to be a candidate material.

A 4 m long in-situ bakeout test is foreseen. The aims of this test are to have a uniform temperature over the whole beam pipe, to study more profoundly the active cooling and the real length technology . This implies that the tube would be heated with different heating circuits over the length of the tube. In addition, the support options of the tube can be studied. Where possible, adhesive tape will be replaced by alternative mounting options.

9. Conclusion

To heat the 1 m long 48.3 mm OD stainless steel tube to 300 °C using active cooling with air and 5 mm thick high performance insulation, the power needed is between 150 W and 200 W depending on the heater and the airflow in the limits of 3 m^3/h and 24 m^3/h. The power can be reduced to 15 W using 10 layers of multilayer insulation under vacuum and heaters which are bonded to the tube.

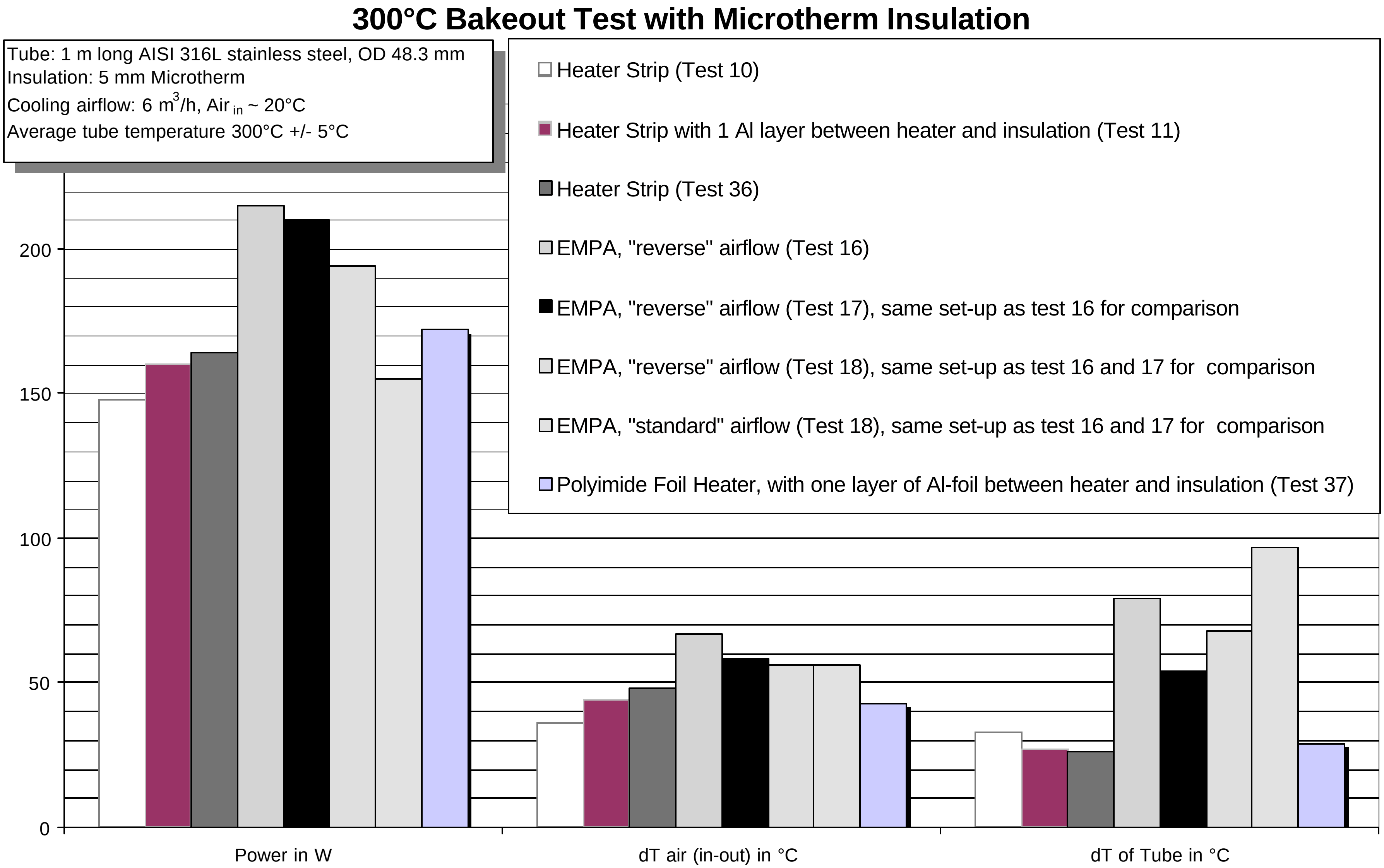
The most suitable in-situ bakeout heater and insulation depends on the parameters given, such as transparency, maximum temperature of cooling air, maximum heat loss into the detector, space, weight, infrastructure for cooling gas and pumping of the insulation vacuum, simplicity, cost for development and production for LHC experimental beam pipes.

If space and transparency constraints dominate over power and maximum temperature of the cooling gas, a multilayer insulation without vacuum could be considered.

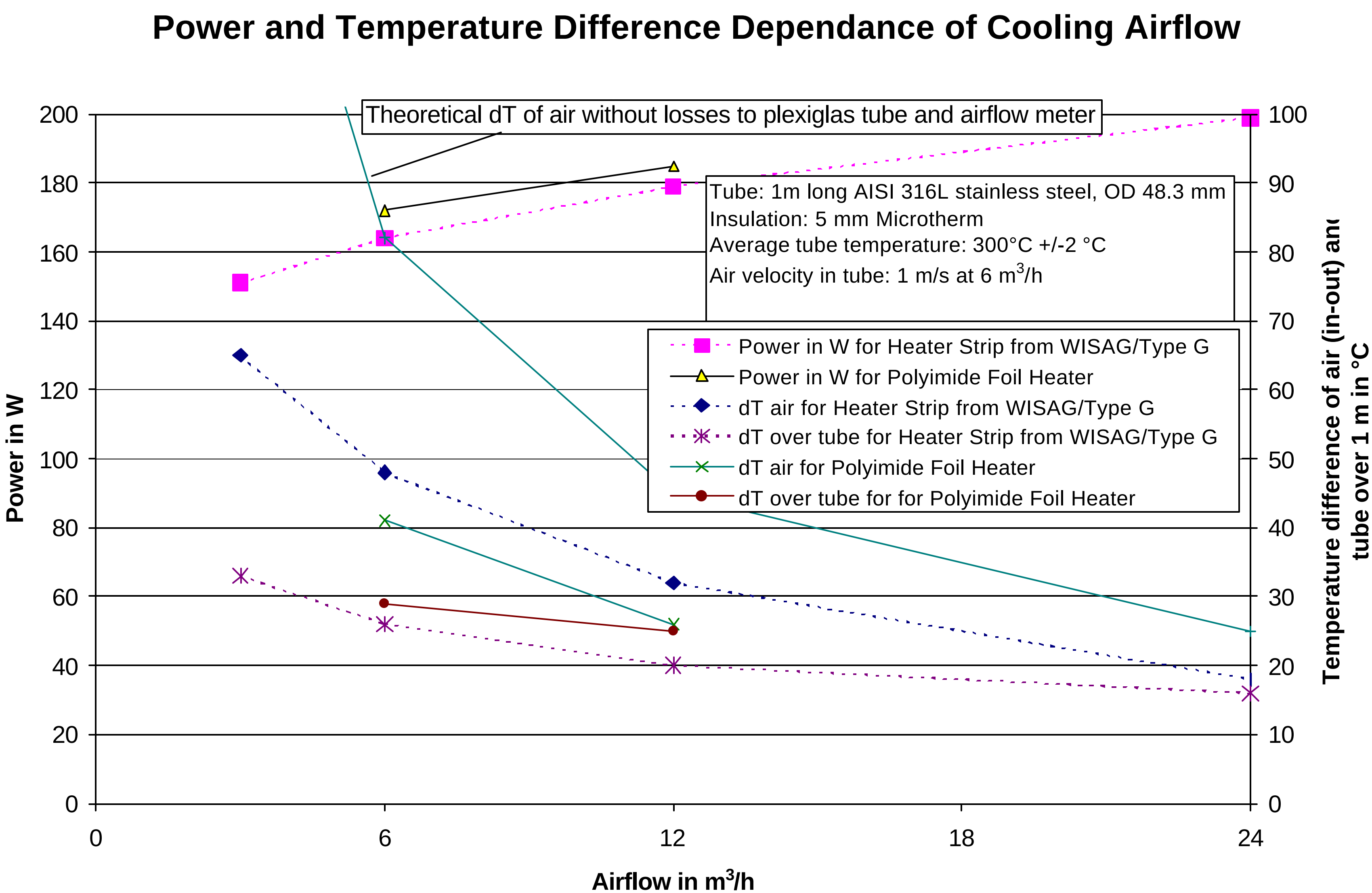
If the tube is heated up to 200 °C, the power is in the order of 100 W using 5 mm Microtherm insulation, and about 10 W if 10 layers of MLI are used under vacuum, depending on the heater and the gap between the beam tube and the insulation vacuum tube.

On the 1 m long model, a significant temperature difference over the length of the tube and the air has been observed. A 4 m long model will be build to study how to avoid this effect. The use of adhesive tape will be reduced or suppressed in the future.

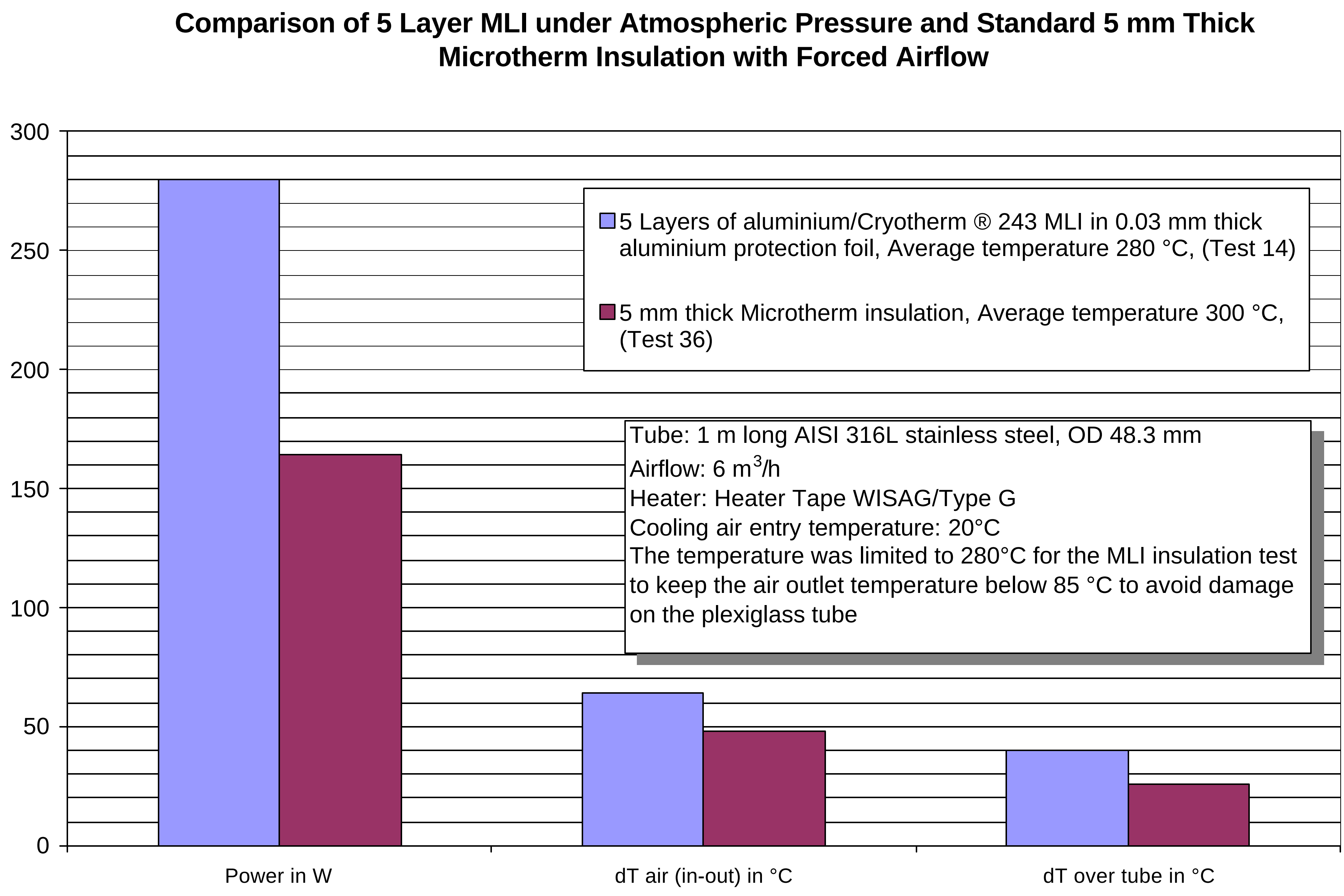
Annex 1



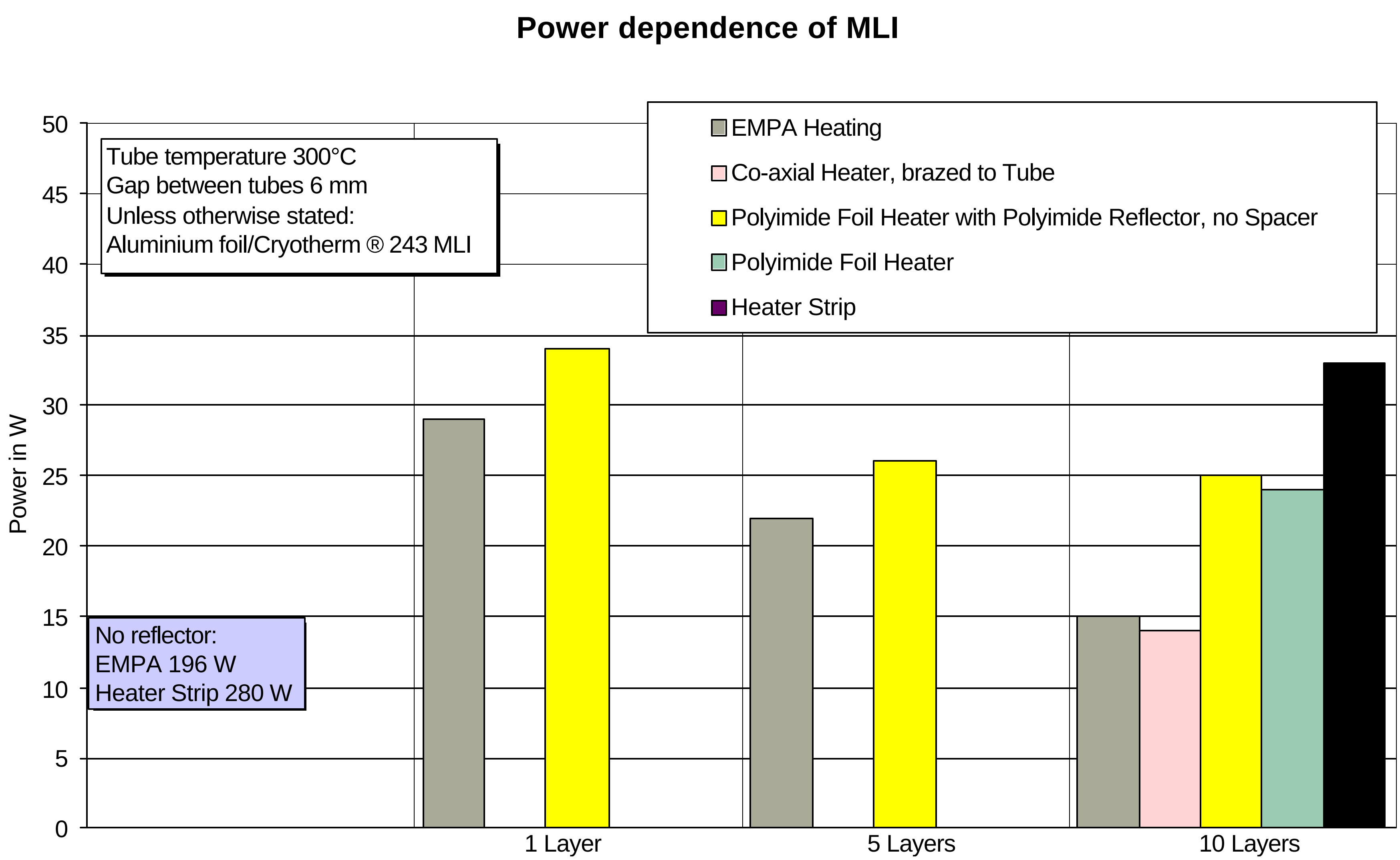
300°C Bakeout Test with Microtherm Insulation
Tube: 1 m long AISI 316L stainless steel, OD 48.3 mm
Insulation: 5 mm Microtherm
Cooling airflow: 6 m3/h, Air in ~ 20°C
Average tube temperature 300°C +/- 5°C
Heater Strip (Test 10)
Heater Strip with 1 Al layer between heater and insulation (Test 11)
Heater Strip (Test 36)
EMPA, "reverse" airflow (Test 16)
EMPA, "reverse" airflow (Test 17), same set-up as test 16 for comparison
EMPA, "reverse" airflow (Test 18), same set-up as test 16 and 17 for comparison
EMPA, "standard" airflow (Test 18), same set-up as test 16 and 17 for comparison
Polyimide Foil Heater, with one layer of Al-foil between heater and insulation (Test 37)
0
50
100
150
200
Power in W
dT air (in-out) in °C
dT of Tube in °C


Power and Temperature Difference Dependance of Cooling Airflow
Theoretical dT of air without losses to plexiglas tube and airflow meter
Tube: 1m long AISI 316L stainless steel, OD 48.3 mm
Insulation: 5 mm Microtherm
Average tube temperature: 300°C +/-2 °C
Air velocity in tube: 1 m/s at 6 m3/h
Power in W for Heater Strip from WISAG/Type G
Power in W for Polyimide Foil Heater
dT air for Heater Strip from WISAG/Type G
dT over tube for Heater Strip from WISAG/Type G
dT air for Polyimide Foil Heater
dT over tube for for Polyimide Foil Heater
Power in W
Temperature difference of air (in-out) and
tube over 1 m in °C
Airflow in m3/h
0
20
40
60
80
100
120
140
160
180
200
0
10
20
30
40
50
60
70
80
90
100
0
6
12
18
24

Annex 3

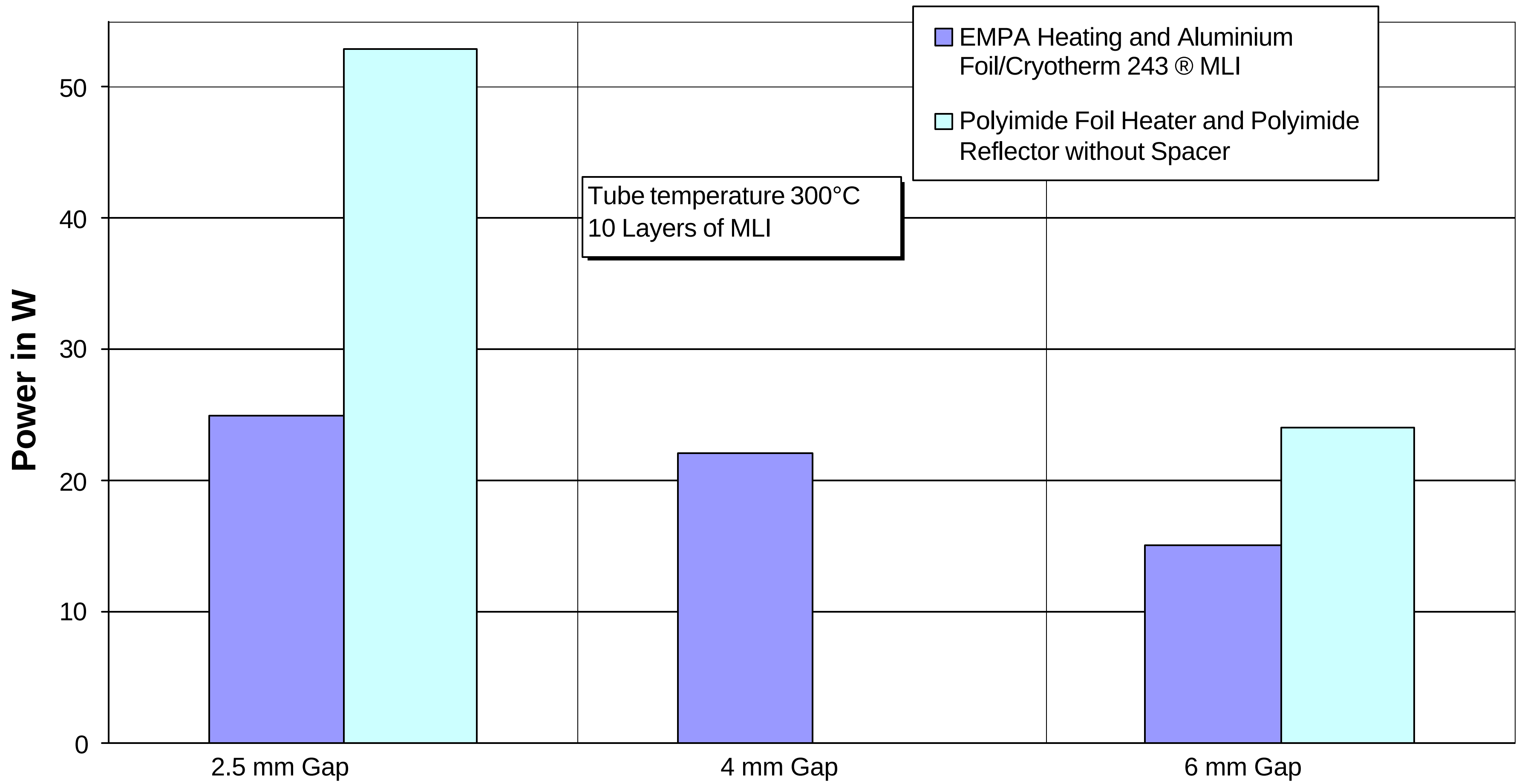

Comparison of 5 Layer MLI under Atmospheric Pressure and Standard 5 mm Thick Microtherm Insulation with Forced Airflow
300
250
200
150
100
50
0
5 Layers of aluminium/Cryotherm ® 243 MLI in 0.03 mm thick aluminium protection foil, Average temperature 280 °C, (Test 14)
5 mm thick Microtherm insulation, Average temperature 300 °C, (Test 36)
Tube: 1 m long AISI 316L stainless steel, OD 48.3 mm
Airflow: 6 m3/h
Heater: Heater Tape WISAG/Type G
Cooling air entry temperature: 20°C
The temperature was limited to 280°C for the MLI insulation test to keep the air outlet temperature below 85 °C to avoid damage on the plexiglass tube
Power in W
dT air (in-out) in °C
dT over tube in °C

Annex 4

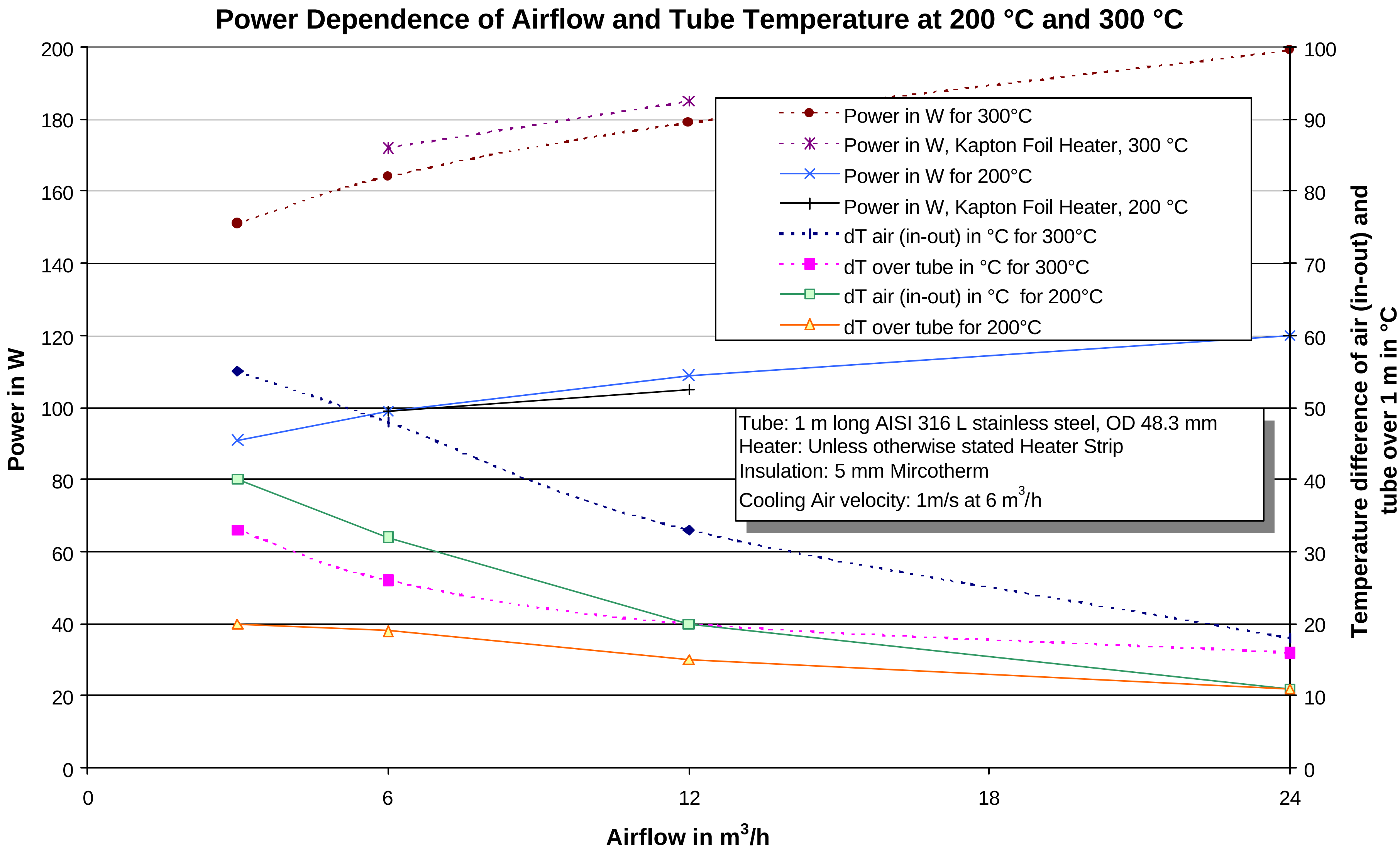

Power dependence of MLI
Power in W
50
45
40
35
30
25
20
15
10
5
0
1 Layer
5 Layers
10 Layers
EMPA Heating
Co-axial Heater, brazed to Tube
Polyimide Foil Heater with Polyimide Reflector, no Spacer
Polyimide Foil Heater
Heater Strip
Tube temperature 300°C
Gap between tubes 6 mm
Unless otherwise stated:
Aluminium foil/Cryotherm ® 243 MLI
No reflector:
EMPA 196 W
Heater Strip 280 W

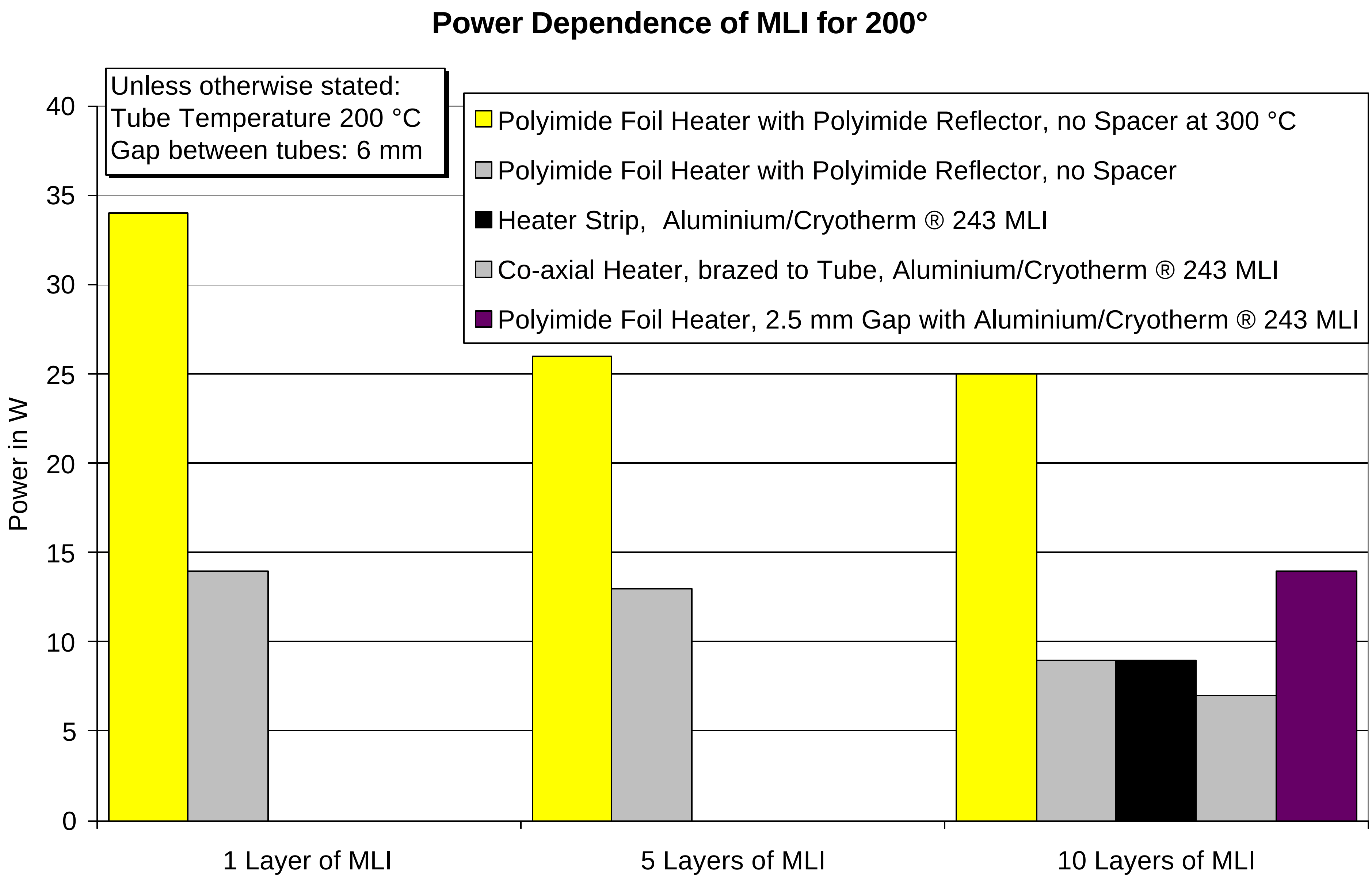
Annex 5

Power Dependence on Gap between Beam Tube and Insulation Vacuum Tube



Annex 6


Power Dependence of Airflow and Tube Temperature at 200 °C and 300 °C
Power in W
Temperature difference of air (in-out) and tube over 1 m in °C
Airflow in m³/h
0
6
12
18
24
0
20
40
60
80
100
120
140
160
180
200
0
10
20
30
40
50
60
70
80
90
100
Power in W for 300°C
Power in W, Kapton Foil Heater, 300 °C
Power in W for 200°C
Power in W, Kapton Foil Heater, 200 °C
dT air (in-out) in °C for 300°C
dT over tube in °C for 300°C
dT air (in-out) in °C for 200°C
dT over tube for 200°C
Tube: 1 m long AISI 316 L stainless steel, OD 48.3 mm
Heater: Unless otherwise stated Heater Strip
Insulation: 5 mm Mircotherm
Cooling Air velocity: 1m/s at 6 m³/h


Power Dependence of MLI for 200°
Unless otherwise stated:
Tube Temperature 200 °C
Gap between tubes: 6 mm
Polyimide Foil Heater with Polyimide Reflector, no Spacer at 300 °C
Polyimide Foil Heater with Polyimide Reflector, no Spacer
Heater Strip, Aluminium/Cryotherm ® 243 MLI
Co-axial Heater, brazed to Tube, Aluminium/Cryotherm ® 243 MLI
Polyimide Foil Heater, 2.5 mm Gap with Aluminium/Cryotherm ® 243 MLI
Power in W
40
35
30
25
20
15
10
5
0
1 Layer of MLI
5 Layers of MLI
10 Layers of MLI

Comparison of Heaters

	Co-axial	EMPA	Polyimide Foil	Heater Strip
Space along tube at electrical connection	 1.5 mm diameter 1.5 mm if warm / cold transition is used	 0.4 mm radial 2.5 mm radial	 0.13 mm 1.3 mm	 2 mm 8 mm
Relative Transparency [4]	ok	ok	good	less favourable
Attachment: 1 m model future	 brazed brazed	 inseparable inseparable	 adhesive tape ?	 adhesive tape ?
Radiation hardness	very good	very good	10 MGray effect of radiation and temperature to be studied	good
Max. Temperature	> 600 °C	> 350 °C	> 300 °C, time and atmosphere dependent	450 °C
Available for 4 m long tube	yes	study ongoing	in 0.6 m long parts	Yes
Industrial production Experience existing	yes	little	little	yes
Relative Outgassing	little	initially water vapour for ceramic	little after backout	from silicone treatment
Safe operation	yes	brittleness to be tested	Margin on max. temperature to be tested	glass fibre insulation can be damaged if often dismounted
Prox. weight per m tube for diameter 48.3 mm OD	0.2 kg	0.3 kg	0.1 kg	0.3 kg
Estimated cost per m tube after development	3000 CHF	5000 CHF	1000 CHF	1000 CHF

[4] Mika Huttinen, private communication, November 1998

Comparison of Insulations

	Multilayer	Microtherm
Space, dependent of: straightness of tubes, deflection of tubes, tubes supports heat load in detector, active cooling	depending on number of reflectors min. 2.5 mm radial gap between beam tube with heater and insulation vacuum tube 6 mm recommended design value + 1.5 mm aluminium insulation vacuum tube + 1.5 mm cooling channel if no heat must be transfered into the detector	recommended thickness: 5 mm Gap for airflow: 5 mm + deflection of tube
Relative Transparency [5]	3 time worse as Microtherm if 1.5 mm thick Al-tube is used compared to 5 mm Mircotherm insulation.	good
Attachment: 1 m model future	 adhesive tape to be investigated	 adhesive tape sewing?
Radiation hardness	very good for aluminium / Cryotherm ® 243, limited to 10 MGray for Polyimide	very good
Max. Temperature	depending on the MLI for aluminium / Cryotherm ® 243 significantly higher than 300°C for Polyimide 300°C is upper limit	650°C
Available for 4 m long tube	yes	yes
Prox. weight per m tube for OD 48.3 mm	MLI, 10 layers <0.1 kg	for 5 mm thickness 350 g
Required infrastructure	Pump with limit pressure < 10^{-5} mbar, tube with minimum 2 l/s conductance for requirement no heat into detector additionally active cooling	Active cooling with air or nitrogen, estimated to >12 m3/h per meter tube heated

[5] Mika Huttinen, private communication, February 1999