Benchmark on HE-FUS3: Lessons learned from MELCOR calculations
Villigen, Switzerland
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1st Meeting of the « European MELCOR User Group »

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Outline

- RAPHAEL
- SP6-ST « SafeTy »
- HE-FUS3 Helium Loop
- HE-FUS3 benchmark analysis

RAPHAEL

> The present V/HTR Project of FP6

- RAPHAEL = ReActor for Process heat, Hydrogen And ELectricity production
- Integrated Project (divided in 8 sub-projects)
- Total budget ~ 20 M€, 34 partners from 10 countries
- Objectives : providing R&D results for
  - Consolidating generic V/HTR technologies
  - Exploring advanced solutions for improving HTR performances
    - higher temperature
    - higher fuel burn-up
    - Improved competitiveness
    - Extending the domains of application (electricity → co-generation of heat and electricity)

SP6-ST "SafeTy"

> WP1 - Objectives

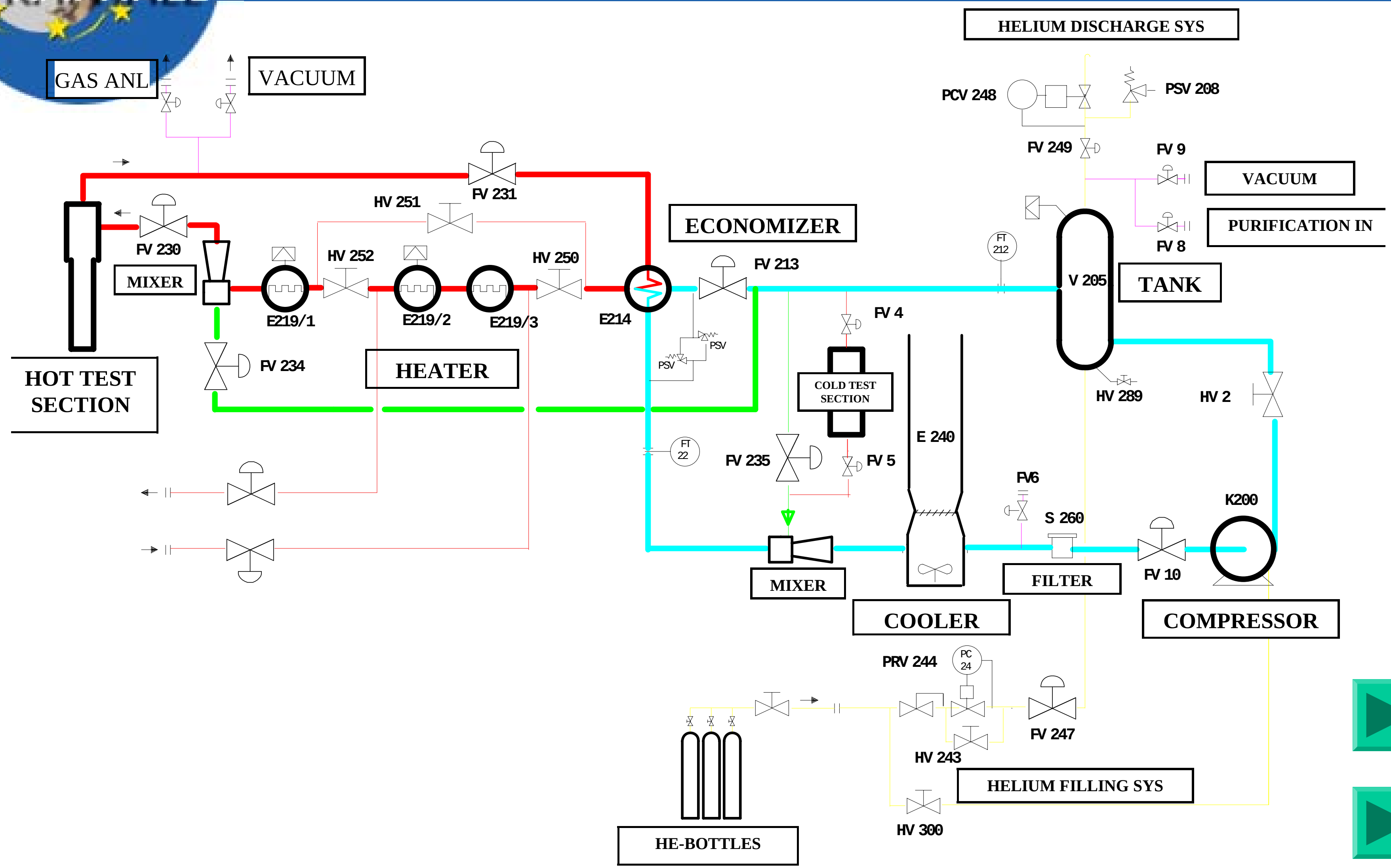
- 'Code Validation of V/HTR reactors' i.e. to assess the safety analysis applicability of the thermo-fluid dynamics codes

	Participants	Codes
EVO benchmark	VUJE/CEA	CATHARE
EVO benchmark	IKE	FLOWNEX
EVO benchmark	NRI	RELAP5/mod3.2
HE-FUS3 benchmark	ANSALDO	RELAP5/mod3.3
HE-FUS3 benchmark	AREVA	MANTA
HE-FUS3 benchmark	IRSN/CEA	CATHARE
HE-FUS3 benchmark	TE	MELCOR 1.8.6

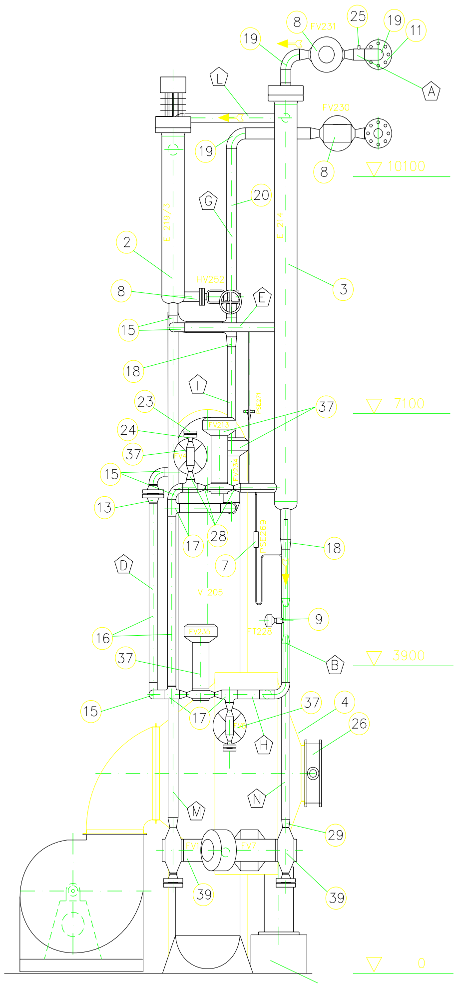
- HE-FUS3 (European Helium Cooled Blanket Test Facility) constructed at ENEA Brasimone in mid '90 for the thermo-mechanical testing of prototypical module assemblies of ITER reactor
- Loop characteristics/configuration not prototypical of V/HTR design
- But useful to assess the WP1 Objectives
  - He operating fluid, P_{max}= 10.5MPa and T_{max}= 530°C
  - Wide range of components : compressor, pipes, diffusers, valves, heaters and heat exchangers
  - Experimental data made available for the benchmark : 10 steady state tests for the T/H characterisation of the loop, 2 LOFA and a test campaign for the characterization of the helium compressor

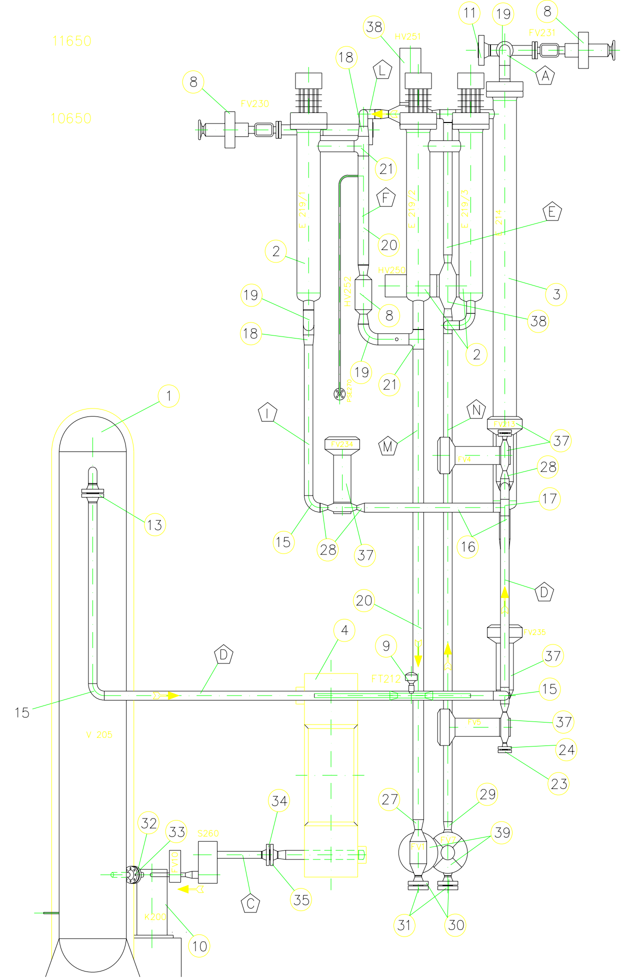
HE-FUS3 Helium Loop

> Facility description (1)



HE-FUS3 Helium Loop
> Facility description (2)

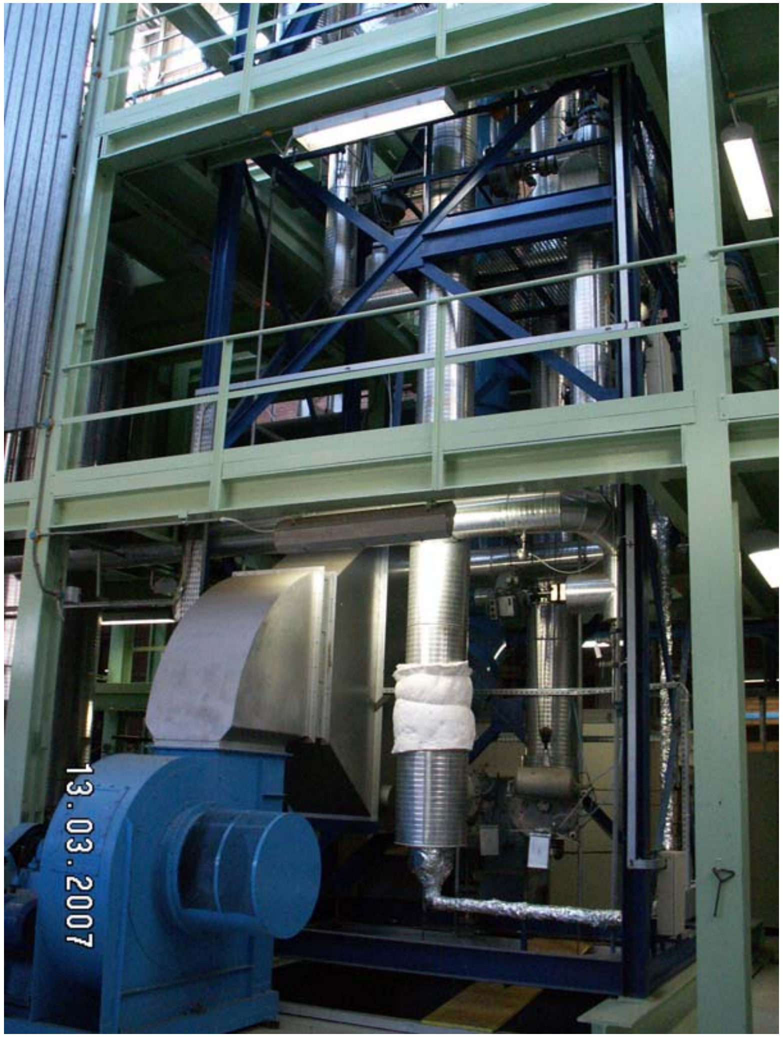




HE-FUS3 Helium Loop

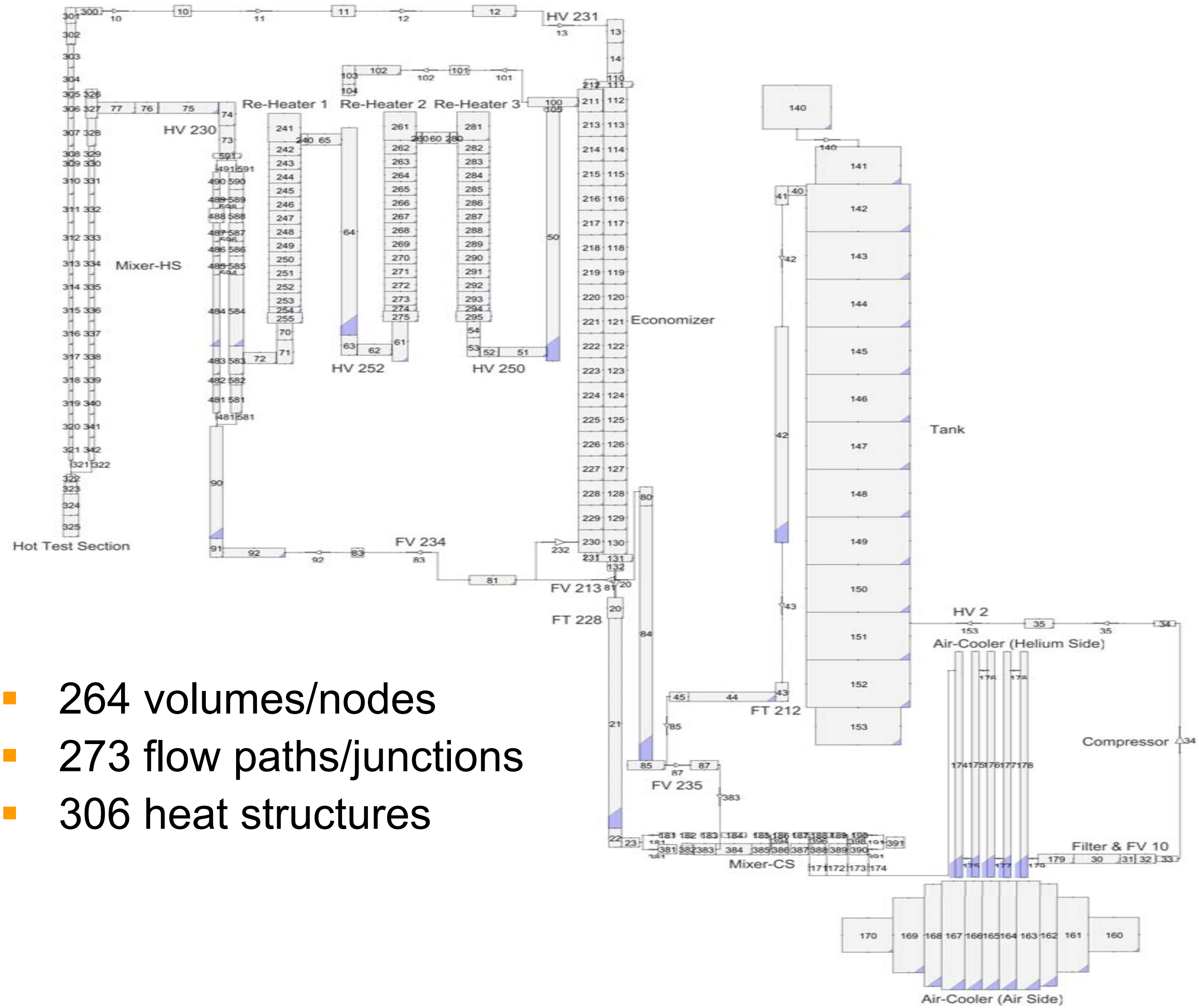
> Facility main performances

• DESIGN PRESSURE	10.5	MPa
• DESIGN TEMPERATURE	530	°C
• MAX TEMPERATURE OUTLET T S	530	°C
• MAX TEMPERATURE INLET COMPR.	100	°C
• COMPRESSOR HELIUM FLOW RATE	0.05-0.35 kg/s	
• MAXIMUM COMPRESSOR SPEED	18.000	rpm
• MAXIMUM COMPRESSOR HEAD	0.5	MPa
• COMPRESSOR ELECTRICAL POWER	136	kVA
• HEATERS ELECTRICAL POWER	210	kW
• ECONOMIZER THERMAL POWER	564	kW
• AIR COOLER THERMAL POWER	280	kW
• HELIUM TANK CAPACITY	3	m^3



HE-FUS3 Helium Loop

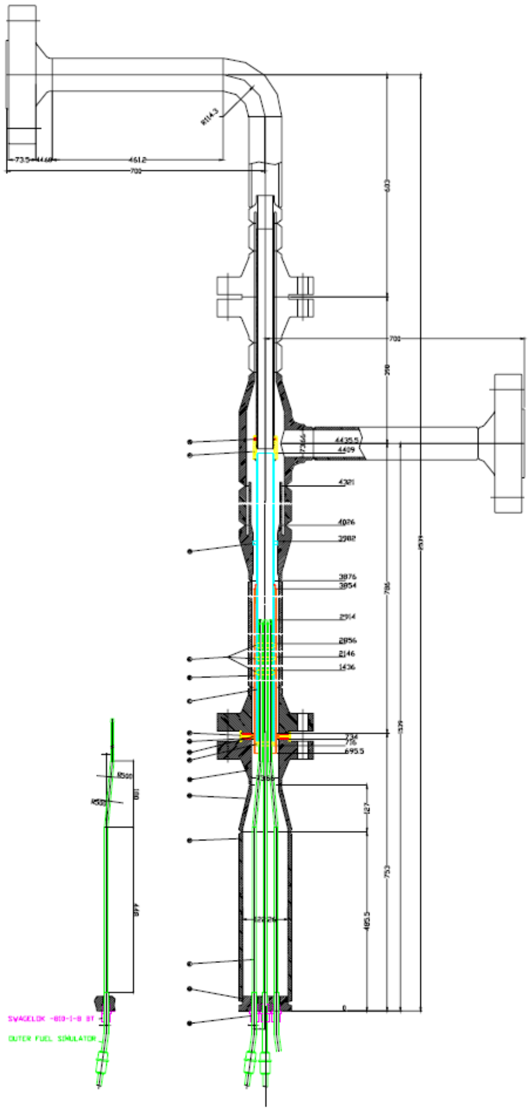
> MELCOR v.1.8.6 Noding

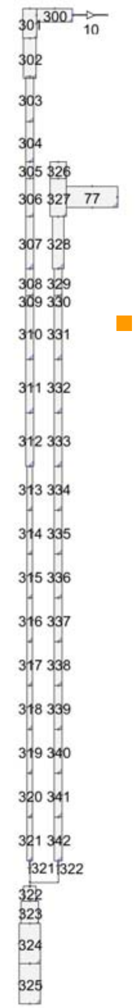


- 264 volumes/nodes
- 273 flow paths/junctions
- 306 heat structures

HE-FUS3 Helium Loop

> Components for code modelling – Facility Test Section Model (1)





Test Section Outlet

Test Section Inlet

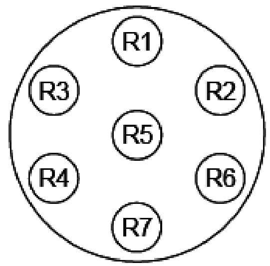
- Dimensionless K factor used, referred to the specific flow area
  - Originally assessed based on Idel’cik
  - Compared to calculated DP at 0.225 kg/s and 50 bar
    - TS annular part: 71 mbar
    - TS inner part: 215 mbar

HE-FUS3 Helium Loop

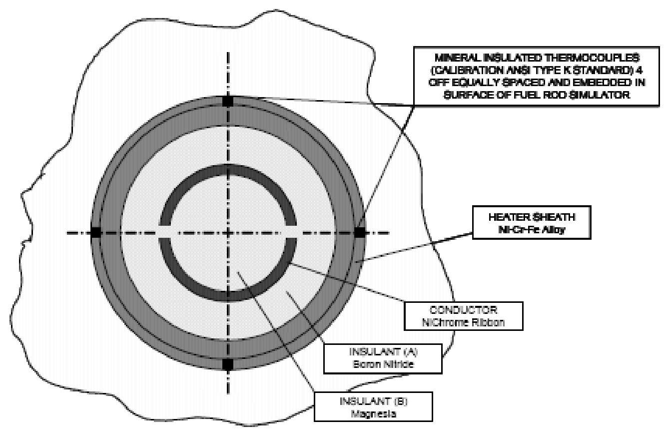
> Components for code modelling – Facility Test Section Model (2)

SENSOR	RESISTOR	SENSOR HEIGHT
TT400	R1	250
TT401	R1	750
TT402	R1	1250
TT403	R1	1750
TT404	R2	250
TT405	R2	750
TT406	R2	1250
TT407	R2	1750
TT408	R3	250
TT409	R3	750
TT410	R3	1250
TT411	R3	1750
TT412	R4	250
TT413	R4	750
TT414	R4	1250
TT415	R4	1750
TT416	R5	250
TT417	R5	750
TT418	R5	1250
TT419	R5	1750
TT420	R6	250
TT421	R6	750
TT422	R6	1250
TT423	R6	1750
TT424	R7	250
TT425	R7	750
TT426	R7	1250
TT427	R7	1750

Thermocouples location



Resistor arrangement



Resistor section

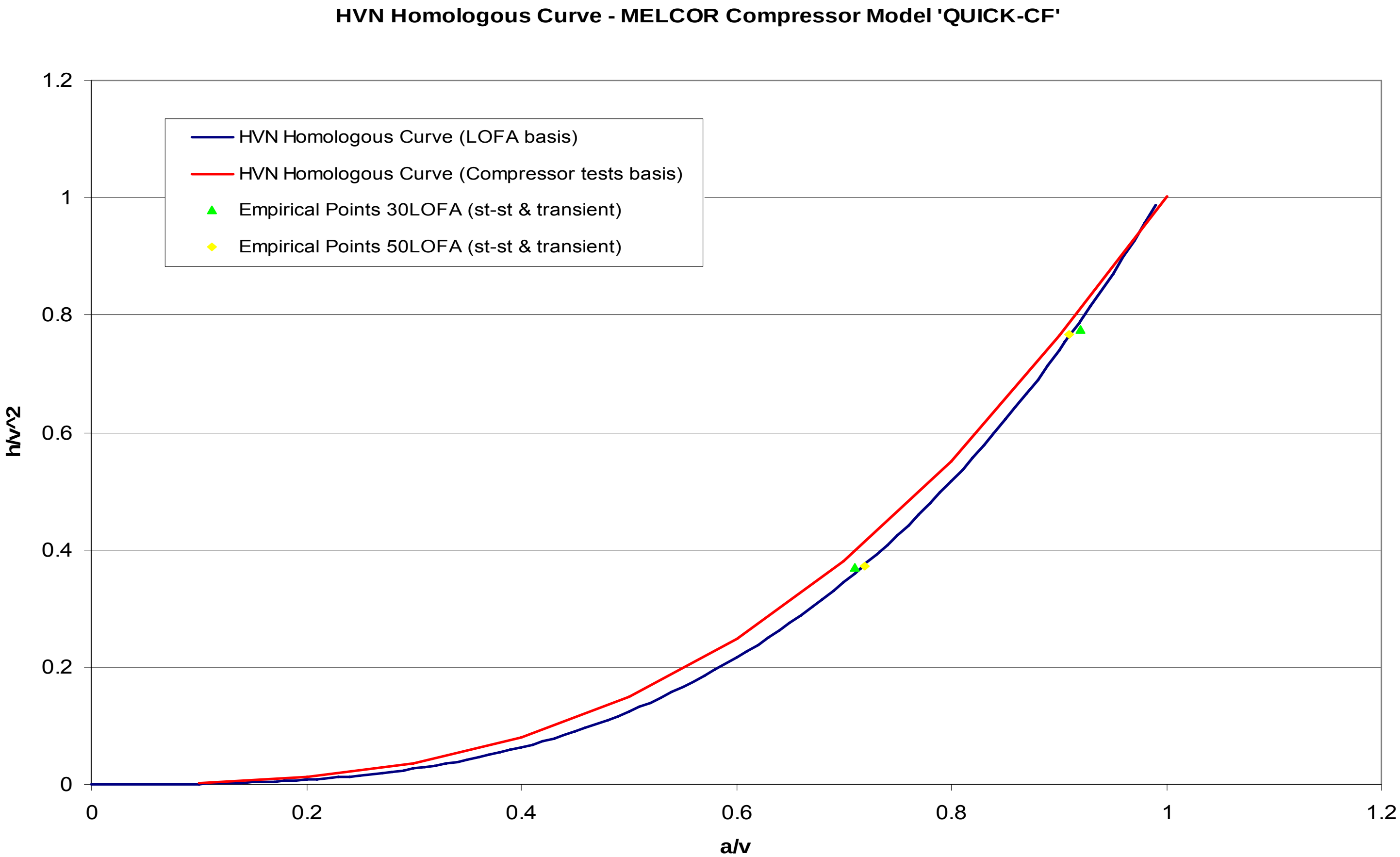
- Tubular pressure vessel and TS pipe modelled entirely with AISI 316; except for the Rock Wool thermal insulation of the TS
- The succesive materials layers inside the pins fully characterized
  - Insulators Magnesia and Boron nitride
  - Ni-Cr Ribbon
  - Ni-Cr-Fe heater sheath

HE-FUS3 Helium Loop
> Components for code modelling – Compressor Model (1)

- Compressor modelled as a MELCOR rotating pump component → "pressure boost" only
- Enthalpy source needs to be explicitely entered by user in volume downstream of the compressor → constant value sufficient for the current application (Power vs DP constant at constant compressor speed)
- Experimental compressor performance curve correlating dimensionless Head (h) and Torque (β) to dimensionless Flow rate (v) and Speed (α)
  - Actual values assumed as measured parameters
  - Rated head, Flow rate, Speed and Torque assumed as Design Compressor parameters
- The homologous curve theory is based on non-compressible fluid

HE-FUS3 Helium Loop
> Components for code modelling – Compressor Model (2)

- Modification of the HVN curve in order to fit LOFA experimental operating points



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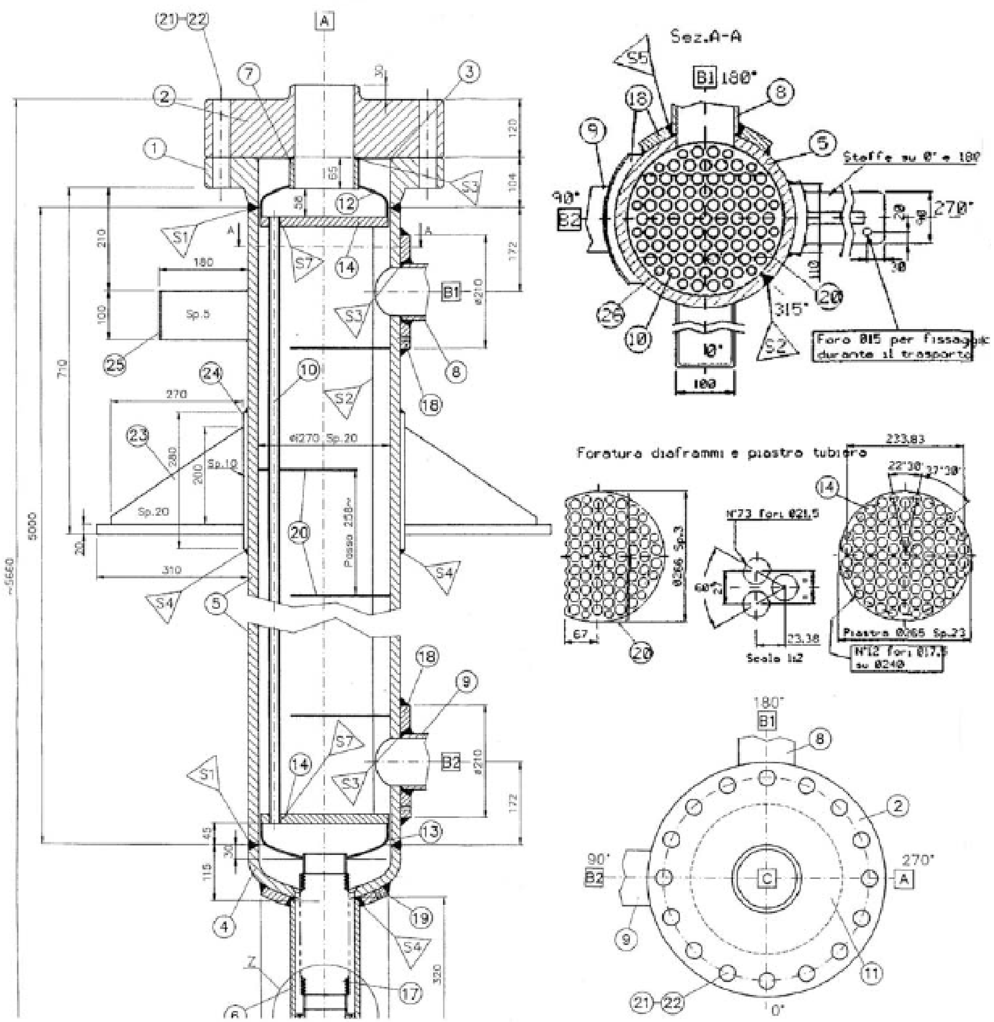
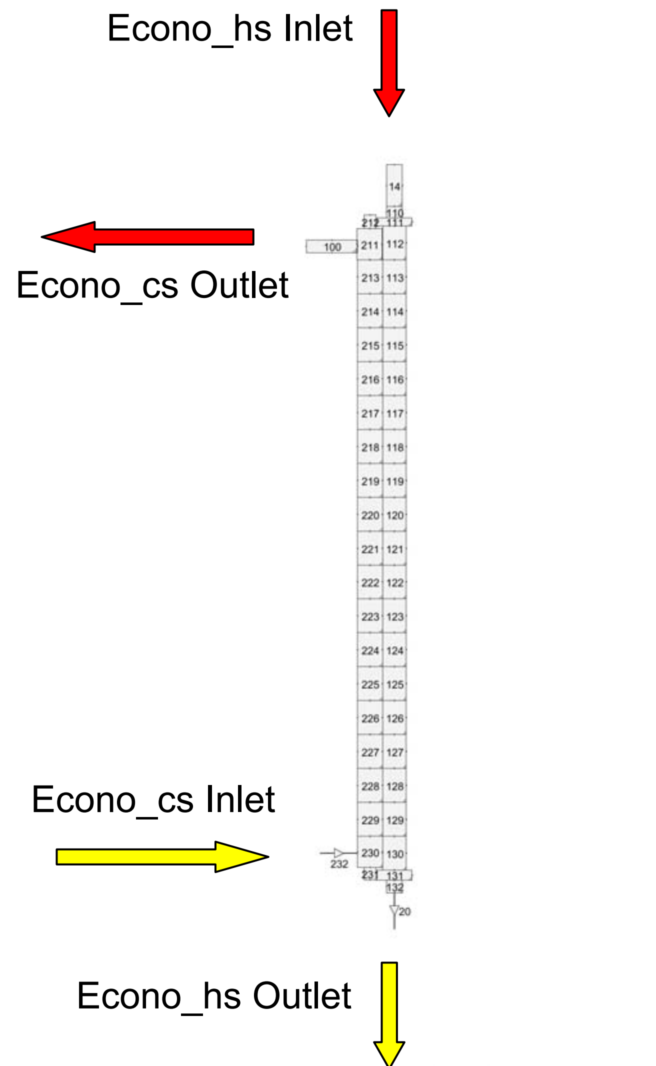
HE-FUS3 Helium Loop
> Components for code modelling - Economizer Model



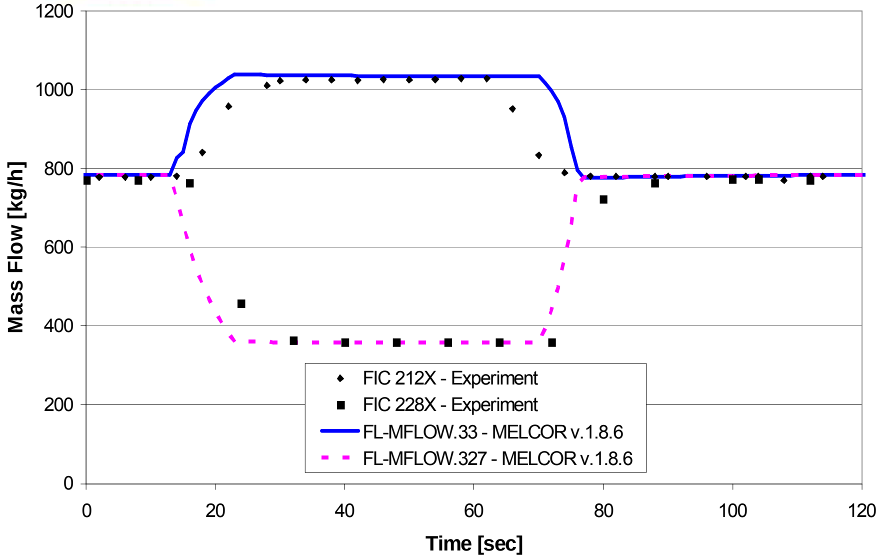


HE-FUS3 benchmark analysis

> Experimental data for benchmark

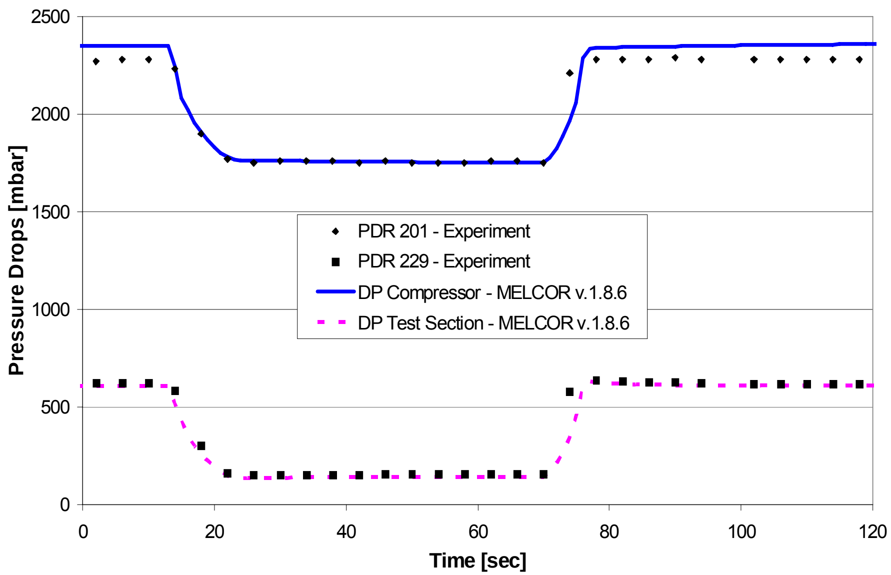
- 10 steady state tests : Pressure 25÷50 bar, Helium Mass Flowrate 0.1÷0.227 kg/s, Power 50÷130 kW, Helium Max Temperature 310÷520 C
- 2 Transient Tests (LOFA) obtained by opening a cold zone by-pass valve :
  - LOFA 30 : Power 71 kW (+ 8.4 kW), Pressure 50 bar, Helium Mass Flowrate from 0.217 to 0.1 kg/s in 20 s, Econo_hs Inlet Temperature from 356 to 394 °C.
  - LOFA 50 : Power 118 kW, Pressure 49 bar, Helium Mass Flowrate from 0.216 to 0.1 kg/s in 20 s, Econo_hs Inlet Temperature from 410 to 448 °C
- Compressor characterization tests for the whole range of mass flowrate, head and speed

HE-FUS3 benchmark analysis
> 50LOFA test results (1)



TS and compressor Mass Flowrate

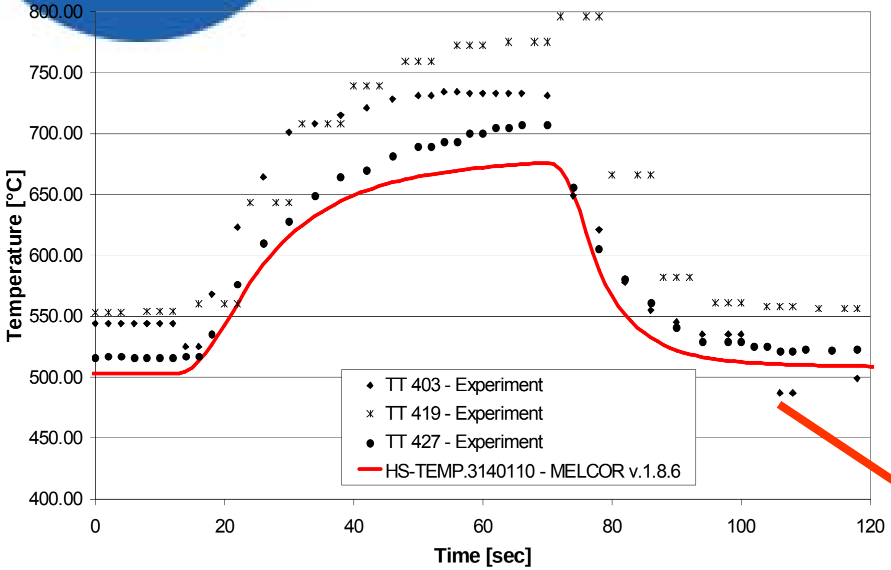
TS and compressor Pressure Drop



HE-FUS3 benchmark analysis

> 50LOFA test results (2)

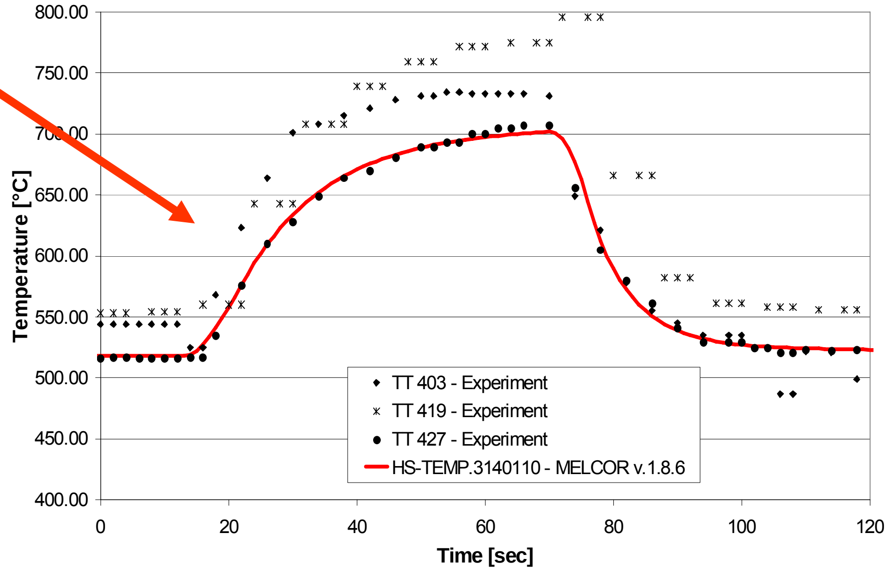
TS rods Temperatures at sensor height 1750 mm



- Correlation used in MELCOR to reproduce the heated metal rods temperature overestimates the heat transfer rate

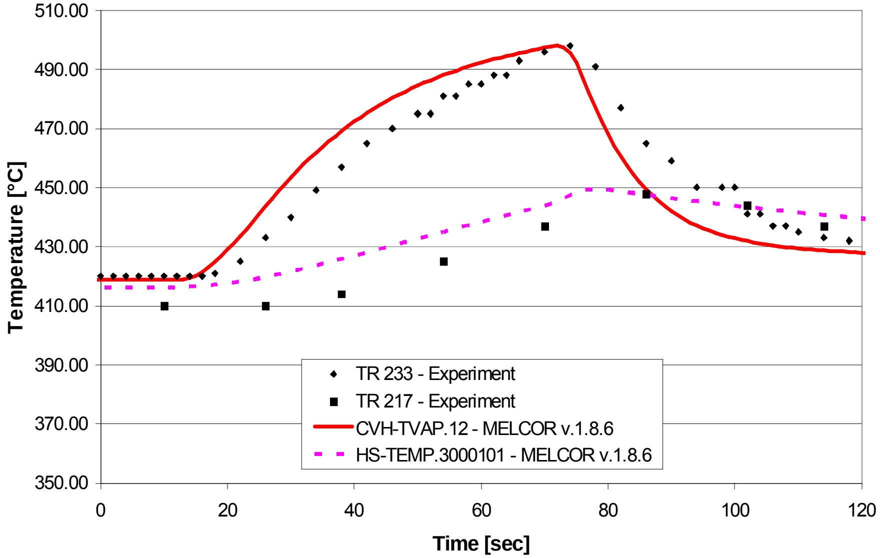
- Improvement of the correlation in case of heated vertical tube :

$$Nu = 0.021\, Re^{0.8}\, Pr^{0.4}\, (T_w/T_b)^{-1/2}$$



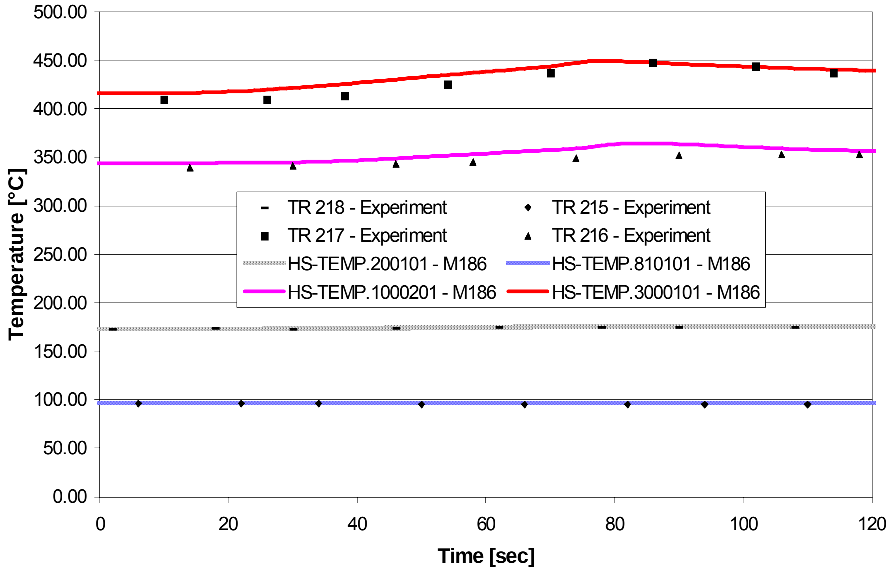
HE-FUS3 benchmark analysis

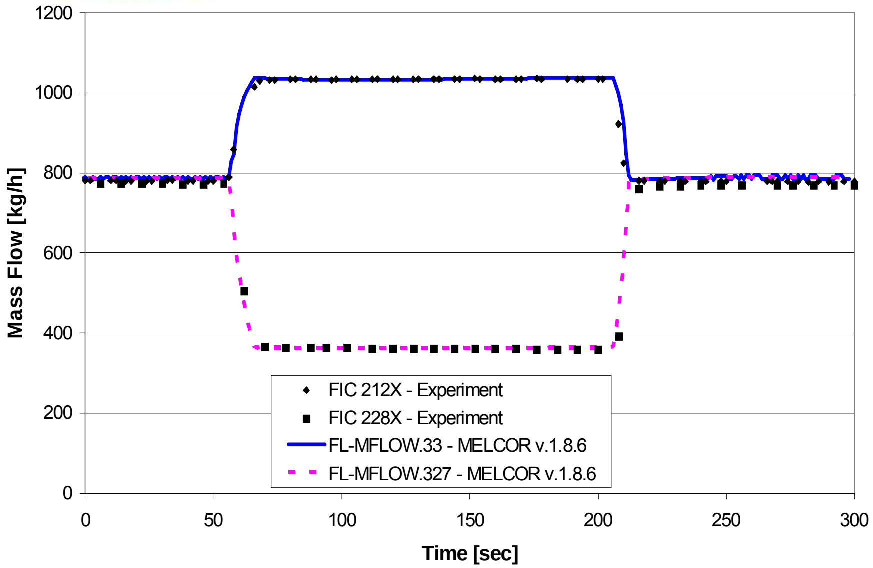
> 50LOFA test results (3)



TS outlet and Econo_hs inlet Temperatures

Econo hot and cold in- and out- let Temperatures





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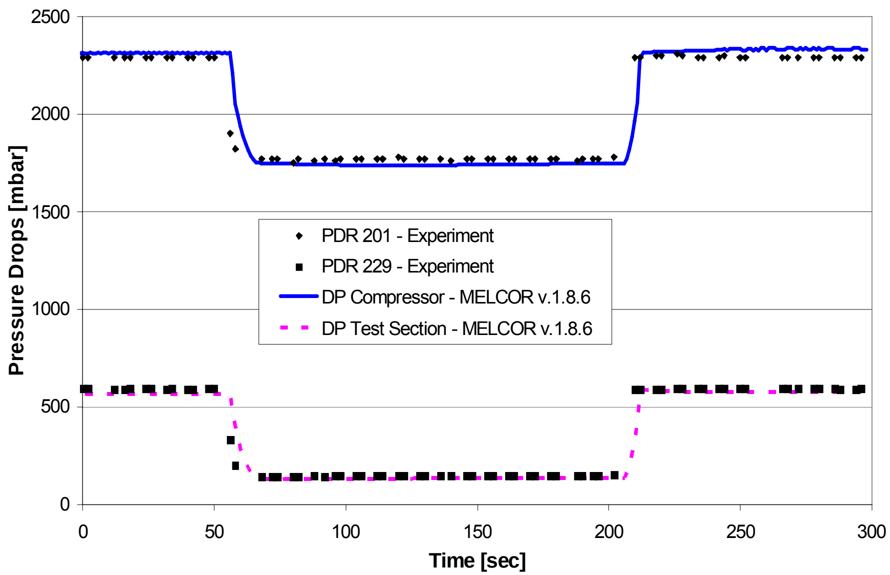
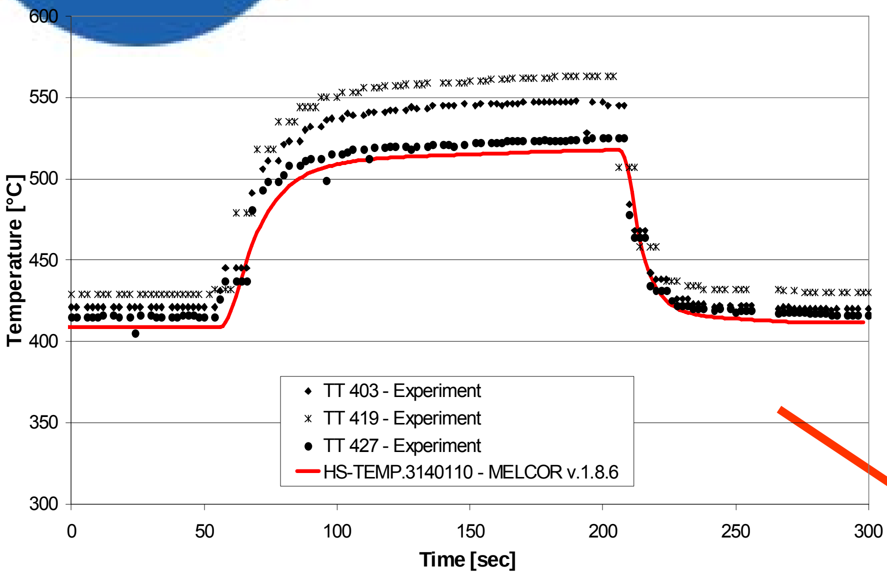


HE-FUS3 benchmark analysis

> 30LOFA test results (2)

TS rods Temperatures at sensor height 1750 mm



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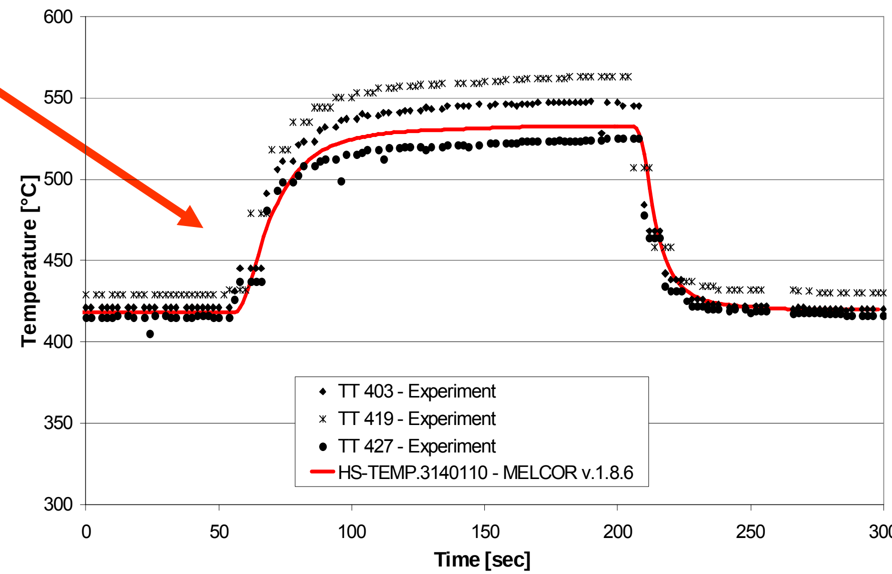

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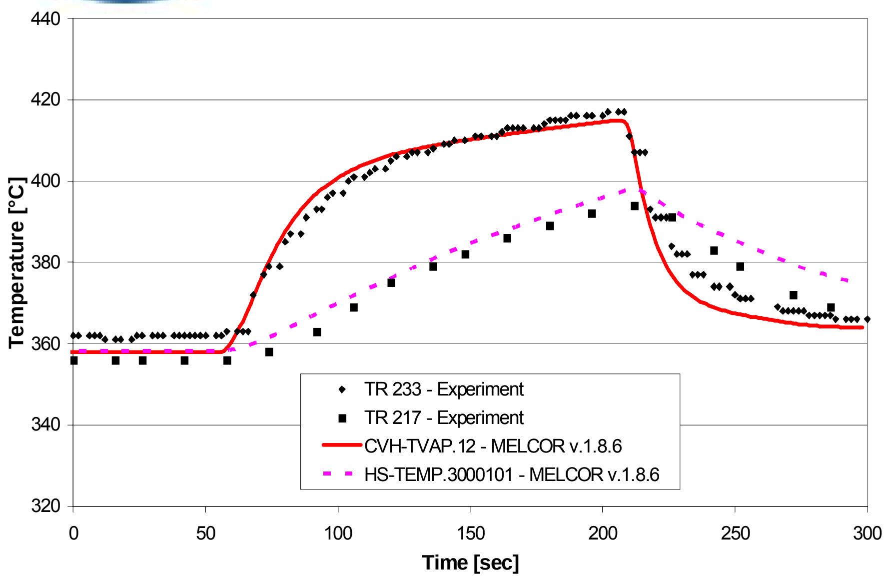

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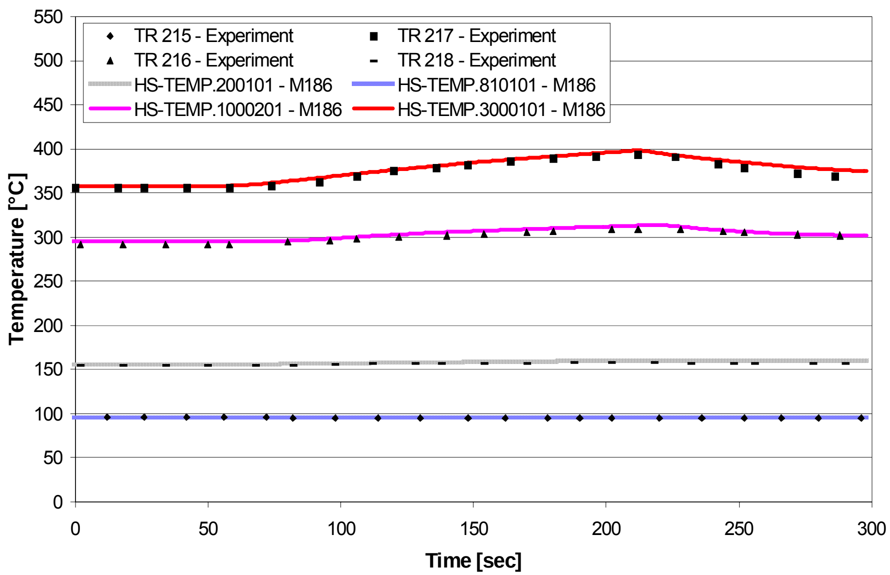

HE-FUS3 benchmark analysis

> Conclusion

- Results given by MELCOR 1.8.6 in good agreement with experiment
- Heat transfer correlations proposed by default in MELCOR lead to acceptable results, i.e. tube side of the IHX component
- However, heat transfer correlation at the economizer shell side and air-cooler air side has been adapted → necessity to provide MELCOR with specific and more versatile modules of HX for VHTR applications
- Correlation used in MELCOR to reproduce the heated metal rods temperature overestimates the heat transfer rate → improvement of the correlation in case of heated vertical tube
- Lack of real compressor model in MELCOR → turbomachinery models needed for VHTR applications