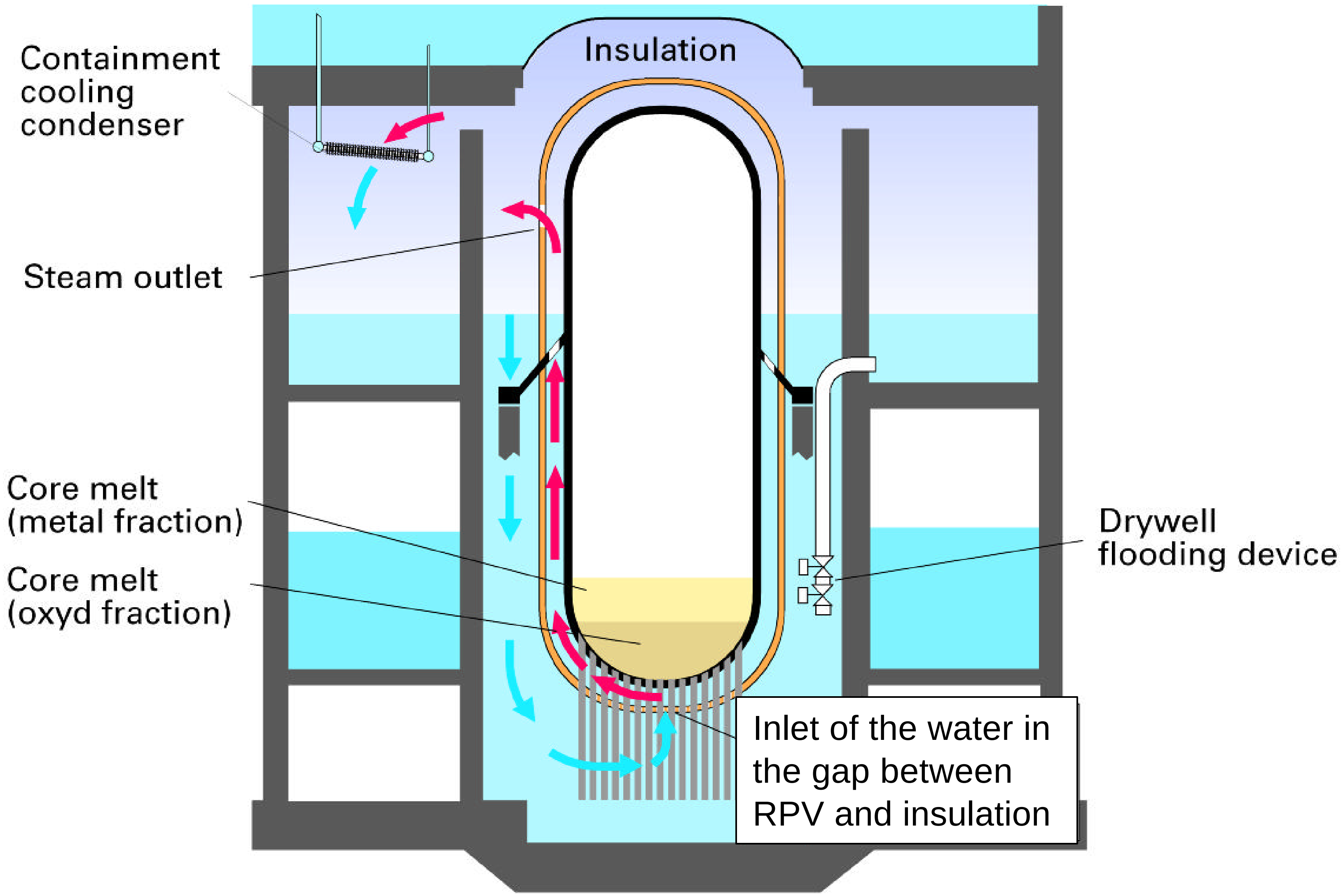
SWR-1000: NRC-Visit

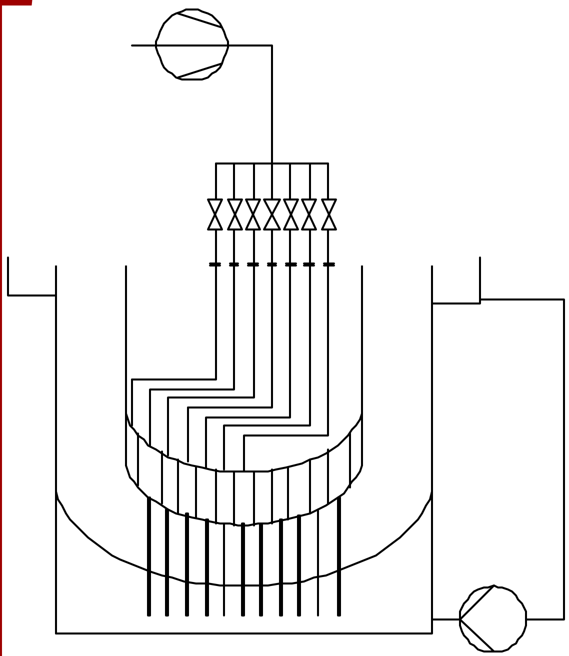
Preparation of the External Vessel Cooling Test

FRAMATOME ANP

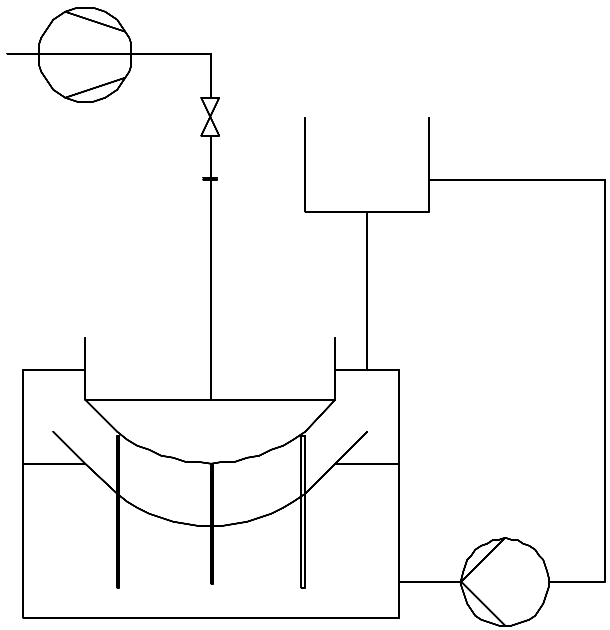
SWR 1000 - Exterior Vessel Cooling



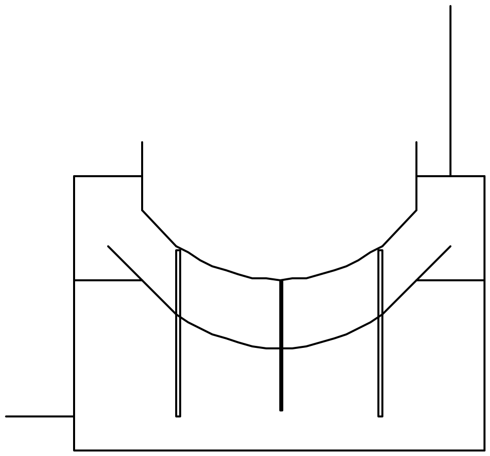
Decoupling of Flow Conditions and Heat Transfer



Water / Air-Experiments Scale 1 : 10
Investigation of the global flow conditions and determination of requirements for the design of a segment

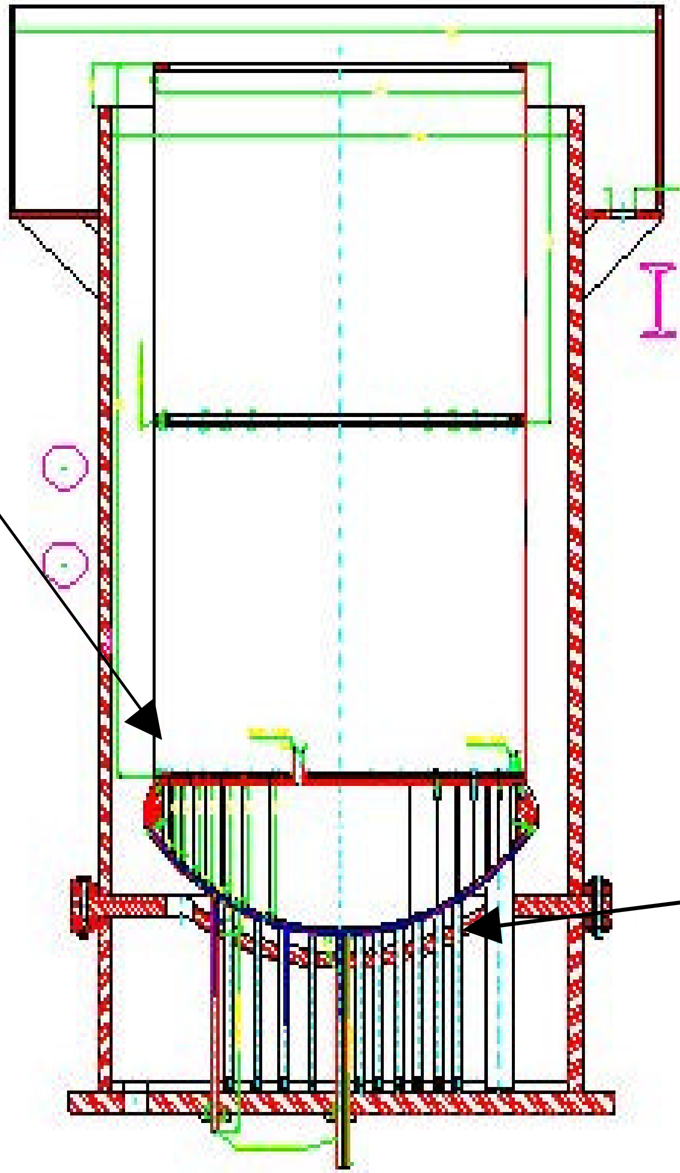


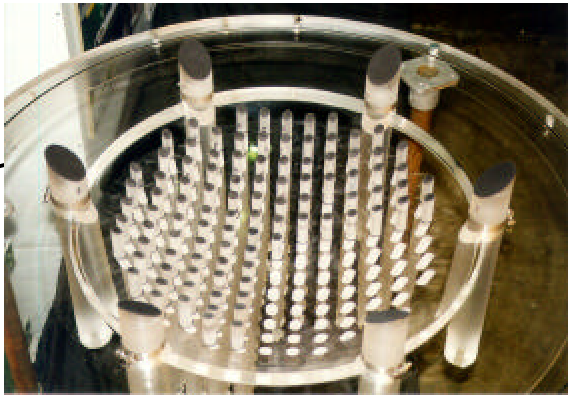
Water / Air-Experiments with a Section
Designing of in- and outlets in order to reach a similar flow behaviour as in the global model



Water / Steam-Experiments with a Section
Measuring the Critical Heat Flux in a 1:1 section model installed in the BENSON test rig
- a flexible water / steam test loop

Global Model





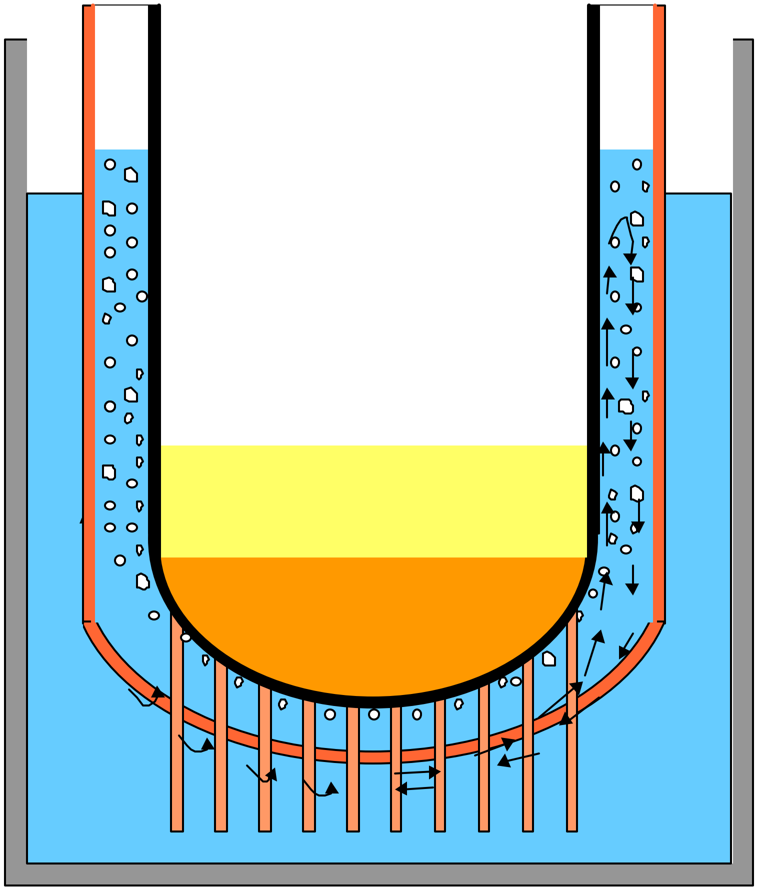
Setup of the RPV:

- **Air injection through a porous structure at the bottom**
- **Eight chambers with adjustable air supply**

Setup of the insulation:

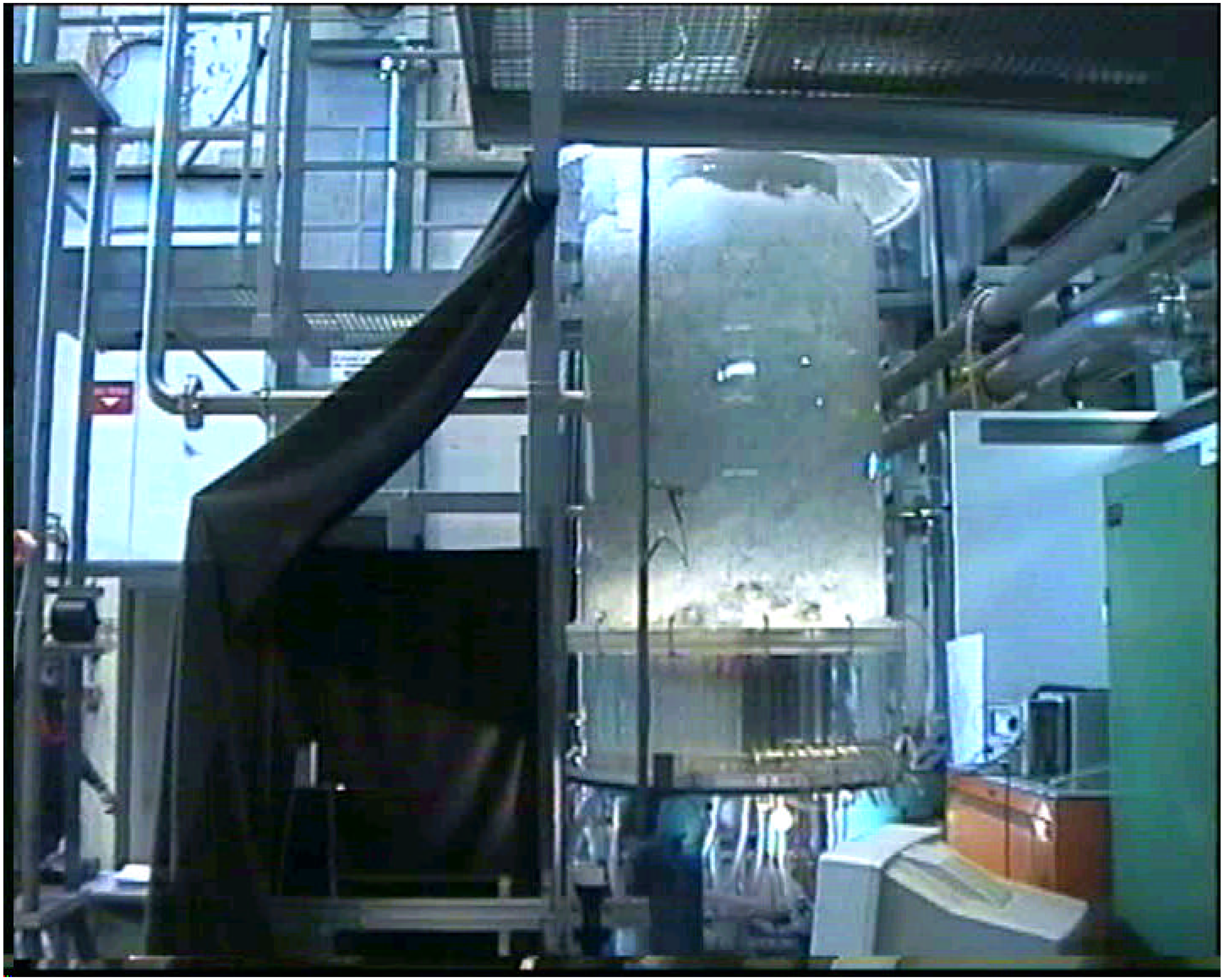
- **Transparent material including CRD and pump housings**
- **Impedance probes for measuring the adequate gas height**
- **Fiber optic probe for measuring the void**

Phenomenology



- Circulation can be observed
  The water / gas mixture will move upwards and will be separated at the swell level. The water will flow back
- Counter current flow can be observed at the bottom
  The water/air mixture flows upwards around the RPV, single-phase water flows downwards around the insulation. A portion penetrates in the water/air mixture
- Flow is approximately rotational symmetric
- Bubbles in the water/air test grow approximately similar to those of boiling tests
- Rotational symmetric slug bands will be formed. In the case of flow without insulation, they are stronger than in the case with insulation

Phenomenology - Global Model in Operation



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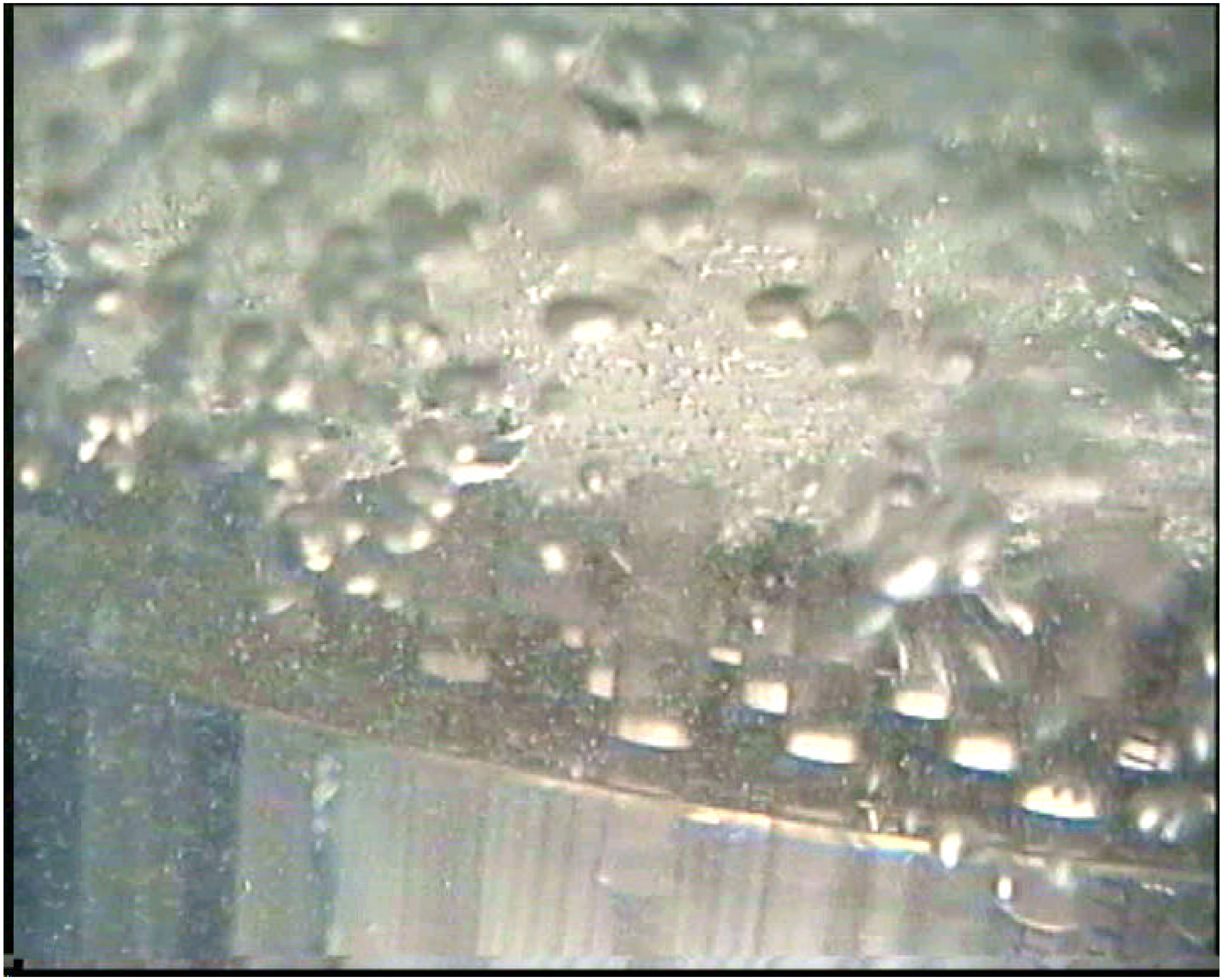
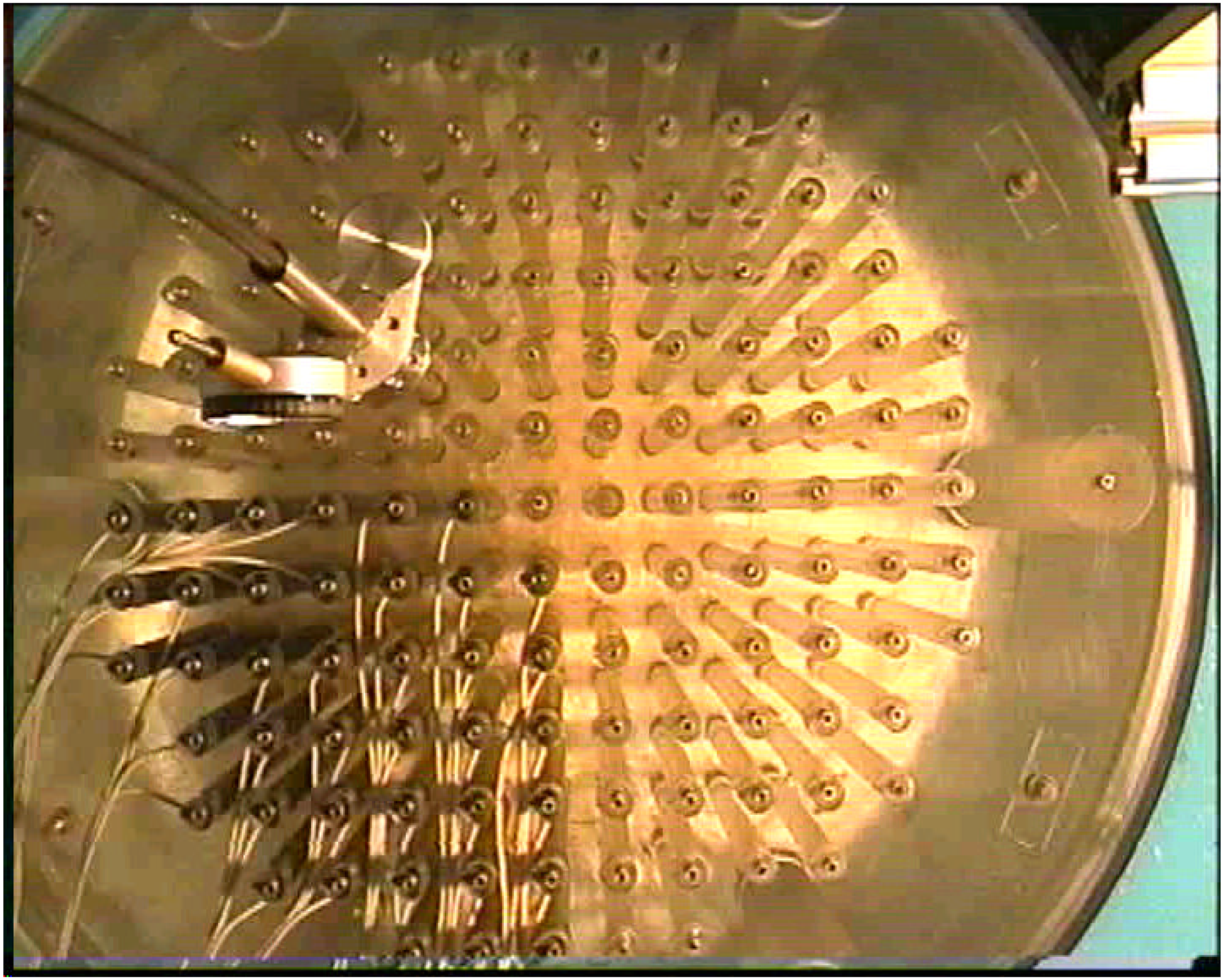
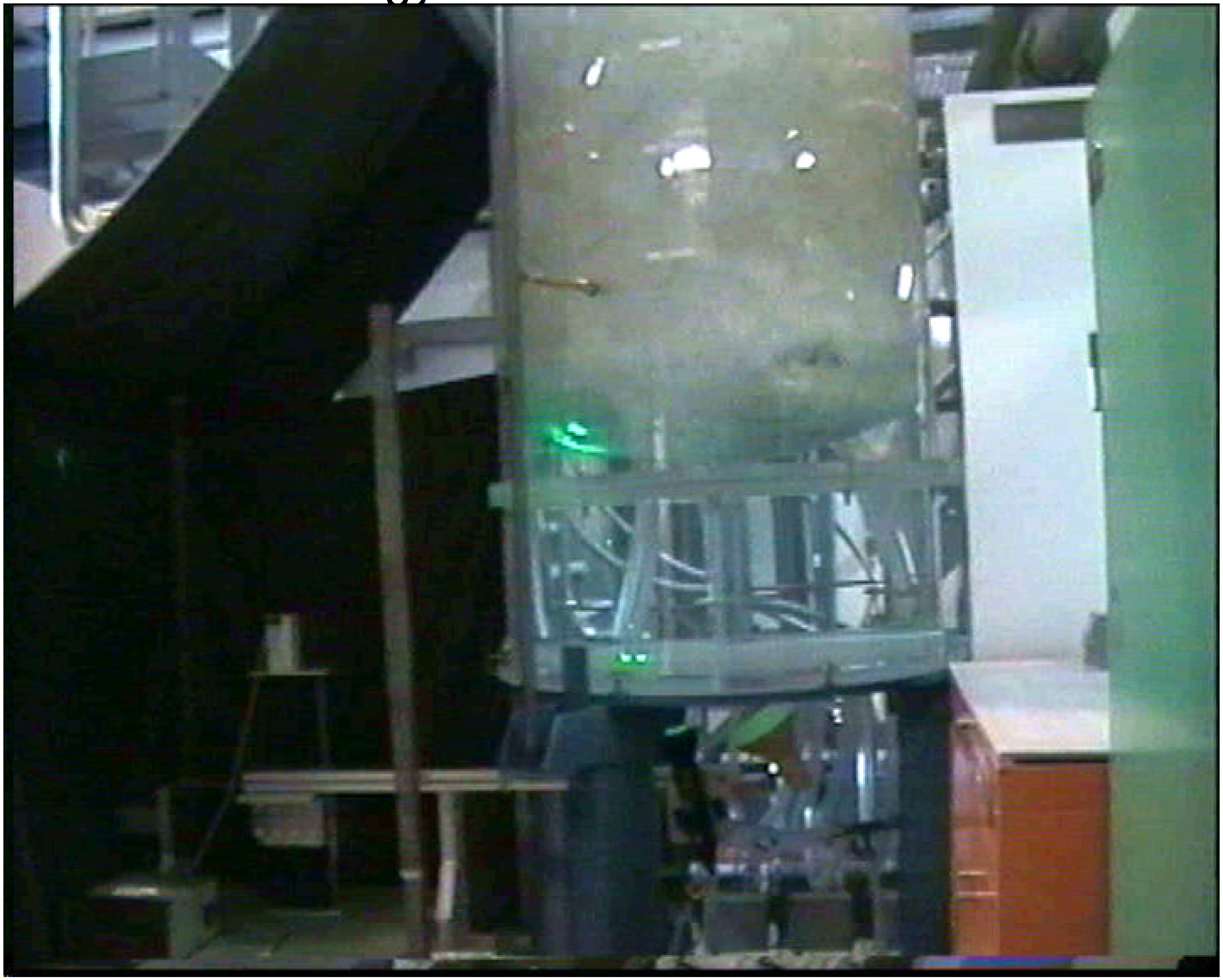
Phenomenology - Counter Current Flow



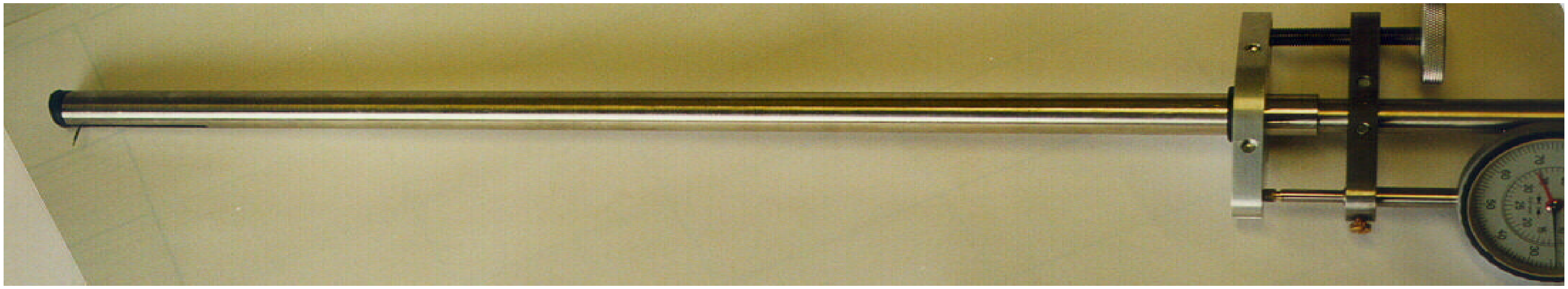
Phenomenology - Flow around the CRD Housings

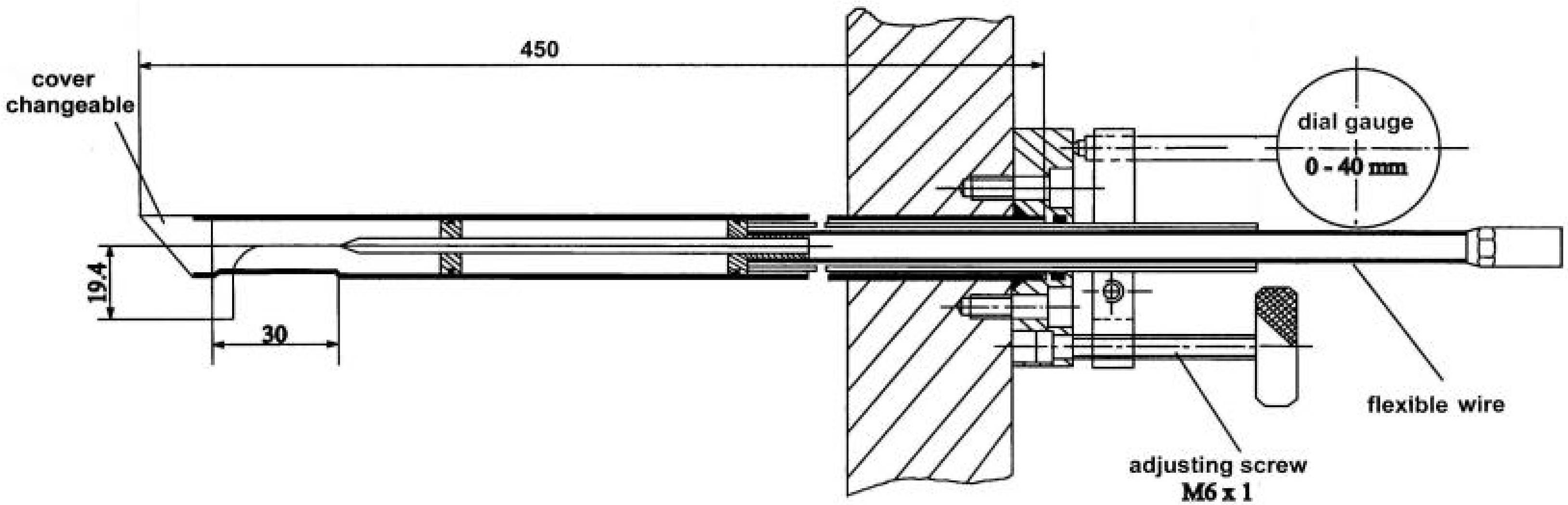


Phenomenology - Movement of Bubbles

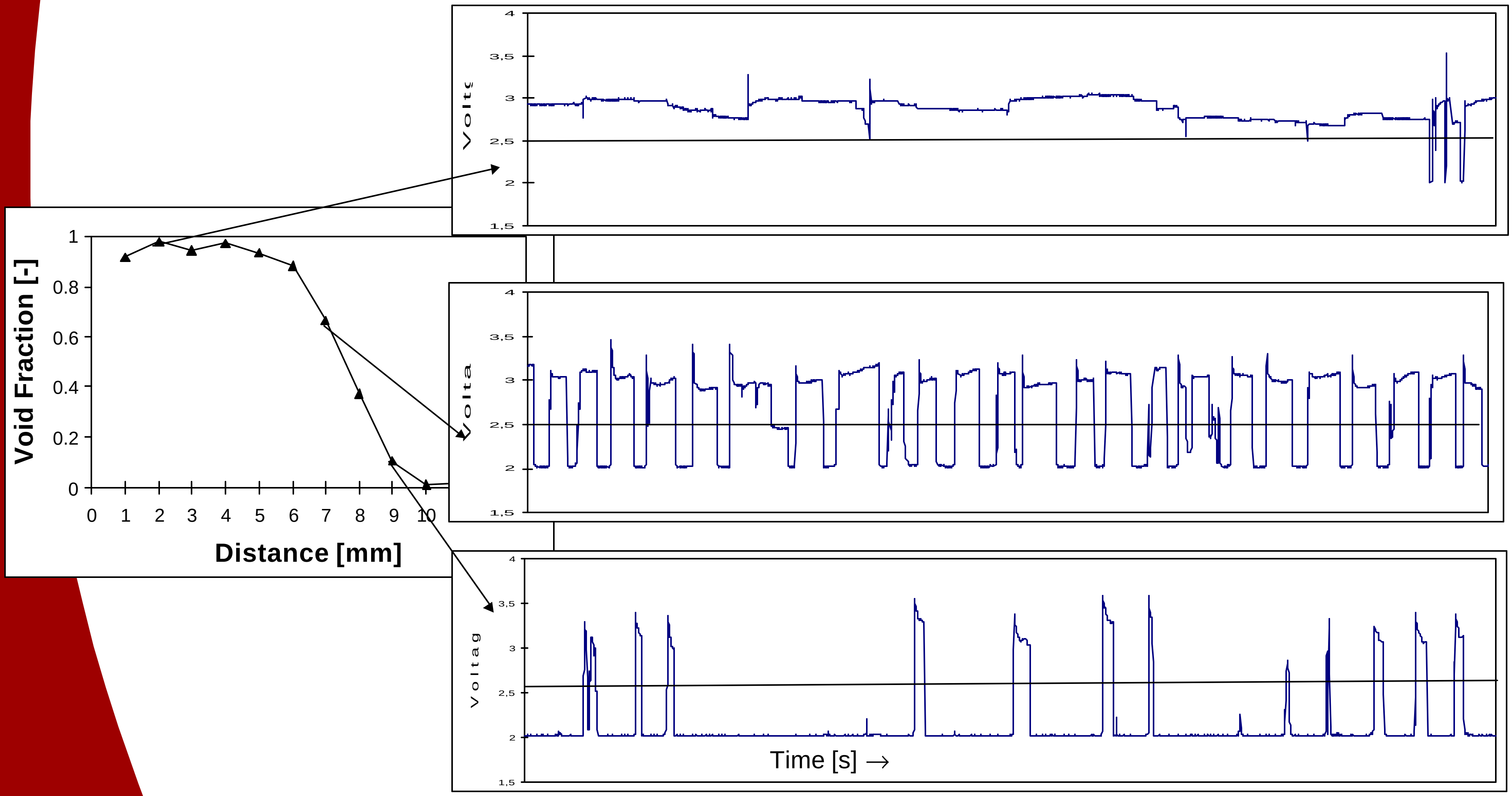


Fiber Optic Probe

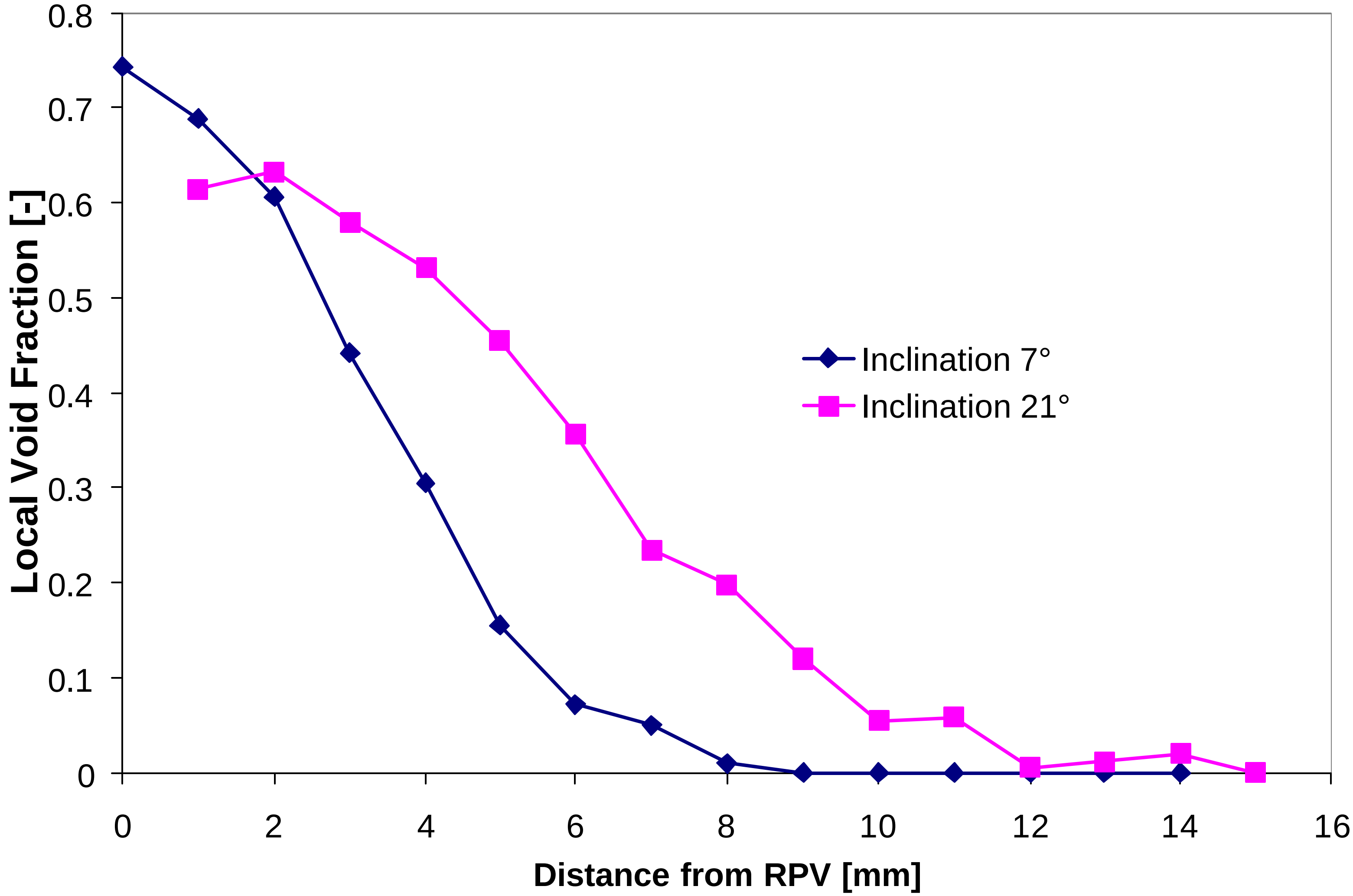




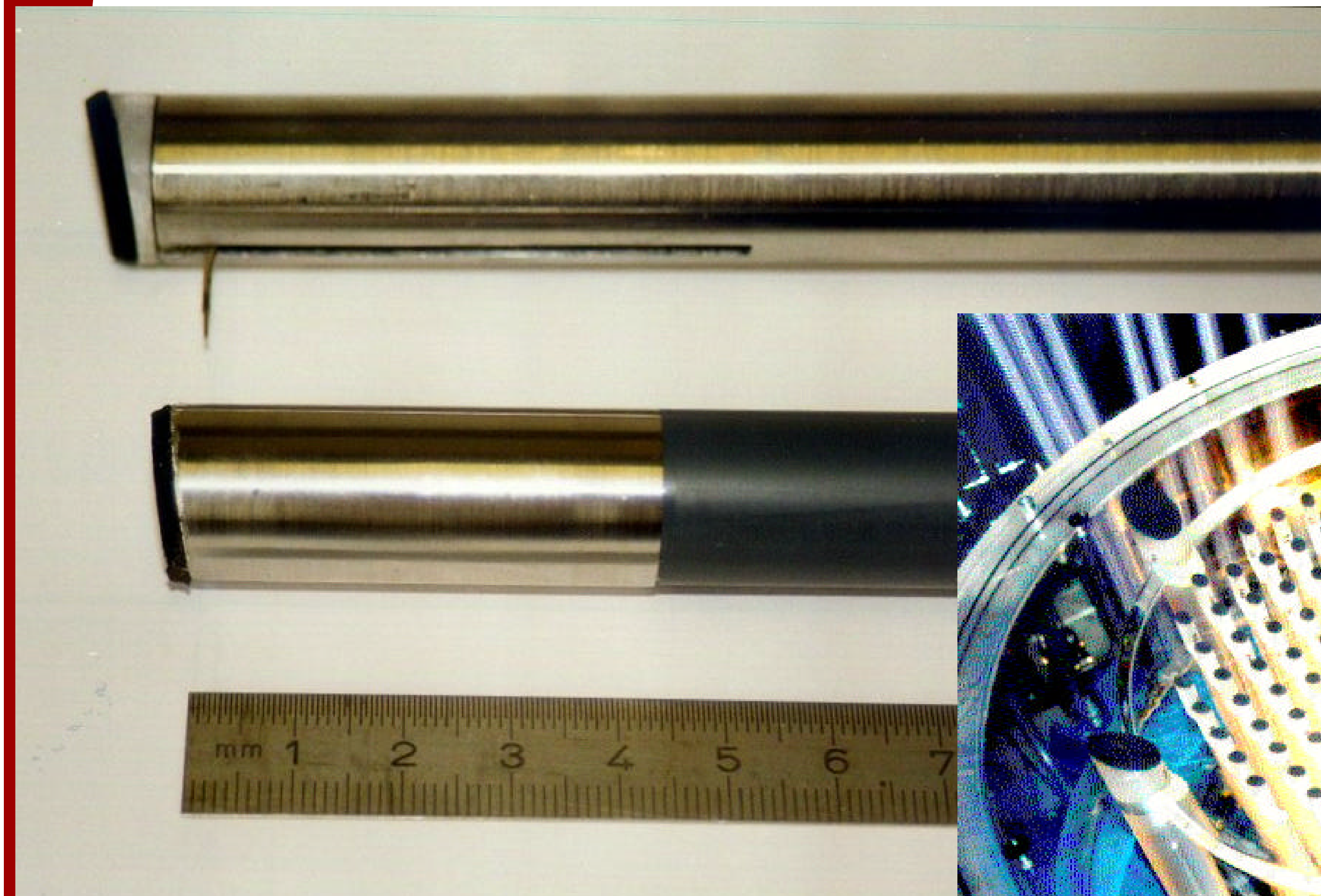
Local Void Fraction Determination

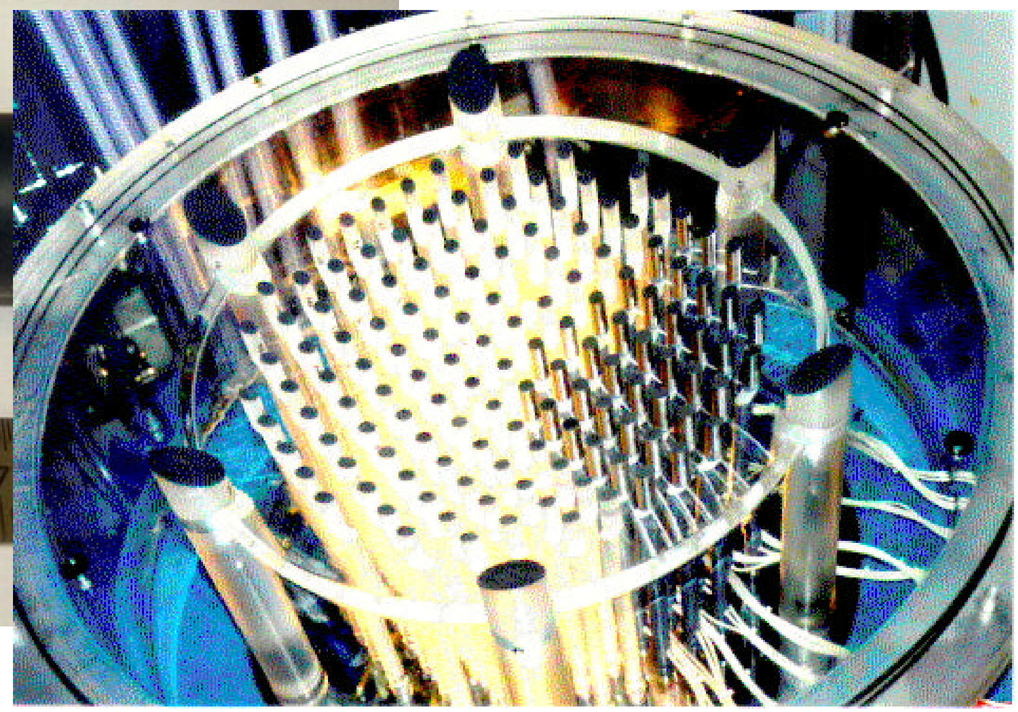


Local Void Fractions at different Inclinations



Dimension and Positions of the Probes





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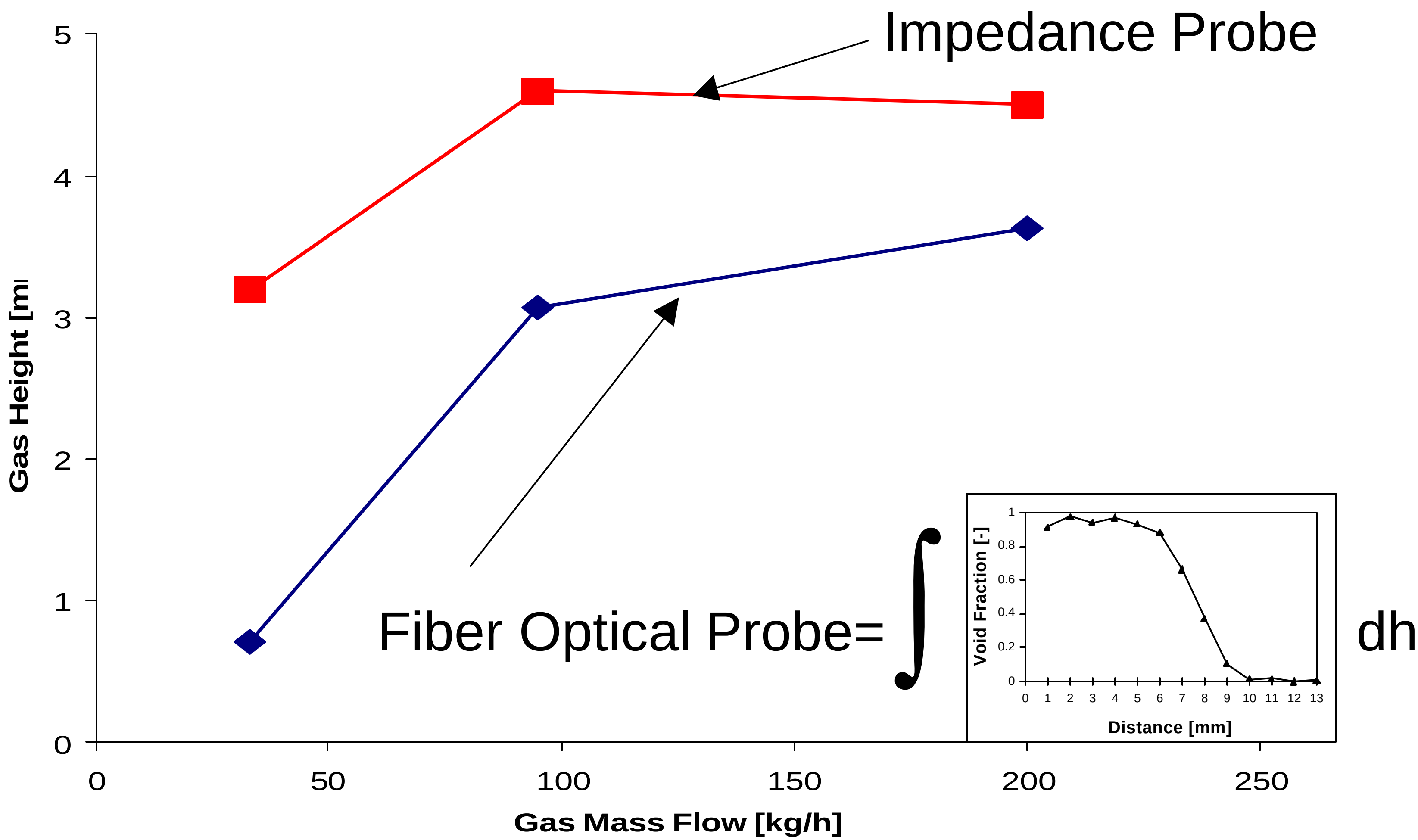
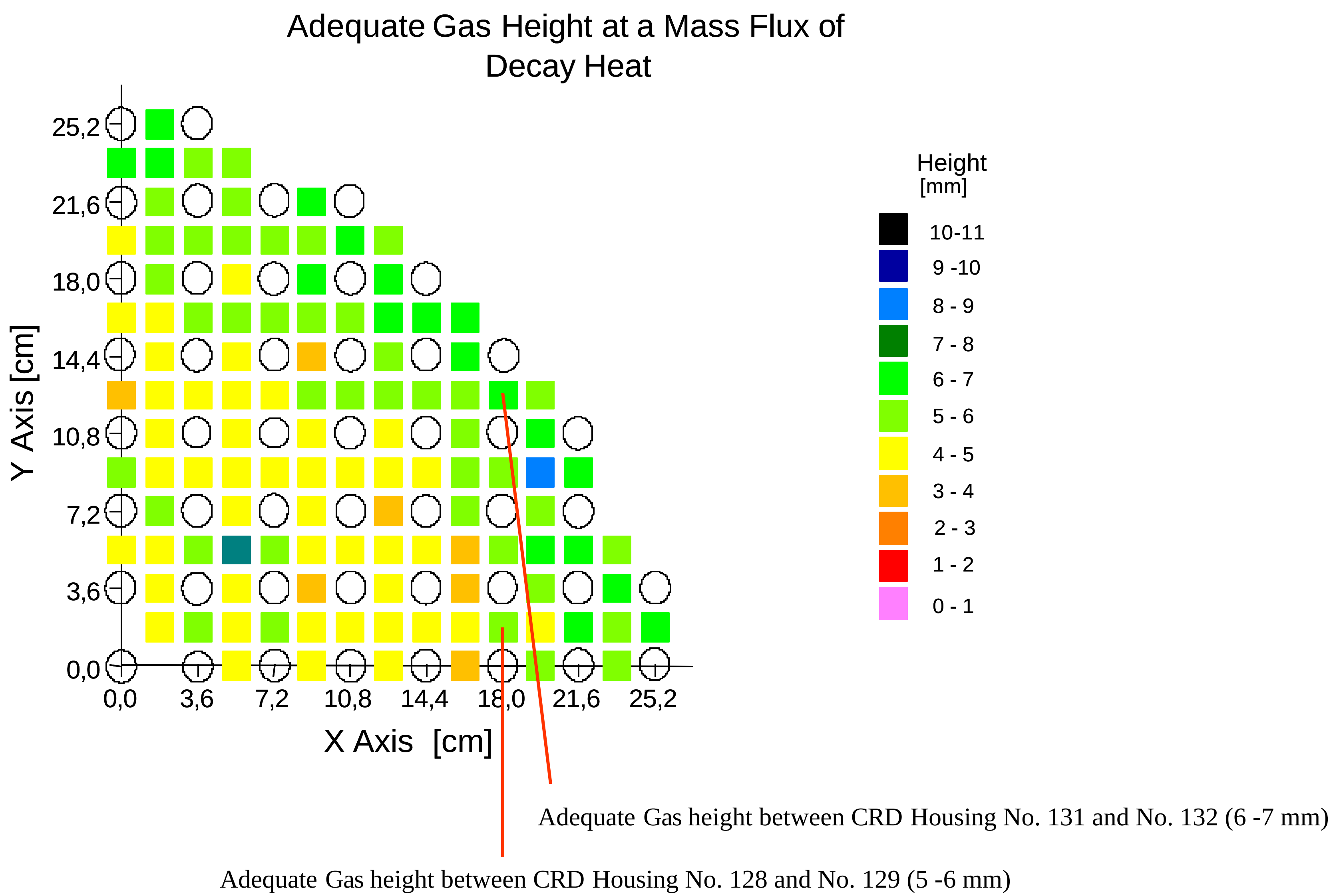
Average Gas Height measured with Fiber Optic Probe and Impedance Probe



Gas Height Distribution



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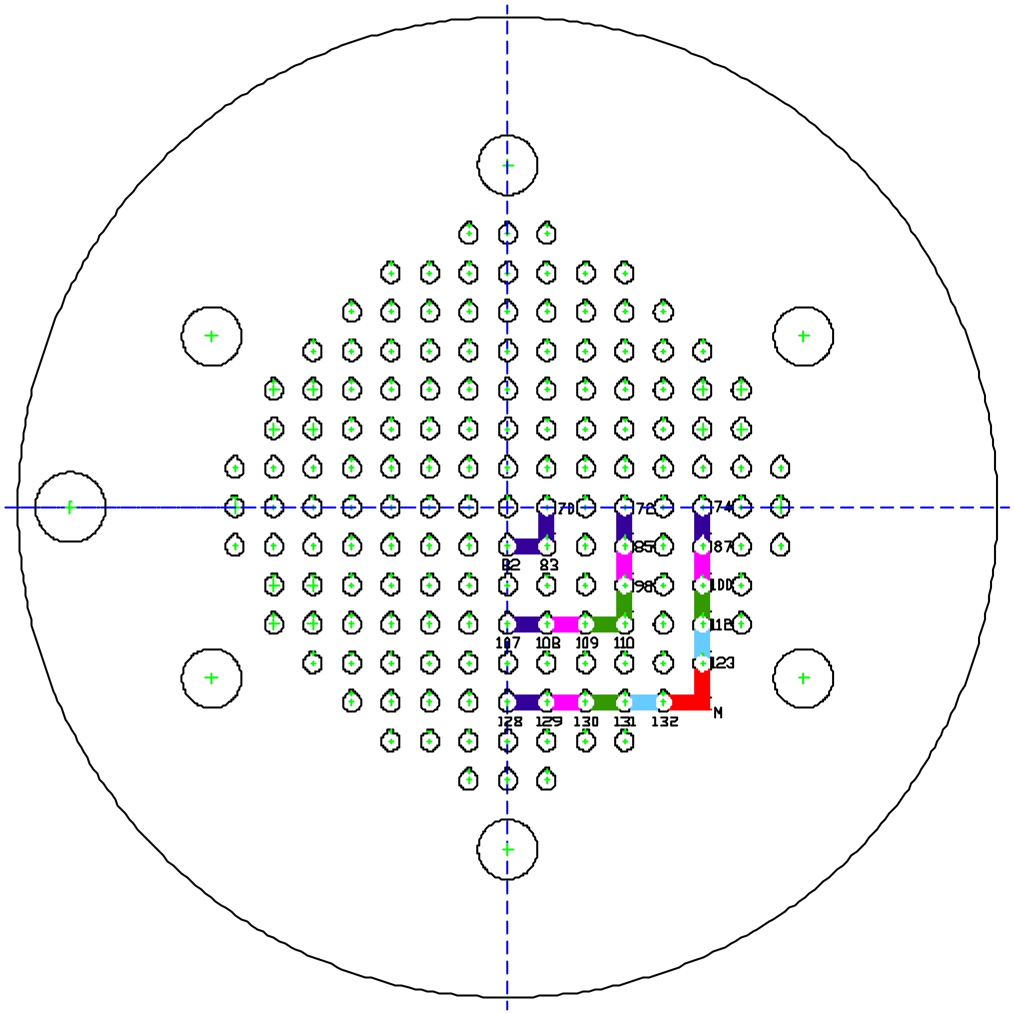
Positions of the LDA Measurements



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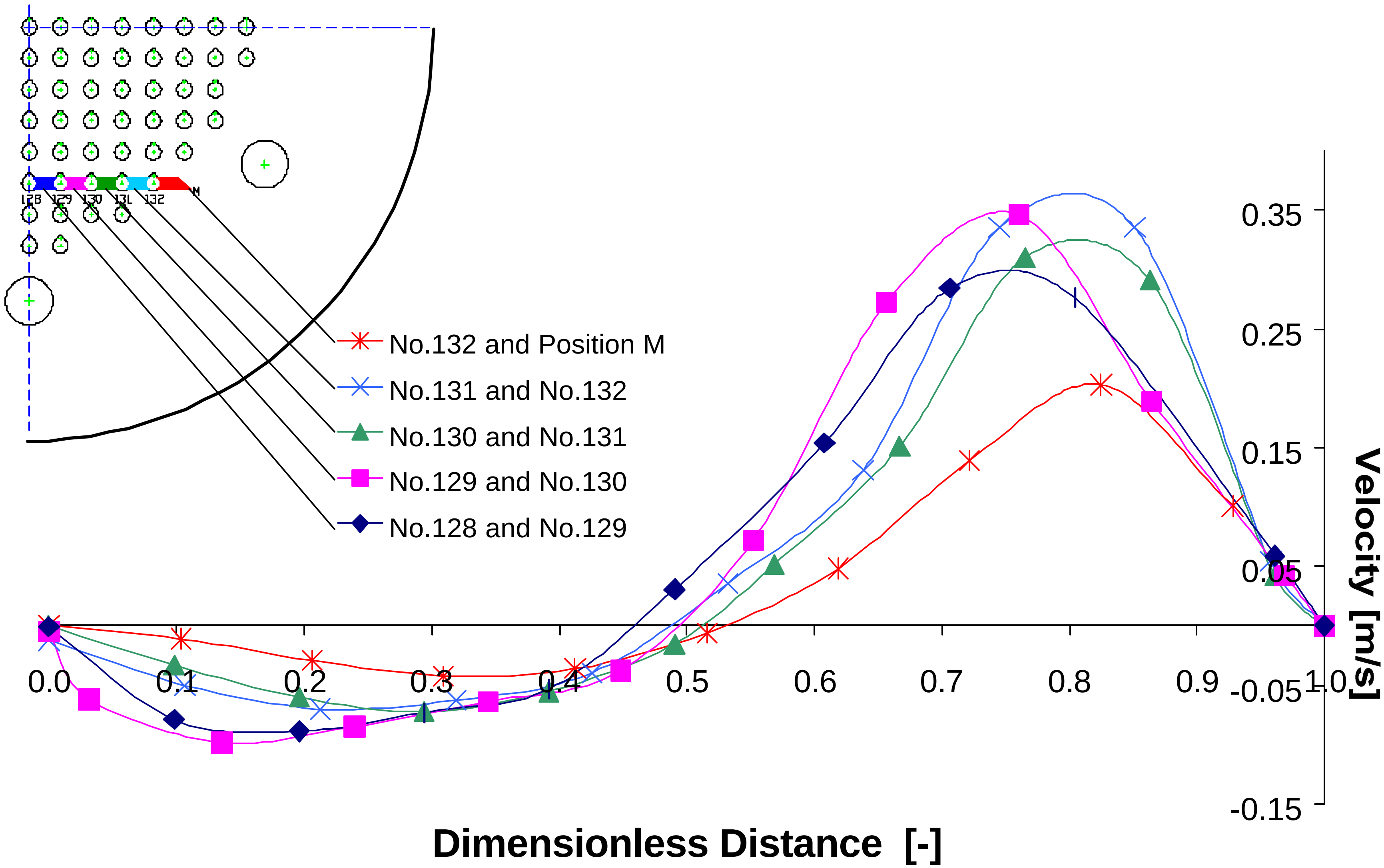
Velocity Distribution as the Function of the Height



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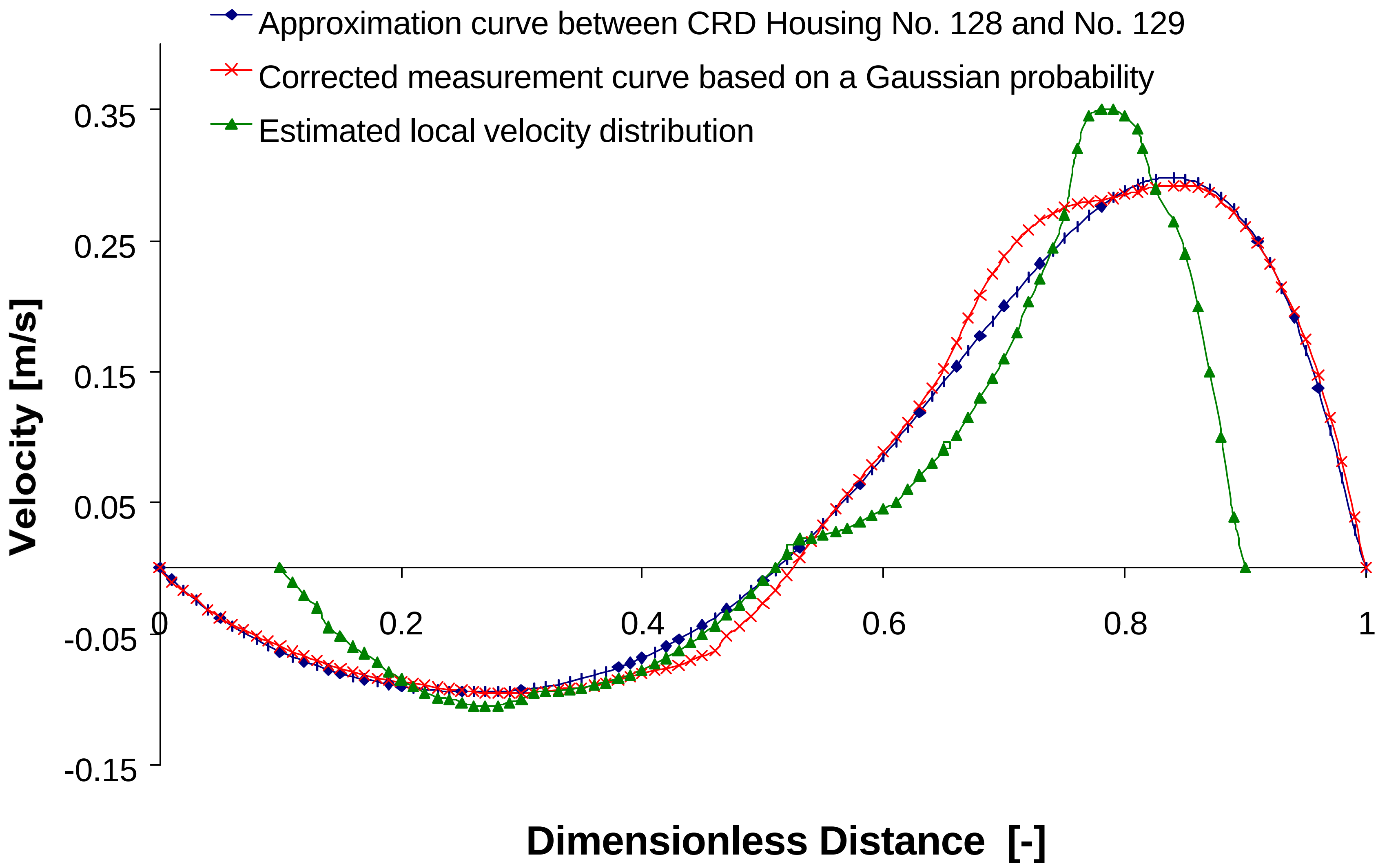
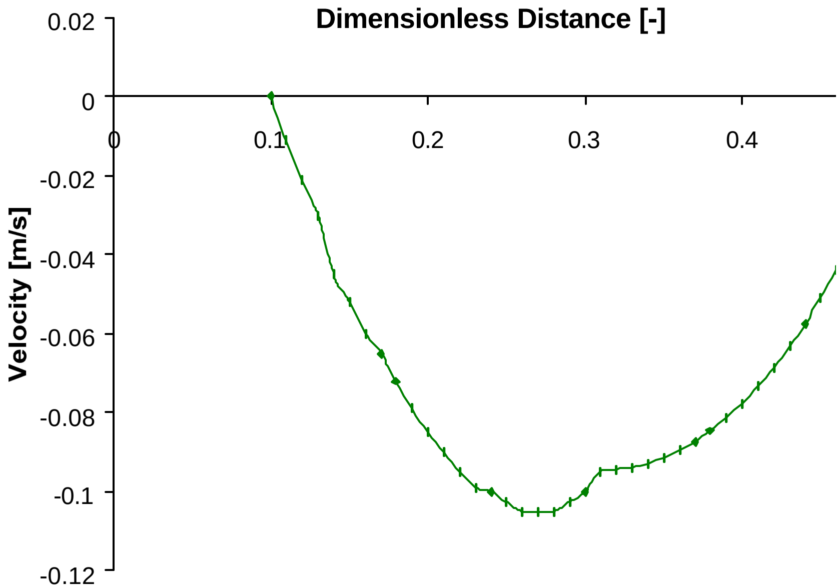
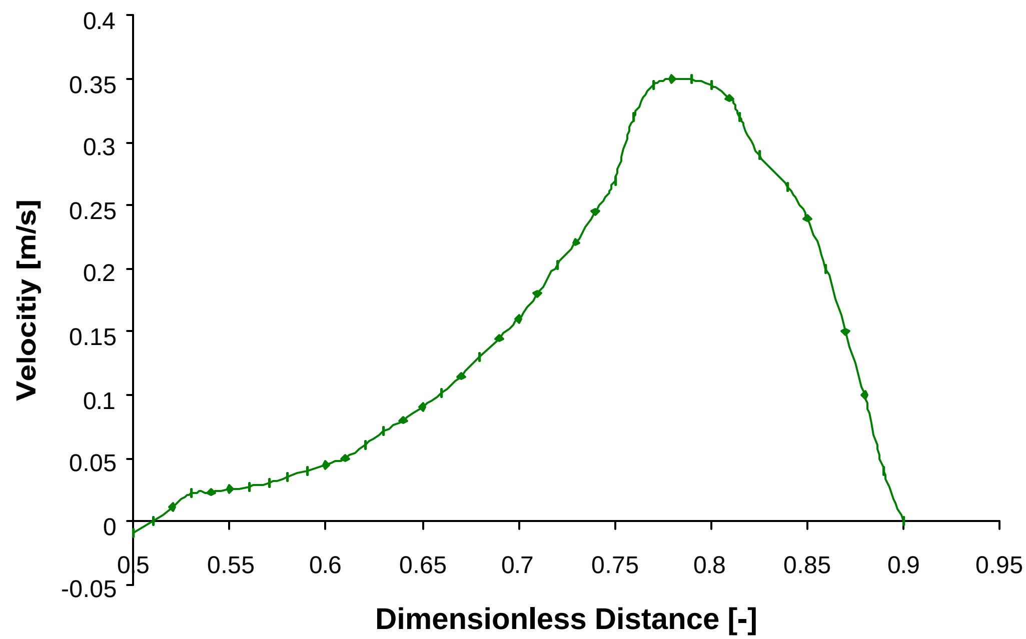
Local Velocities



Water Mass Flow Balance

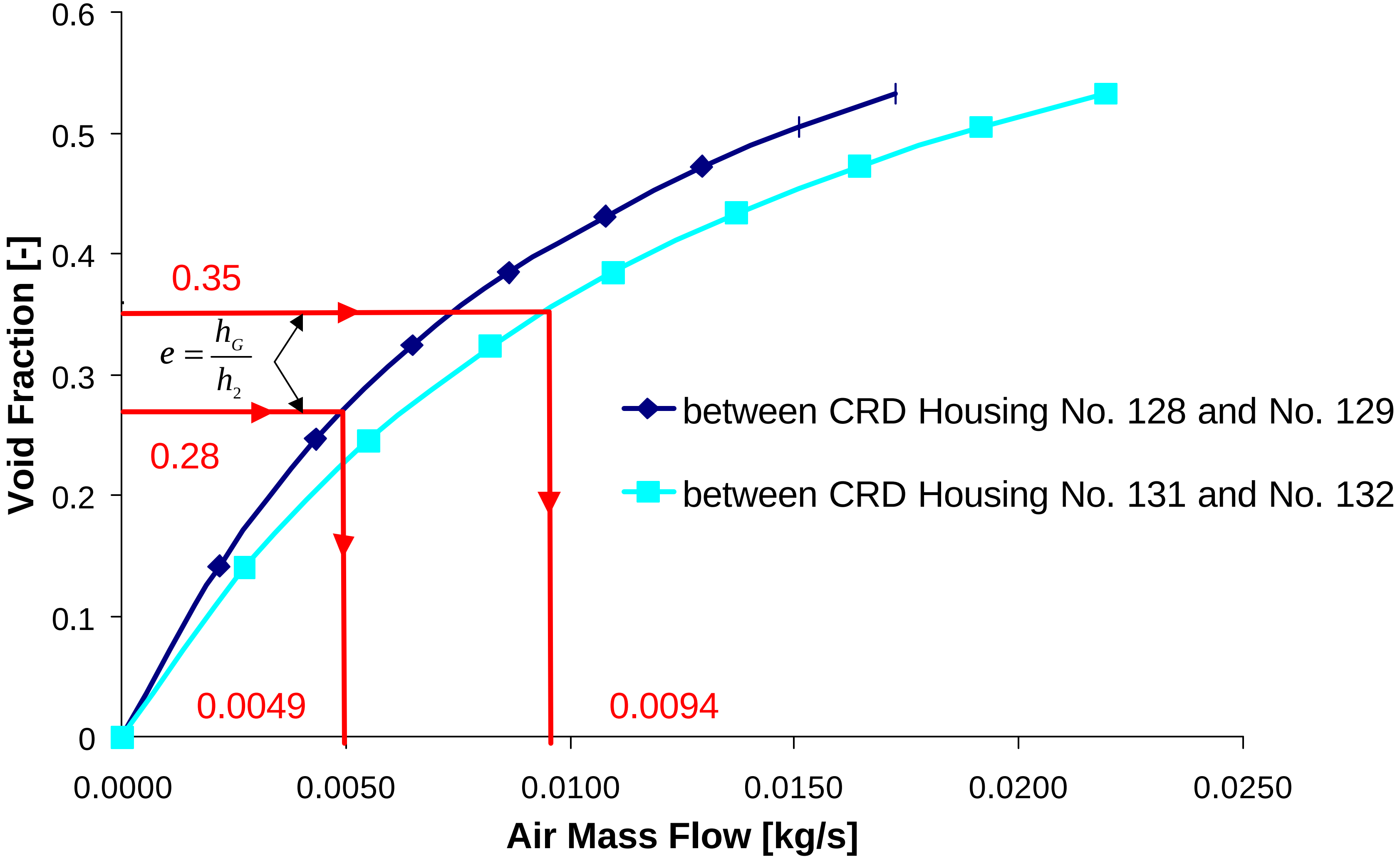




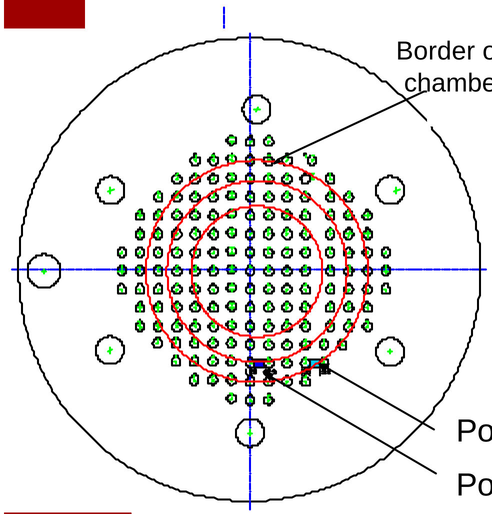
$$\dot{M}_{W;in} = \left\{ \sum_{i=1}^{\substack{\text{Number of positions} \\ \text{in the area with} \\ \text{negative velocities}-1}} \left[\left(x_{i+1}-x_i\right)\left(v_i\,\left(e_i-1\right)+v_{i+1}\,\left(e_{i+1}-1\right)\right)\, r_L\, \frac{1}{2} \right] \right\} b\,(-1) \overset{!}{=}$$

$$\dot{M}_{W;out} = \left\{ \sum_{i=1}^{\substack{\text{Number of positions} \\ \text{in the area with} \\ \text{positive velocities}-1}} \left[\left(x_{i+1}-x_i\right)\left(v_i\cdot\left(e_i-1\right)+v_{i+1}\cdot\left(e_{i+1}-1\right)\right)\, r_L\, \frac{1}{2} \right] \right\} b$$

Gas Mass Flow Balance

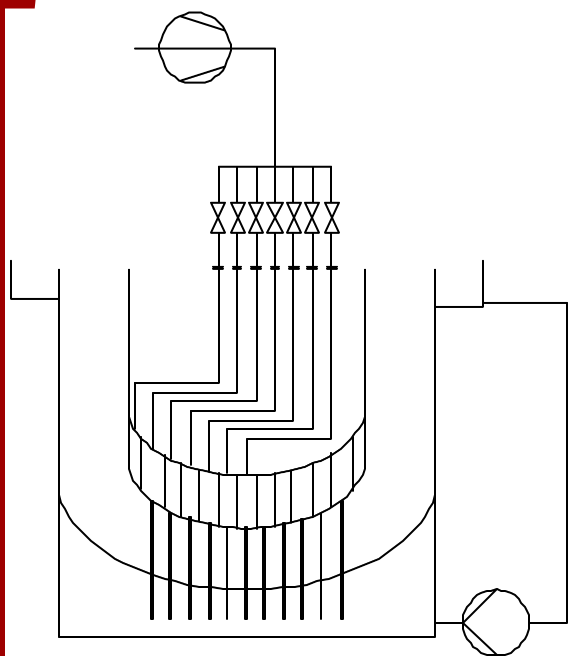


Results of the Mass Flow Balances

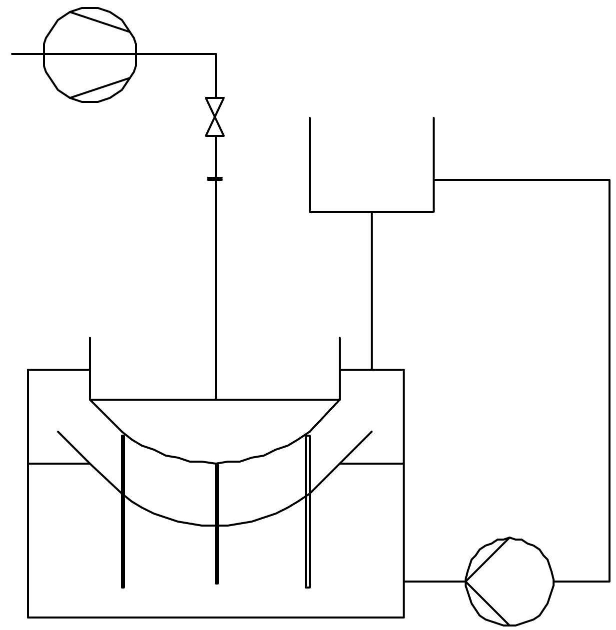


	Position 128-129	Position 131-132
Water Mass Flow, Inlet [kg/s]	1,19	1,36
Water Mass Flow, Outlet [kg/s]	1,40	1,59
Ratio Water Mass Flow Out/In	1,18	1,17
Air Mass Flow, Injected [kg/s]	0,0043	0,0085
Air Mass Flow, Acc. Fig. 13 [kg/s]	0,0049	0,0094
Ratio Out/In	1,14	1,11

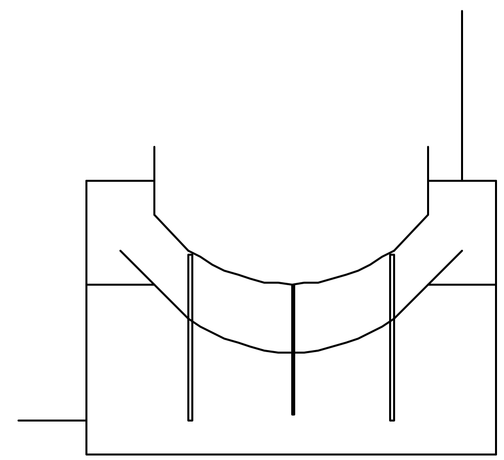
Decoupling of Flow Conditions and Heat Transfer



Water / Air-Experiments Scale 1 : 10
Investigation of the global flow conditions and determination of requirements for the design of a segment

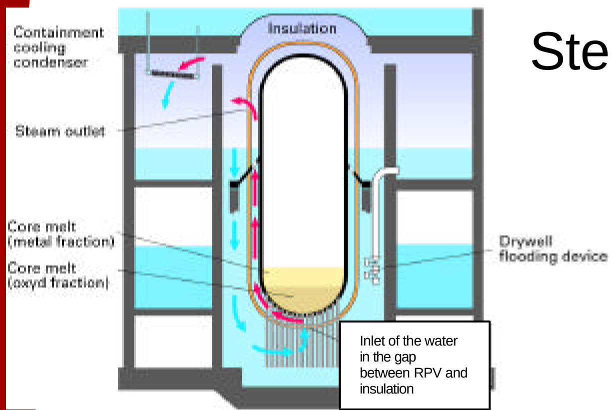


Water / Air-Experiments with a Section
Designing of in- and outlets in order to reach a similar flow behaviour as in the global 1 : 1 model



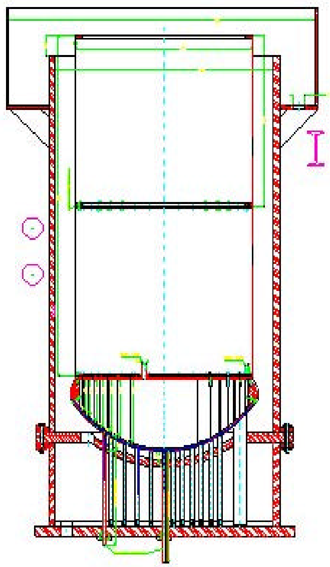
Water / Steam-Experiments with a Section
Measuring the Critical Heat Flux in a 1:1 Section Model installed in the BVS - a flexible Water / Steam-Test Loop

Scaling Procedure and Intention



Steam generation

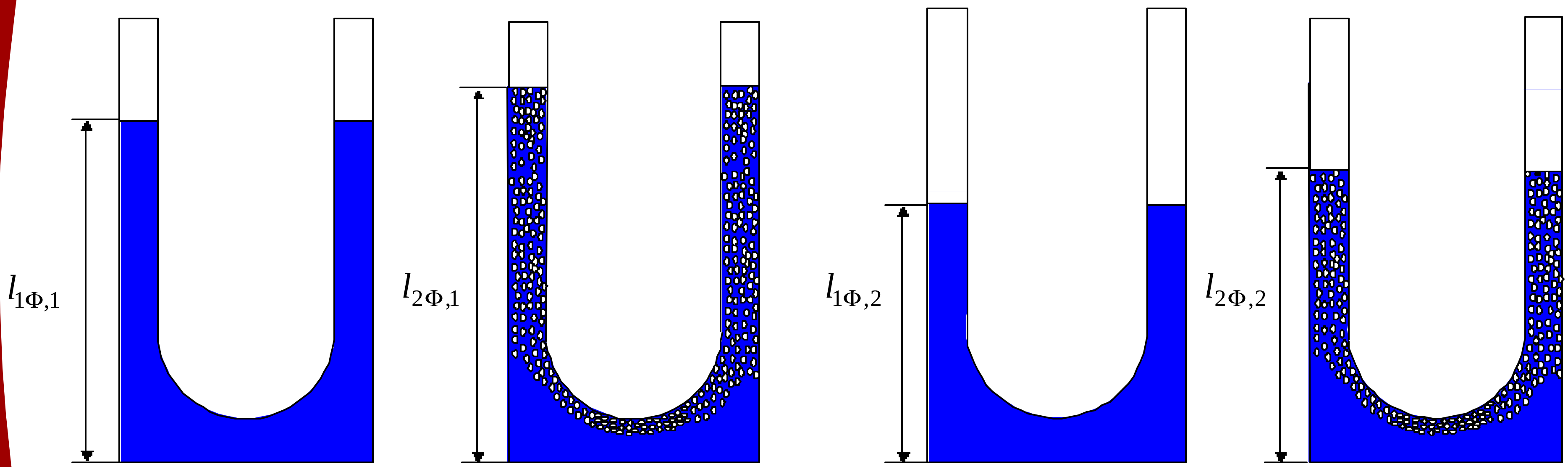
Air injection

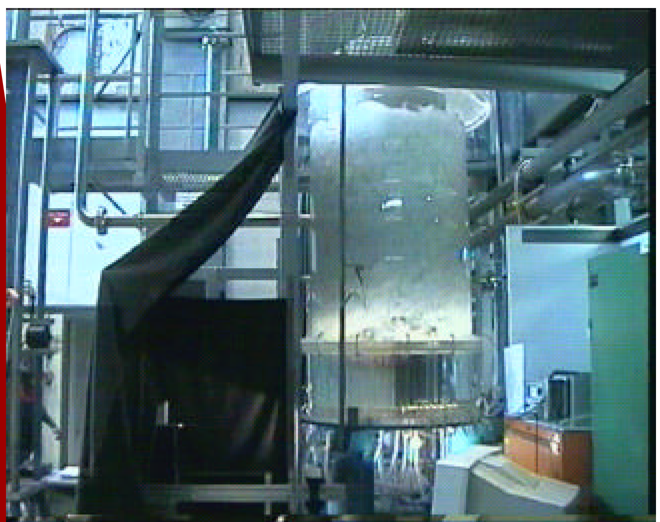


Procedure:

- Void measurements in the model
- Approximation of drift flux correlation parameters
- Calculation of the void fraction based on the new correlation
- Calculation of the air mass flow with similar void fraction

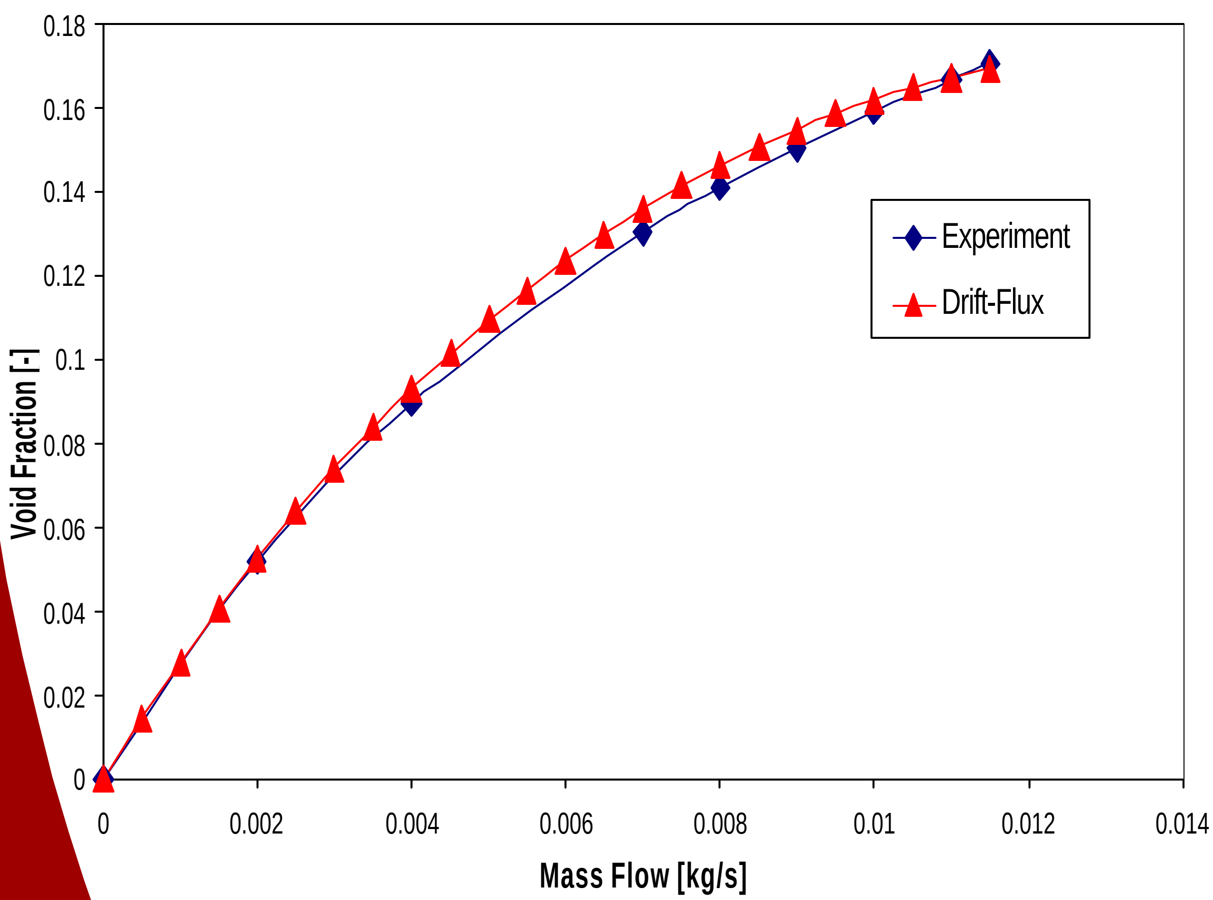
Void Fraction Measurement Method





$$e = \frac{(l_{2\Phi,1} - l_{1\Phi,1}) - (l_{2\Phi,2} - l_{1\Phi,2})}{(l_{2\Phi,1} - l_{1\Phi,1}) - (l_{2\Phi,2} - l_{1\Phi,2}) + (l_{1\Phi,1} - l_{1\Phi,2})}$$

Measured Void Fraction and Developed Correlation



$$\varepsilon = \left(\frac{C_0}{\varepsilon_{hom}} + \frac{\rho_g * u_{gi}}{\dot{x} * \dot{m}} \right)^{-1}$$

$C_0 = 3,03654$

$$u_{gi} = 0,77575 * \left[\frac{\sigma * g * (\rho_l - \rho_g)}{\rho_l^2} \right]^{0,25}$$

$$\varepsilon = \left(3,03654 + \frac{\rho_g * 0,77575 * \left[\frac{\sigma * g * (\rho_l - \rho_g)}{\rho_l^2} \right]^{0,25}}{\dot{m}} \right)^{-1}$$

Mass Flows for the Tests with the Global Model

<u>SWR 1000, Original</u>

- Properties of Water/Steam (P =2-5 bar)
- Mass flux (P =2-5 bar, Q =4,5;9;13,5 MW)

<u>SWR 1000, Model</u>

- Properties of Water/Air (P=1 bar)
- Void (ε =0,16;0,24;0,28)

$$e = \left(3,03654 + \frac{r_g * 0,77575 * \left(\frac{s * g * (r_i - r_g)}{r_l^2} \right)^{0,25}}{\dot{M}_g / A} \right)^{-1}$$

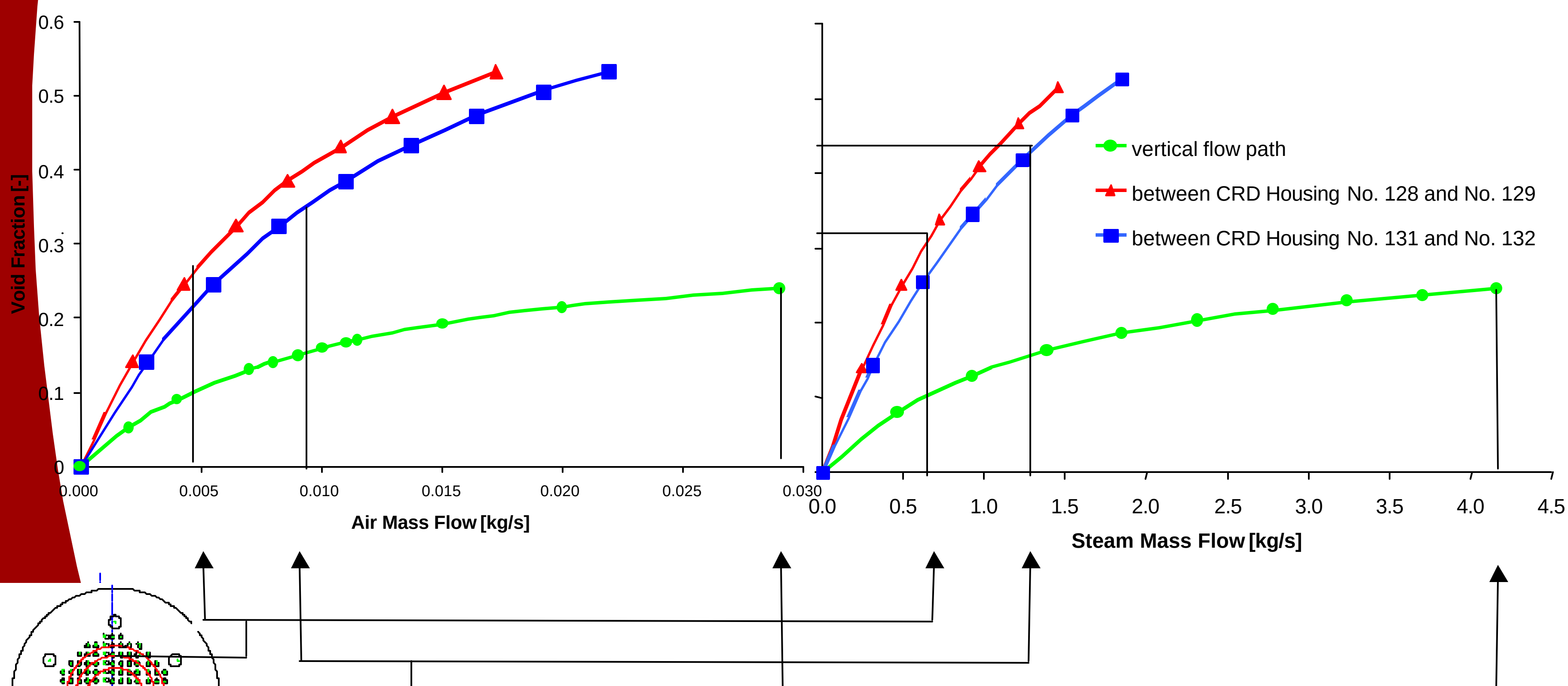
Void ε

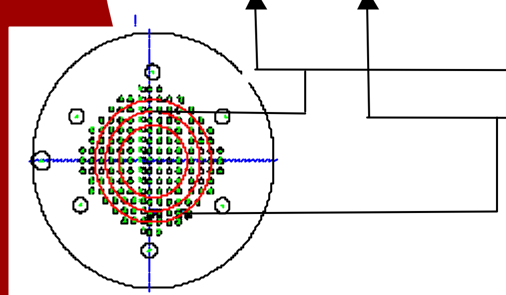
Q \ P	2 [bar]	3 [bar]	4 [bar]	5 [bar]
4.5 [MW]	0.2224	0.1956	0.1777	**0.1598**
9 [MW]	0.2655	**0.2454**	0.2309	0.2152
13,5 [MW]	**0.2839**	0.2682	0.2564	0.2433

Air Mass Flow

Void ε	M [kg/s]
0.16	**0.010**
0.24	**0.029**
0.28	**0.061**

Comparison of Void Trends -
Model (Air 1 bar) and „Original“ (Steam 3 bar)

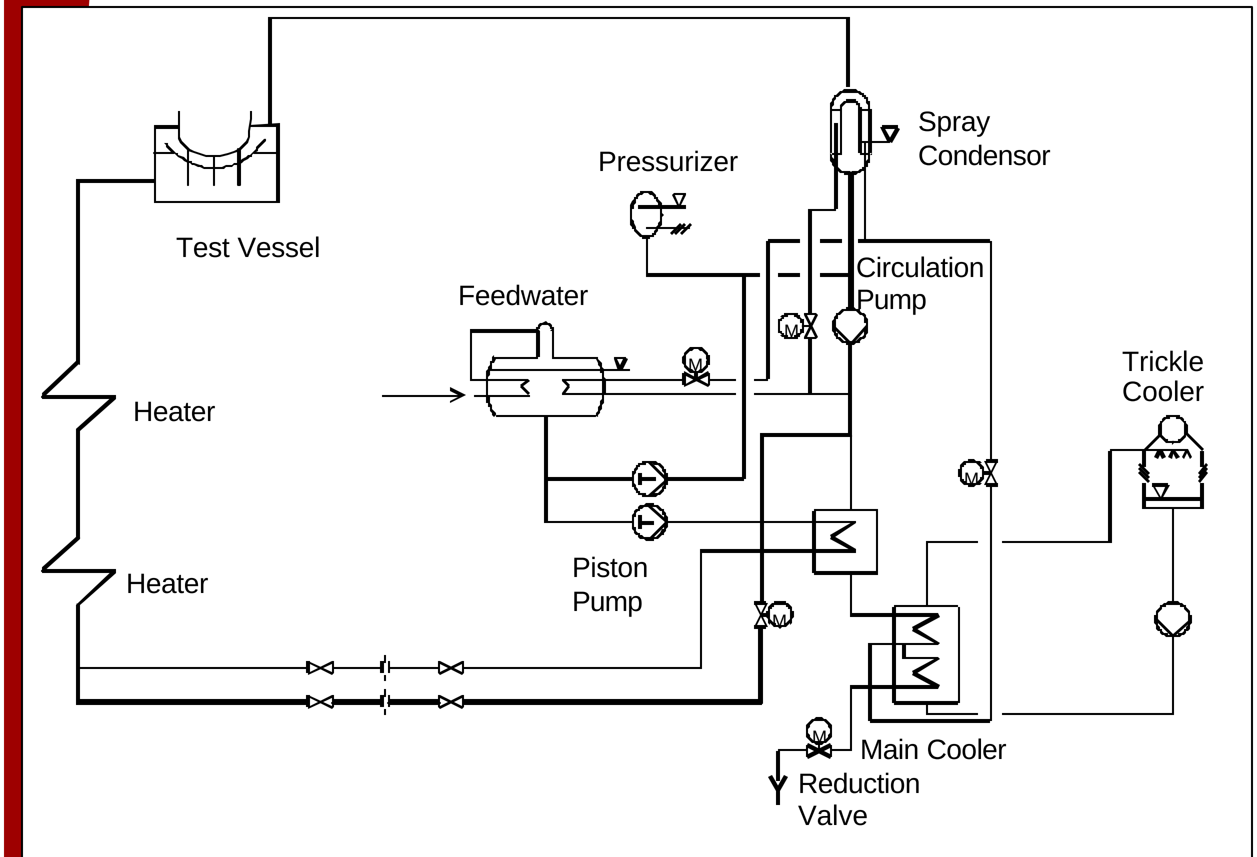




Corresponding mass flows according mass sources

(injection / evaporation) for the 100% decay heat case

Measurement of Safety Margins



Aim of the experiments:

Measurement of the Critical Heat Flux above decay heat

Procedure:

- Implementation of a 1:1 scaled segment in the BVS by considering the in- and outflow conditions evaluated from the water / air - experiments
- Instrumentation of the RPV-wall with thermocouples in order to identify the location of the boiling crisis (CHF)
- Adjusting the mass flow in such a way that the feed water mass flow is equal to the evaporated
- Increasing the heat input stepwise until a boiling crisis-occurred or a relevant safety margin is reached.

Conclusions and Consequences

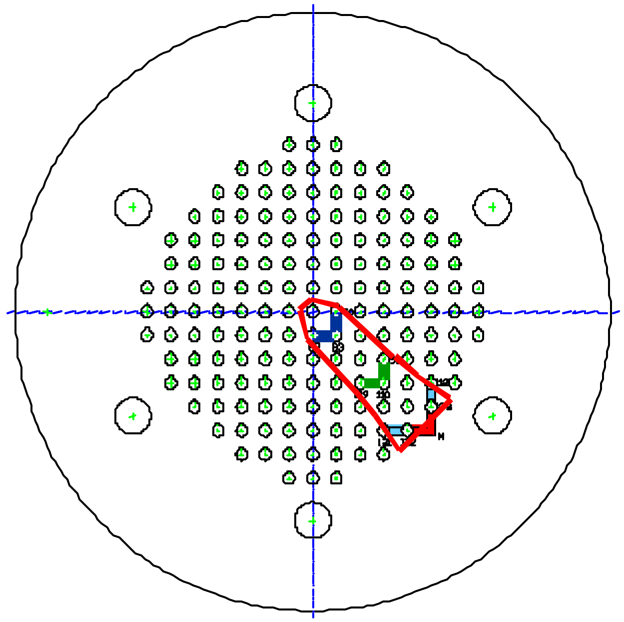
- The natural circulation inside the gap between the insulation and RPV is very strong - compared to the water supply of the external circulation. Thus, it is necessary to simulate the internal circulation in a water steam experiment.
- The flow experiments indicate almost rotational symmetric flow conditions.

The effect of flow and heating conditions is unknown, which might be influenced by the flow orientation from the centre position:

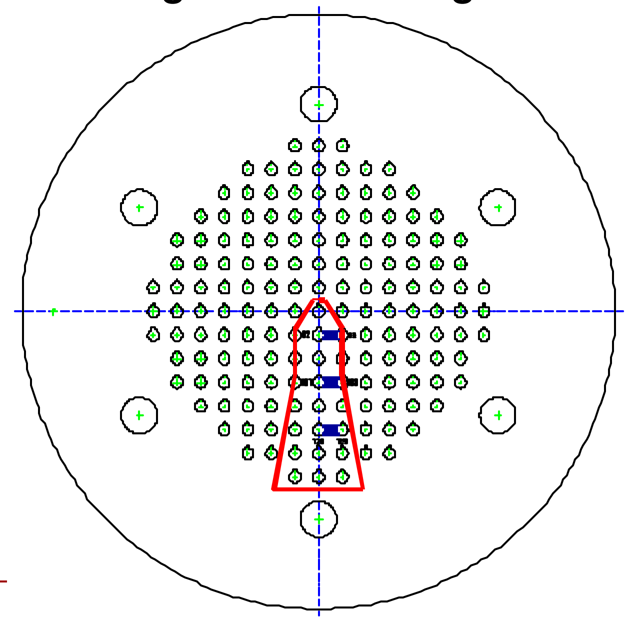
- The effect of a straight-line configuration will be lower flow resistance - compared to a non-straight-line configuration - and herewith a higher mass flows in this area.
- The effect of a non-straight-line configuration will be a better heat transfer behaviour - compared to a straight line configuration.

Conclusion: There will be no significant cross flow between the different orientations if the flow conditions are almost similar for both extreme configurations. In this case it is conservative to use the straight line configuration for a heatable test section.

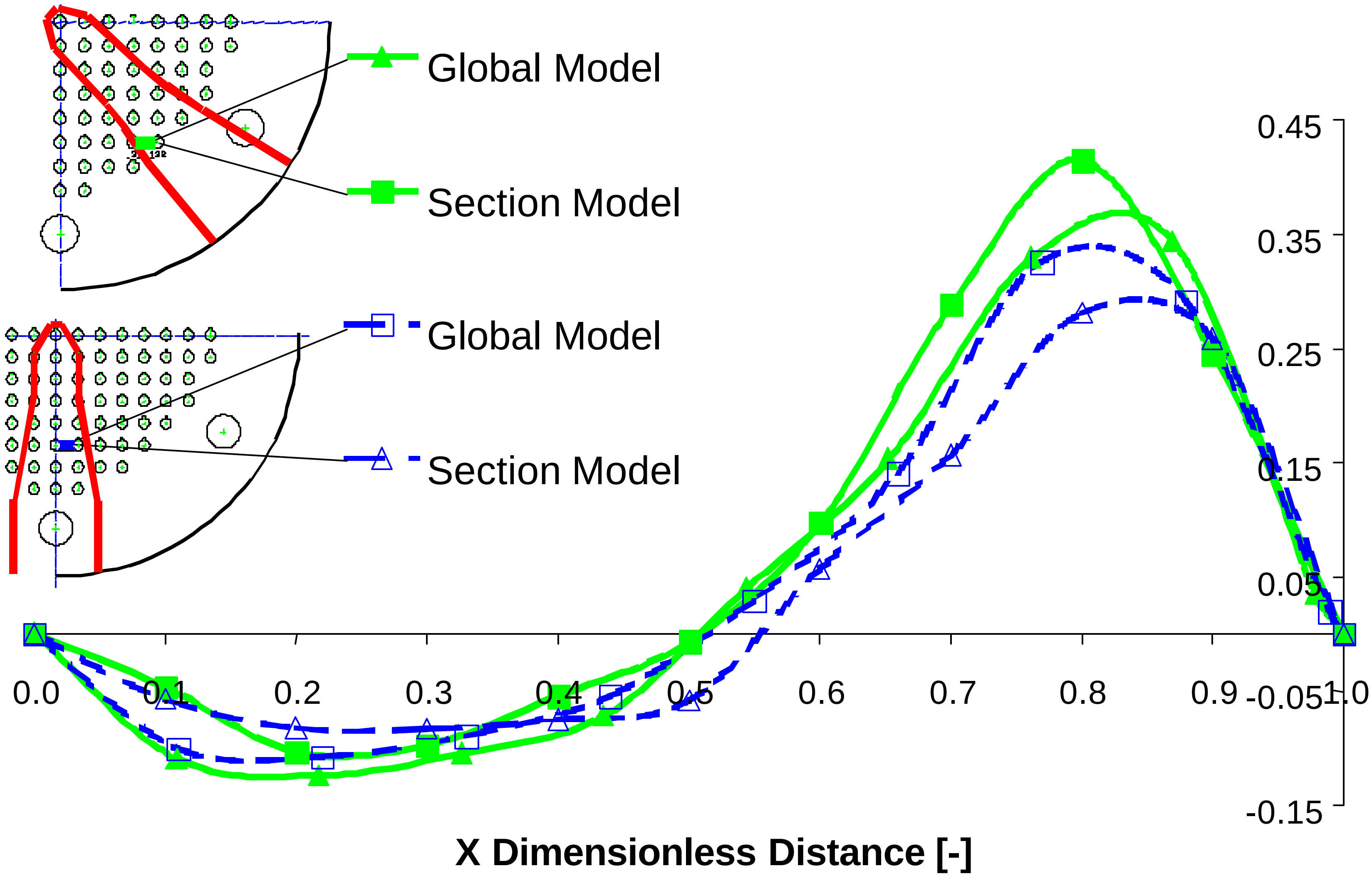
Non-Straight-Line Configuration



Straight-Line Configuration



Global and Section Model Measurements



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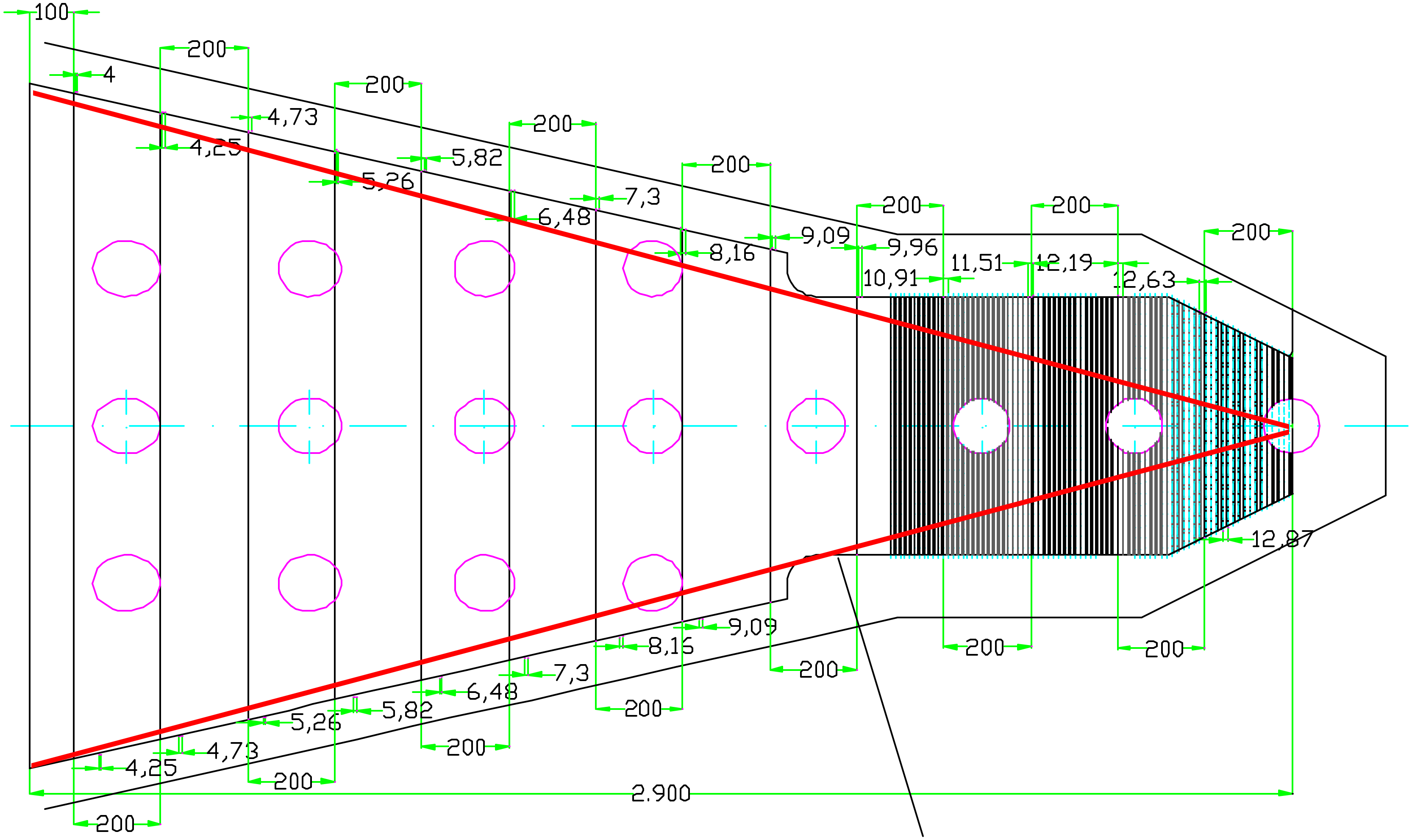
Heatable Section Model - Top View



Borders
of a comparable section

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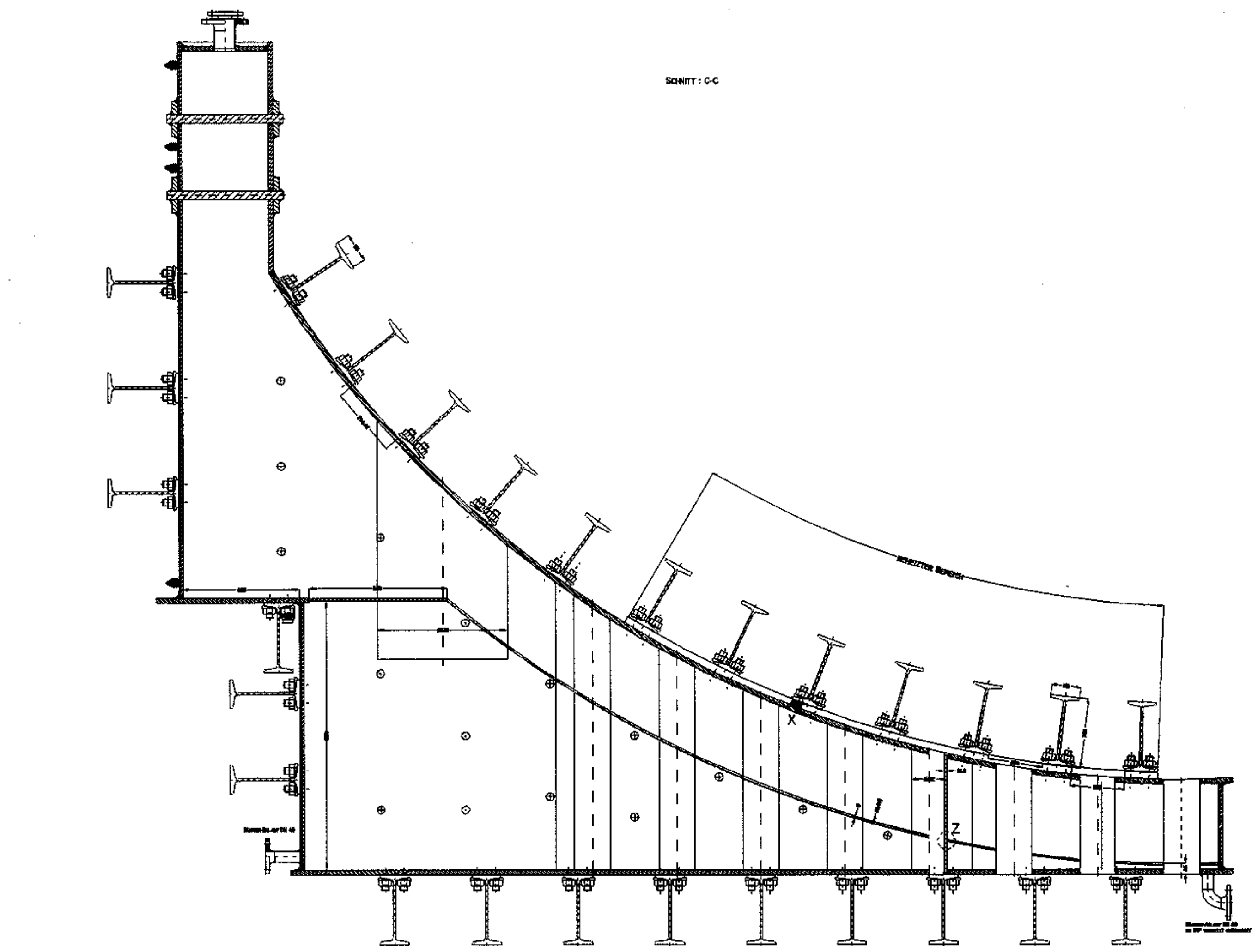
Heatable Section Model - Side View



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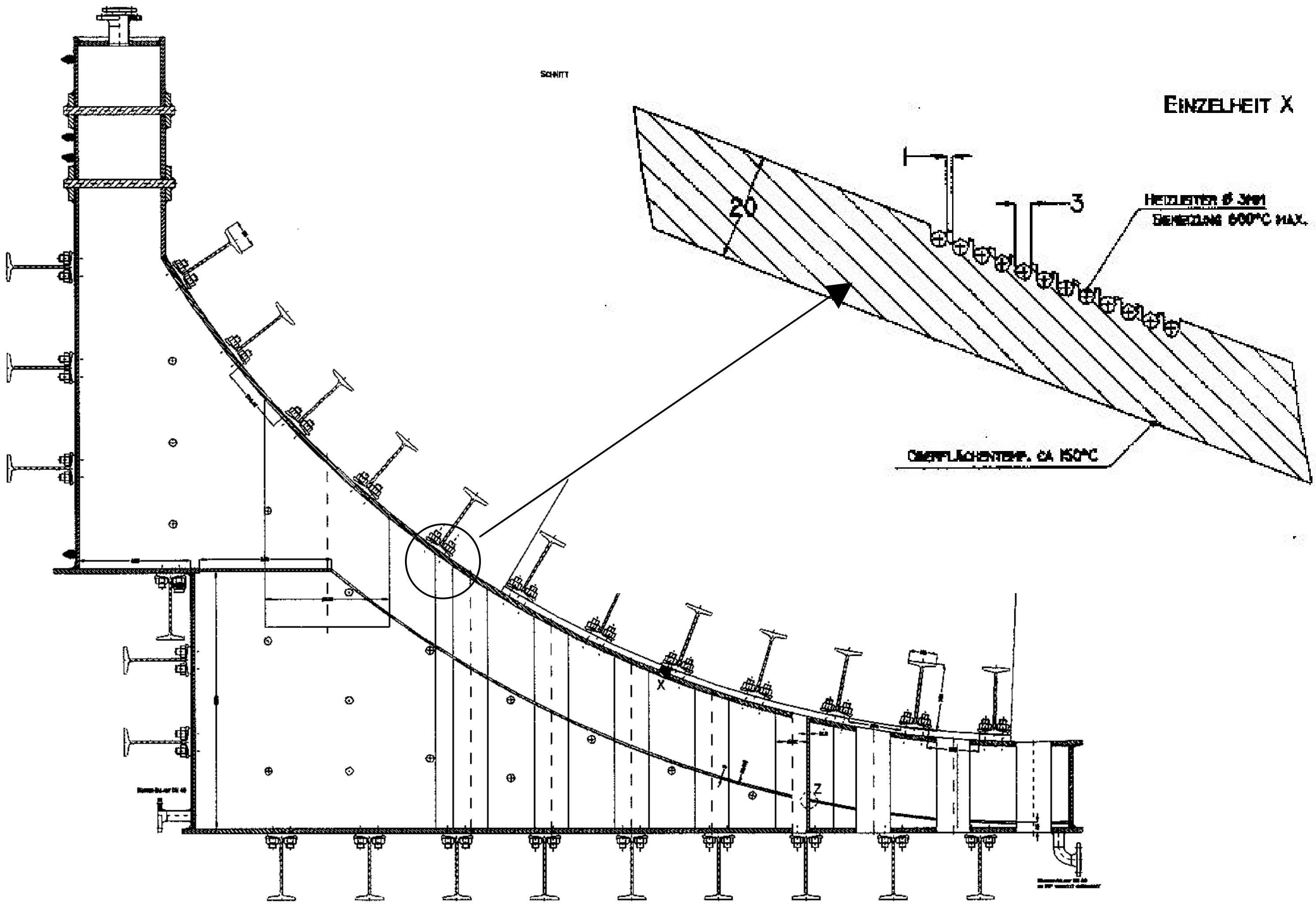
Heatable Section Model - Heating Concept



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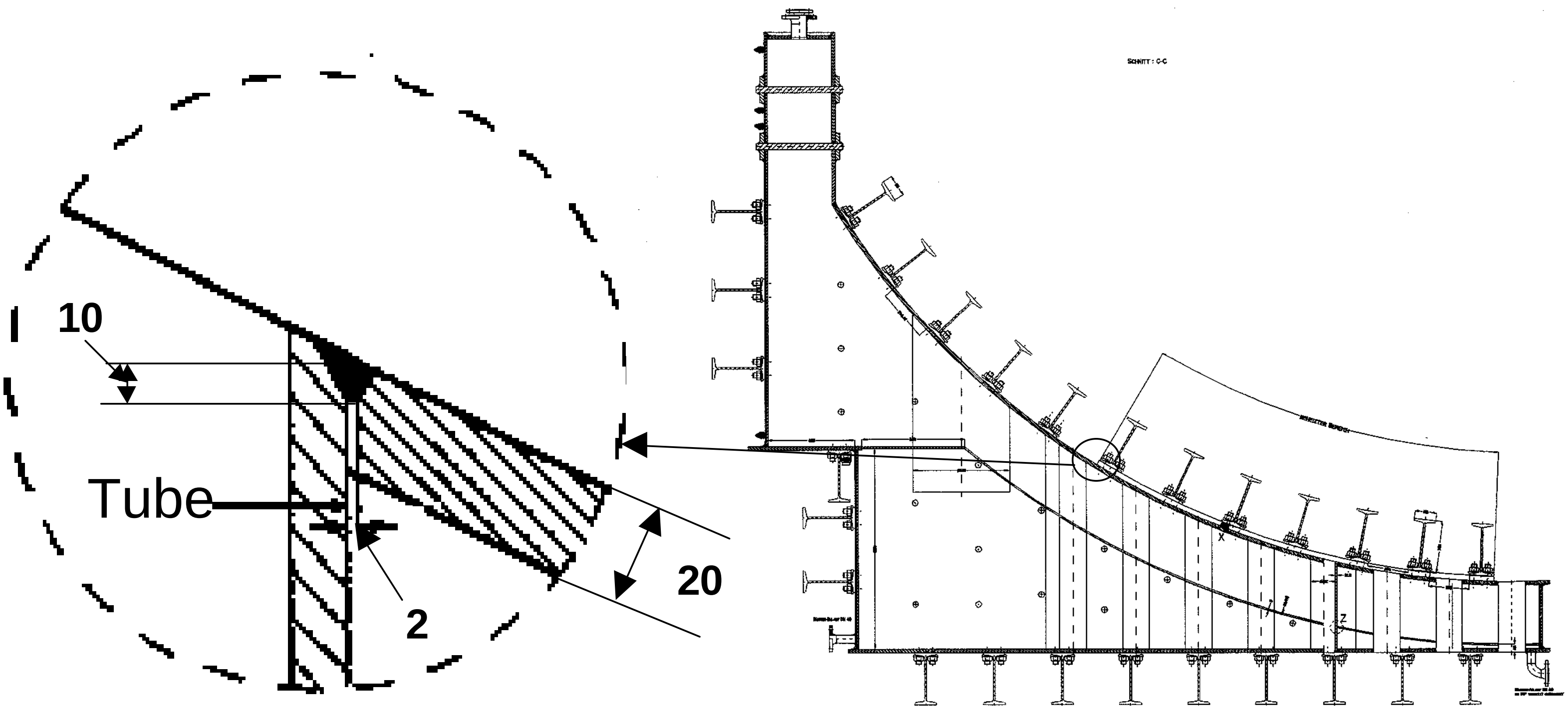
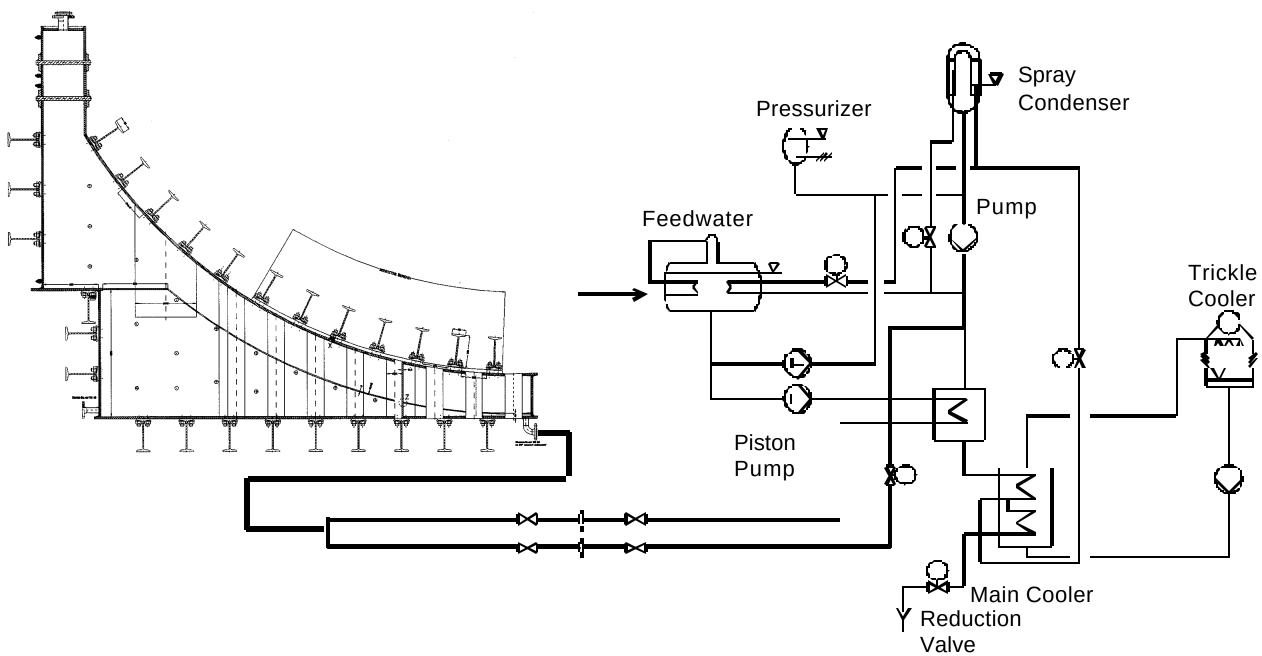
Heatable Section Model - CRD Housing connection



External Vessel Cooling Test
- Test Objective

Identification of the safety margins of the exterior cooling concept of the RPV, taking into consideration the influence of the control rod drive housings



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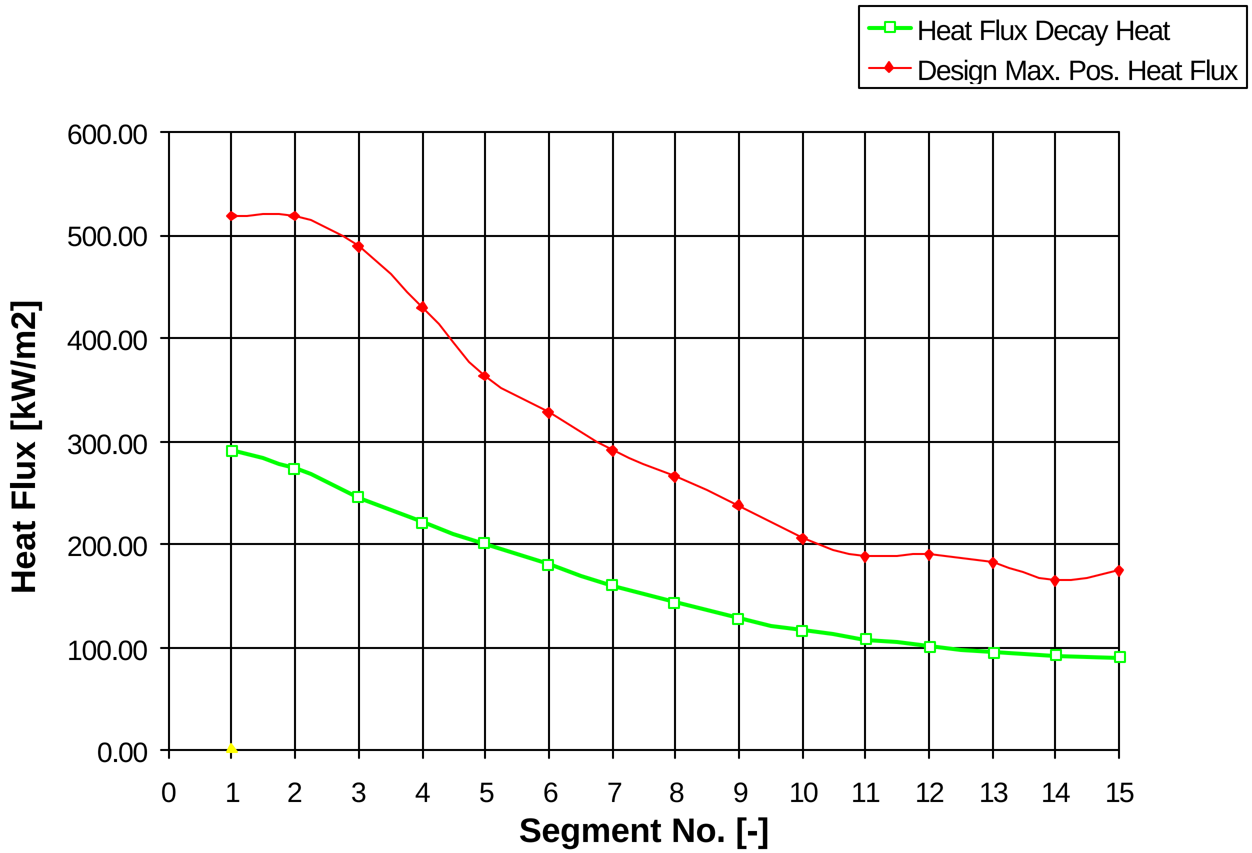
External Vessel Cooling Test
- Manufacturing, Heating Wires (1)



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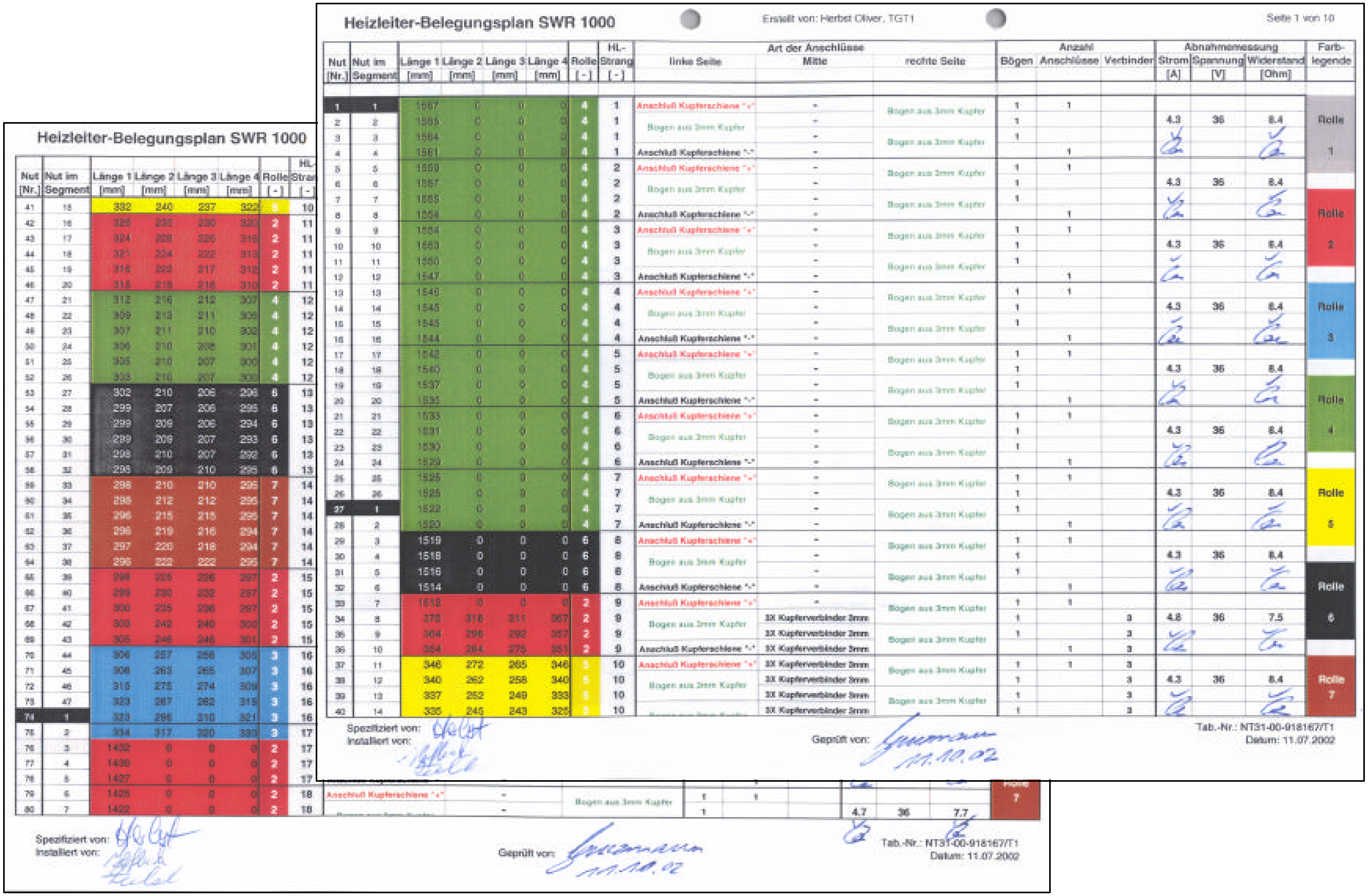
External Vessel Cooling Test
- Manufacturing, Heating Wires (2)



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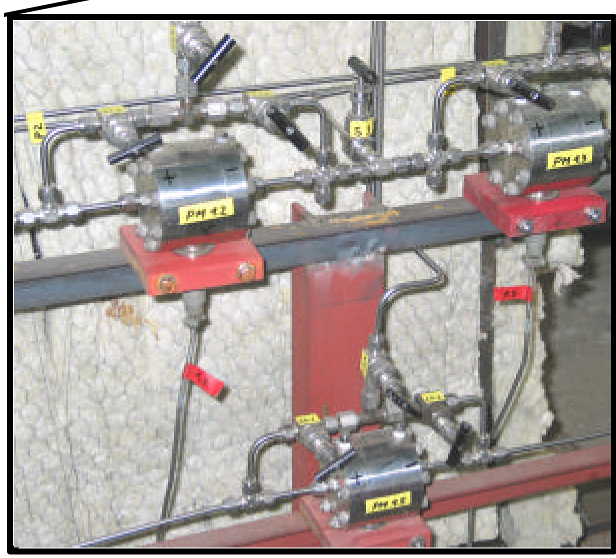
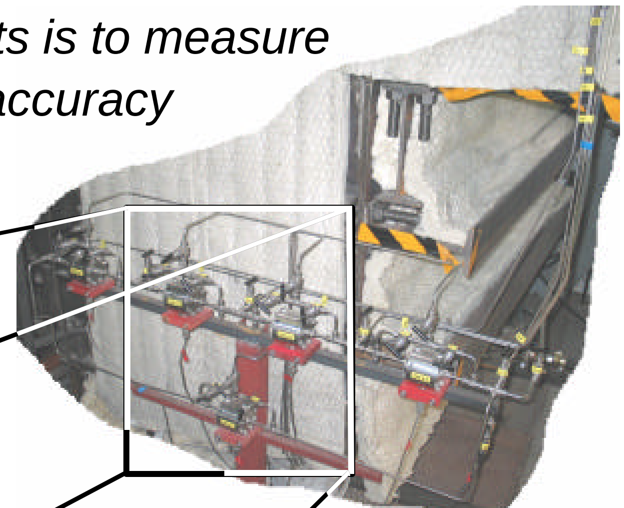
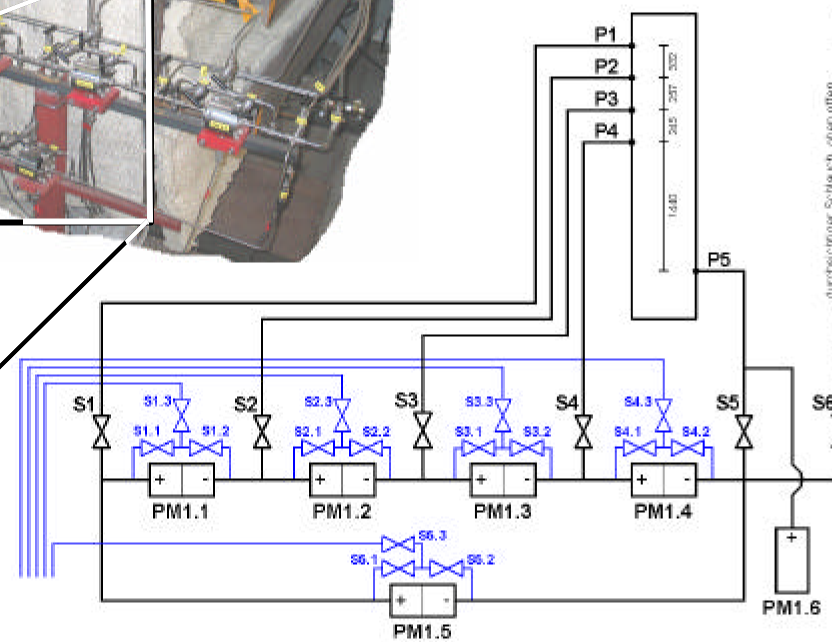
External Vessel Cooling Test
- Measuring Equipment, Pressure/Level

Pressure differences shall be measured at three different levels

- *Each of the pressure and pressure drop sensors has to be checked against a calibrated pressure checking device or a water column*
- *The aim of these measurements is to measure the water level. Therefore, an accuracy of +/- 2% can be accepted*







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External Vessel Cooling Test
- Measuring Equipment, Mass Flow

The inlet mass flow will be measured via an orifice. This measurement will be checked via the measurement of the time to fill a defined volume of 60 liters

- *The orifice should be chosen in a way that a mass flow could be measured from 0.4 to 0.0025kg/s at 104°C*
- *The aim of these measurements is to check, whether the test object will be supplied with almost constant flow conditions. Therefore, an accuracy of +/- 4% can be accepted*

Meßblende SWR1000-Versuche
(Durchlaufbetrieb, Meßblende P17 D=22.5mm / d=5.583mm, Einspeisetemperatur 20°C)

Berechnung:

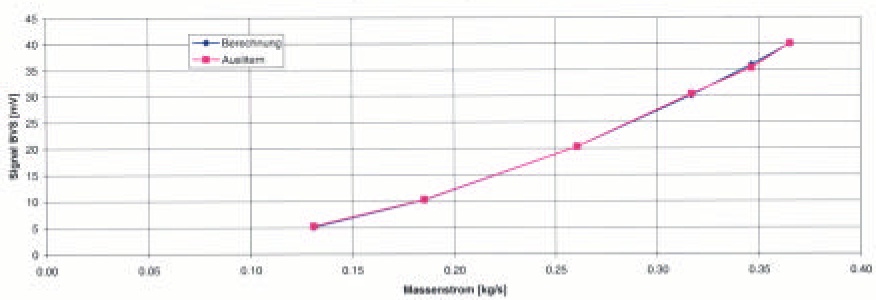
Blende	M	k	Signal	Signal BVS
d [mm]	(kg/s]	[m²]	[bar]	[mV]
5.583	0.13	2.19E-05	0.360	5.138
	0.19	2.19E-05	0.721	10.291
	0.26	2.19E-05	1.423	20.302
	0.32	2.19E-05	2.107	30.068
	0.35	2.19E-05	2.515	35.885
	0.37	2.19E-05	2.798	39.932

Rho $_{Wasser}$ = 998.30kg/m3 (20°C)

Ausliterversuch:

Zeit	Zeit	Volumen	V	M	Signal BVS
[min]	[s]	[l]	[l/s]	[kg/s]	[mV]
07:37	457	60	0.1313	0.131067834	5.3
05:23	323	60	0.1858	0.185442724	10.3
03:50	230	60	0.2609	0.260426087	20.3
03:09	189	60	0.3175	0.316920635	30.3
02:53	173	60	0.3468	0.346231214	35.3
02:44	164	60	0.3659	0.365231707	40.0

Vergleich Berechnung-Auslitern

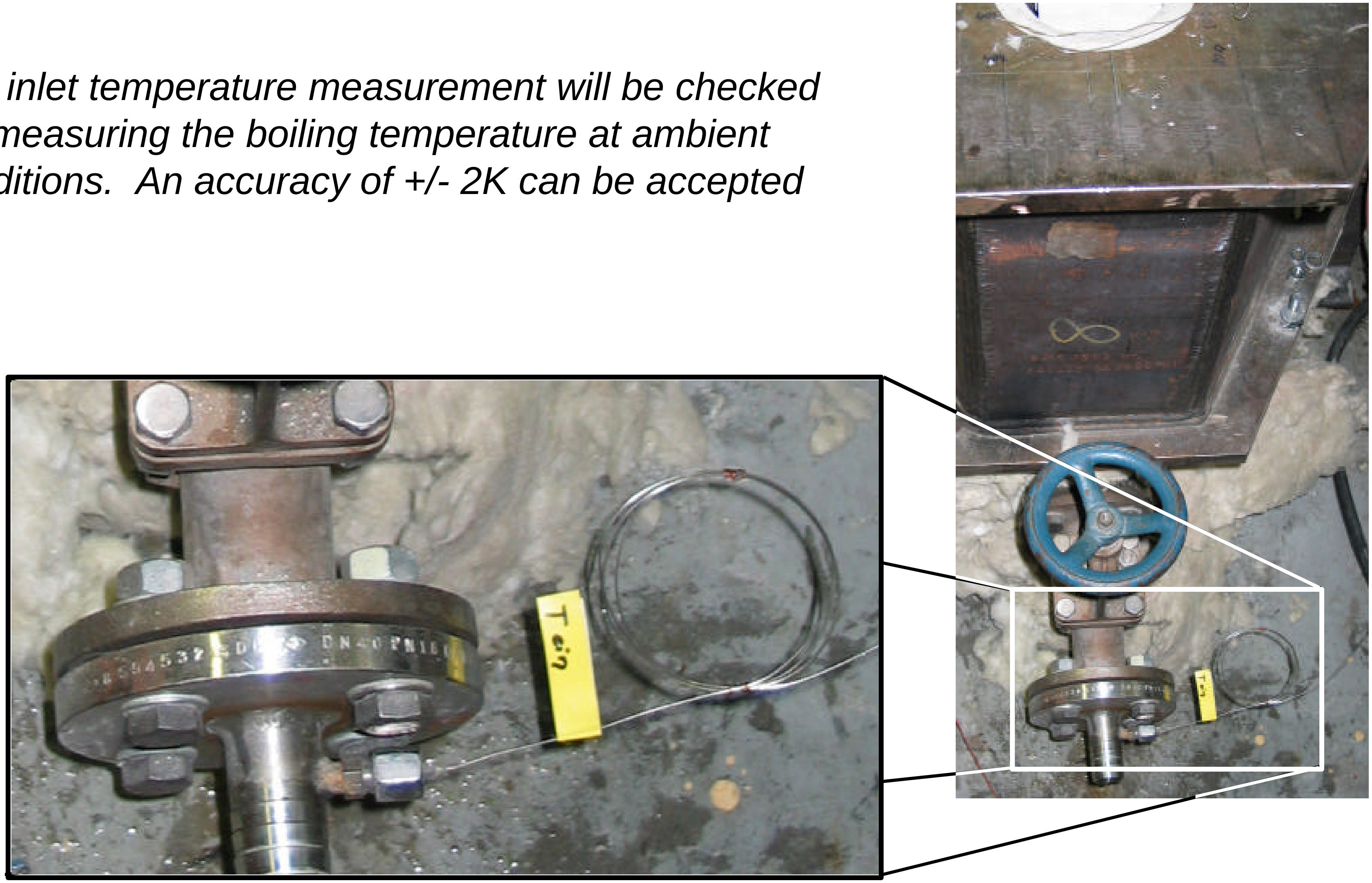


korrigierter k-Wert = 0.00002185

FANP TGT1
Klemm
24.09.02

External Vessel Cooling Test
- Measuring Equipment, Inlet Temperature

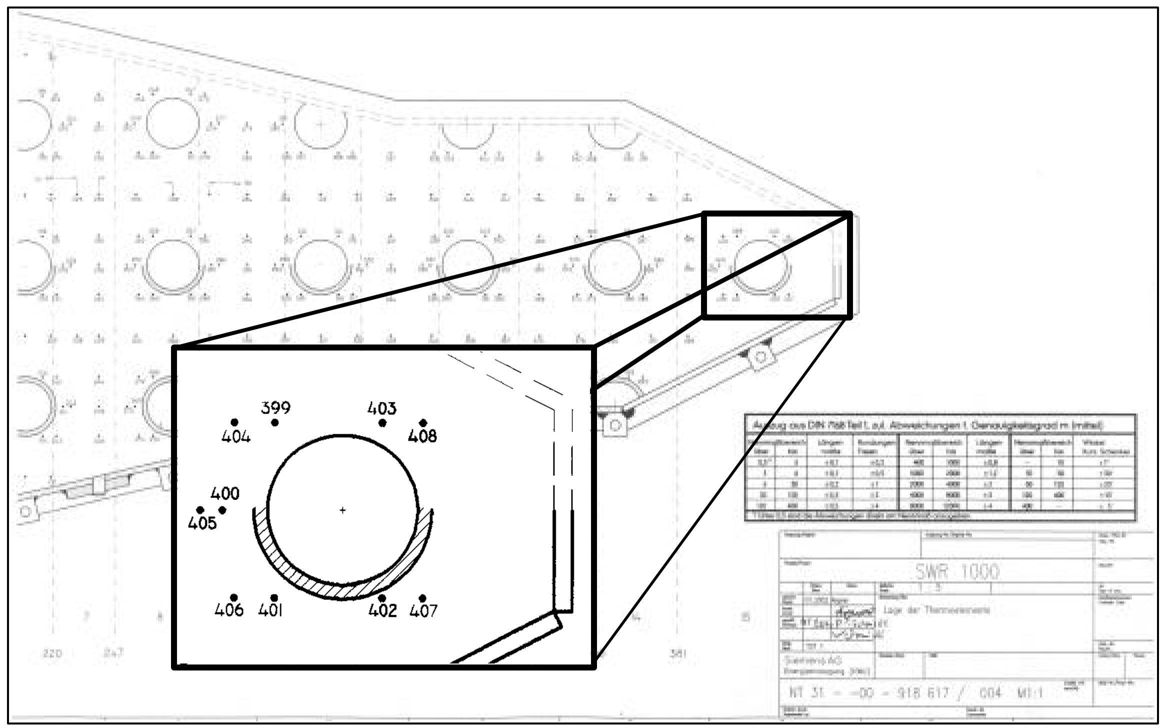
The inlet temperature measurement will be checked via measuring the boiling temperature at ambient conditions. An accuracy of +/- 2K can be accepted



External Vessel Cooling Test
- Measuring Equipment, Heated Surface (1)

> *The temperature measurements of the heated surface will be checked based on plausibility*

- *Plausibility check is described in the Test Procedure (FANP TGT1/02/e42)*
- *Installation has to be done and checked according to the respective drawing*



External Vessel Cooling Test
- Measuring Equipment, Heated Surface (2)

Belegungsplan SCXI 1303 - Module

Chassis	Slot	Kanal auf Platine	Thermoelement-Nr.	Kanal - Nr. in Meßstellenliste
1	3	0	RWT 001	0
1	3	1	RWT 002	1
1	3	2	RWT 003	2
1	3	3	RWT 004	3
1	3	4	RWT 005	4
1	3	5	RWT 006	5
1	3	6	RWT 007	6
1	3	7	RWT 008	7
1	3	8	RWT 009	8
1	3	9	RWT 010	9
1	3	10	RWT 011	10
1	3	11	RWT 012	11
1	3	12	RWT 013	12
1	3	13	RWT 014	13
1	3	14	RWT 015	14
1	3	15	RWT 016	15
1	3	16	RWT 017	16
1	3	17	RWT 018	17
1	3	18	RWT 019	18
1	3	19	RWT 020	19
1	3	20	frei	frei
1	3	21	RWT 022	21
1	3	22	RWT 023	22
1	3	23	RWT 024	23
1	3	24	RWT 025	24
1	3	25	RWT 026	25
1	3	26	RWT 027	26
1	3	27	frei	frei
1	3	28	RWT 029	28
1	3	29	RWT 030	29
1	3	30	frei	frei
1	3	31	Vergleichsstelle	31

Chassis	Slot	Kanal auf Platine	Thermoelement-Nr.	Kanal - Nr. in Meßstellenliste
1	4	0	RWT 032	32
1	4	1	RWT 033	33
1	4	2	frei	frei
1	4	3	RWT 035	35
1	4	4	RWT 036	36
1	4	5	RWT 037	37
1	4	6	RWT 038	38
1	4	7	RWT 039	39
1	4	8	RWT 040	40
1	4	9	RWT 041	41
1	4	10	RWT 042	42
1	4	11	RWT 043	43
1	4	12	RWT 044	44
1	4	13	RWT 045	45
1	4	14	RWT 046	46
1	4	15	frei	frei
1	4	16	RWT 048	48
1	4	17	RWT 049	49
1	4	18	RWT 050	50
1	4	19	RWT 051	51
1	4	20	frei	frei
1	4	21	RWT 053	53
1	4	22	frei	frei
1	4	23	RWT 055	55
1	4	24	RWT 056	56
1	4	25	RWT 057	57
1	4	26	RWT 058	58
1	4	27	RWT 059	59
1	4	28	frei	frei
1	4	29	frei	frei
1	4	30	RWT 062	62
1	4	31	Vergleichsstelle	63

Geprüft 14.3.03

FANP TGT1 / Herbst / 3/13/03

Meßstellenliste:

Autor: Herbst
Datei: SWR1000.mst
Versuchsdatum: 01.11.02

MST	KAN STF	Bezeichnung	Kurz-bezeichnung	Meß-wandler	Meßbereich	SI-Meßbereich	Meßort	Bemerkung
1	0	Temperatur 001	TE RWT001	SCXI-11 02		0 - 1000 °C		SCXI Chassis1 SLOT03
2	1	Temperatur 002	TE RWT002	SCXI-11 02		0 - 1000 °C		SCXI Chassis1 SLOT03
3	2	Temperatur 003	TE RWT003	SCXI-11 02		0 - 1000 °C		SCXI Chassis1 SLOT03
4	3	Temperatur 004	TE RWT004	SCXI-11 02		0 - 1000 °C		SCXI Chassis1 SLOT03
5								SCXI Chassis1 SLOT03
6								SCXI Chassis1 SLOT03
7								SCXI Chassis1 SLOT03
8								
9								
10								

NATIONAL INSTRUMENTS

Certificate of Calibration

Board Information

Certificate Information

National Instruments certifies that at the time of manufacture, the above product was calibrated in accordance with the applicable National Instruments procedures. These procedures are in compliance with relevant clauses of ISO 9002 and are designed to assure that the product listed above meets or exceeds National Instruments specifications.

National Instruments further certifies that the measurements standards and instruments used during the calibration of this product are traceable to the National Institute of Standards and Technology or are derived from accepted values of natural physical constants.

The environment in which this product was calibrated is maintained within the operating specifications of the instrument and the standards.

For questions or comments, please contact National Instruments Technical Support.

Signed,

J.E. Brochtrup

Joseph Brochtrup
Test Engineering Manager

FRAMATOME ANP

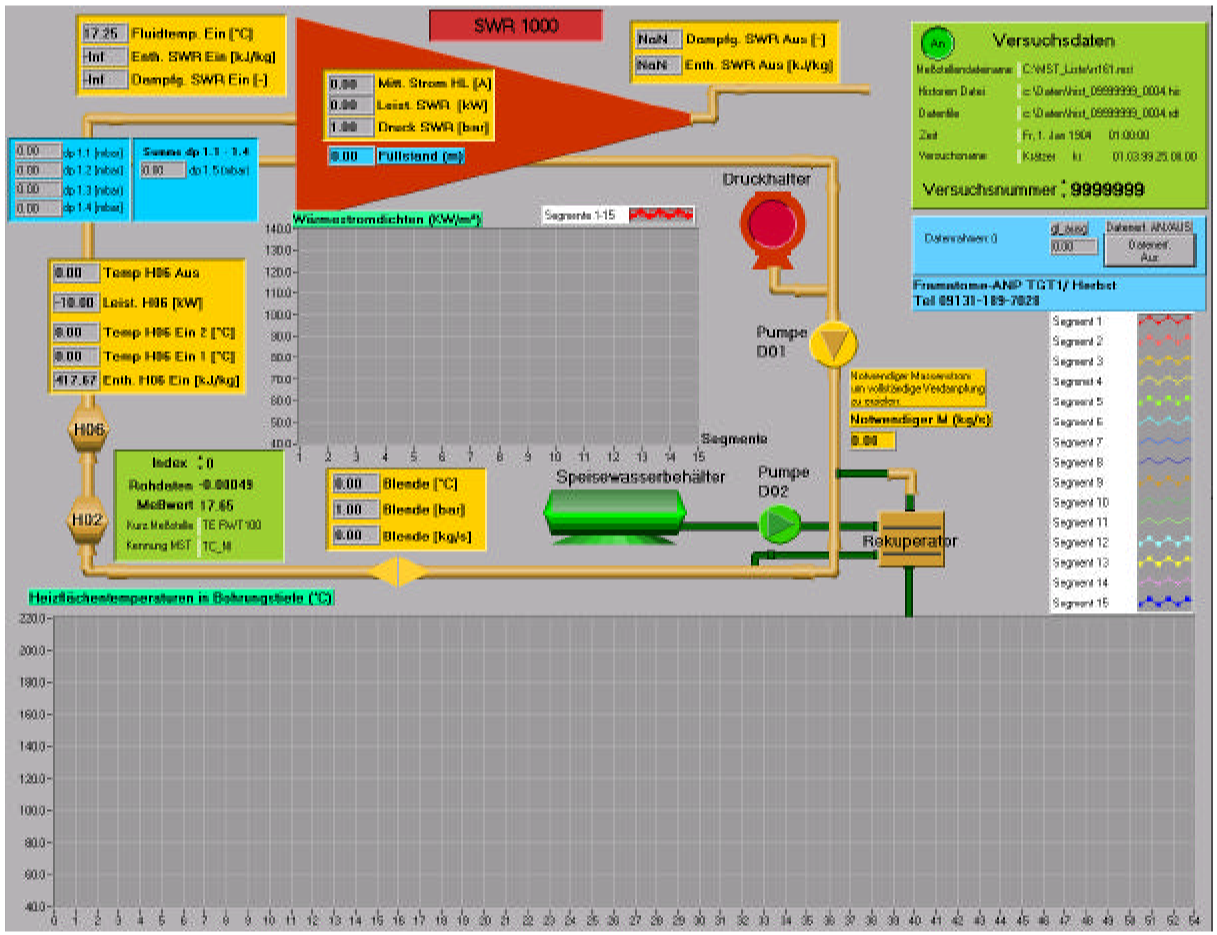
External Vessel Cooling Test
- Measuring Equipment, Power Supply

The measurement of voltage and current supplying the heating wires is part of the BENSON test rig instrumentation.

- *The functioning of this has been checked during test running in August 2002*
- *Within further tests in the following years this standard instrumentation will be checked regularly again*

External Vessel Cooling Test
Data Acquisition Software (1)

Online display



External Vessel Cooling Test
- Data Acquisition Software (2)

"Quicklook"