

Liquid metal facilities to investigate thermal-hydraulics and behaviour of materials up to sodium boiling





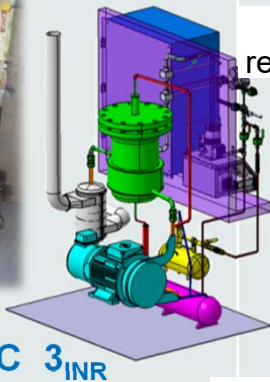

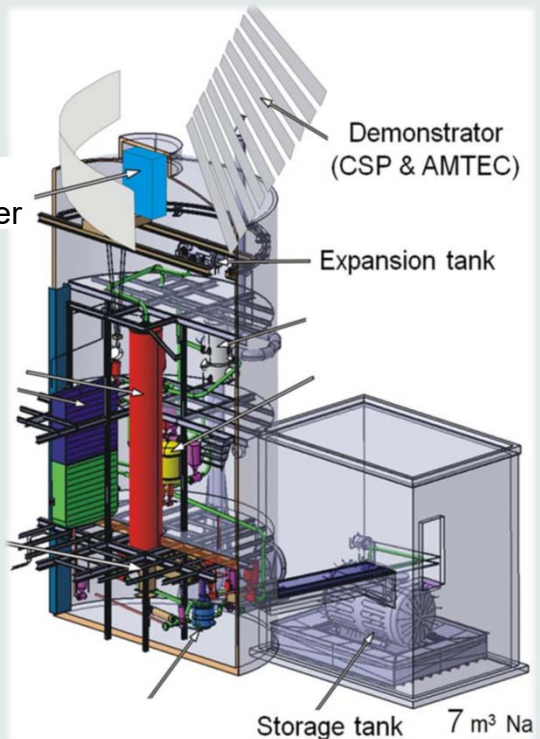
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Karlsruhe Institute of Technology

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Na – Facilities: Operating, Qualifying, Preparation, Design

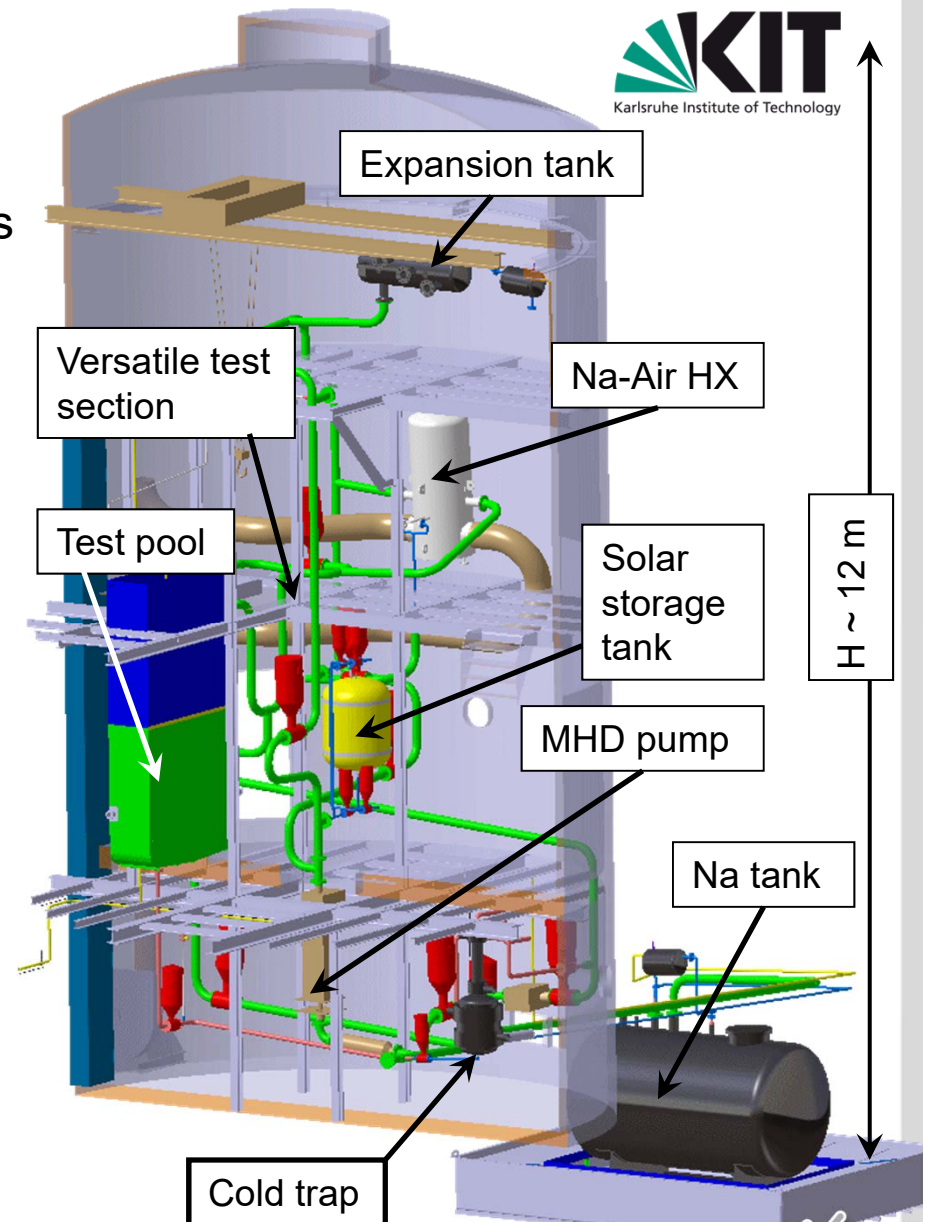
Basic physics (Electro-chemistry)	System level (Materials)	Medium Scale / Demonstrator
<p>AMTEC ATEFA →</p>   <p>← DITEFA</p>  <p>← KARIFA</p>	<p>„Energy“ - materials SOLTEC 1_{AWP} – 2_{IHM}</p>   <p>SOLTEC 3_{INR}</p>  <p>← MHD Pump</p> <p>← CORTINA_{AWP}</p>	<p>Thermal storage: KASOLA facility</p>  <p>Na-receiver</p> <p>Demonstrator (CSP & AMTEC)</p> <p>Expansion tank</p> <p>Storage tank 7 m³ Na</p>

KIT-INR – Overview liquid metal facilities

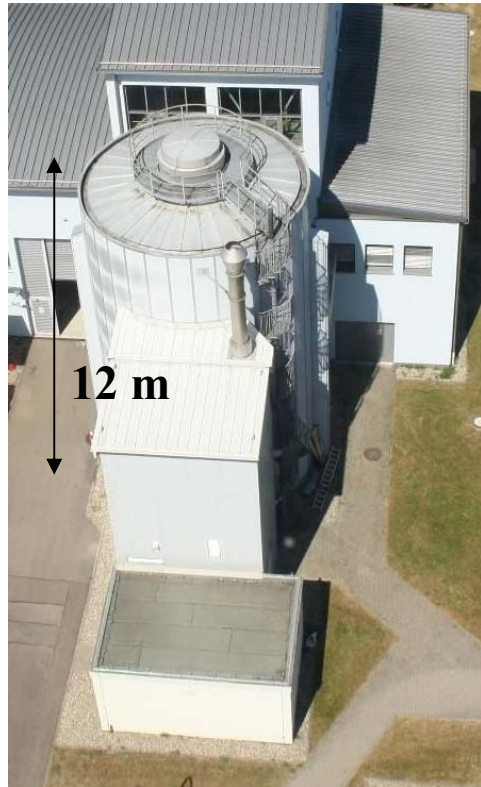
Facility (start Op.)	Purpose	Size	Power [kW]	Fluid (Vol)	Range [K]	Remarks
NECEX	Long term chemical compatibility/corrosion tests of steels	SET	~ 2	NaK	< 780	
NaKWET (2017)	Test of wetting of different surface structures and materials	SET	~ 2	NaK	< 630	
DITEFA (2017)	Qualification of instrumentation and flow diagnostics, education	small	< 2	GaInSn	< 320	
ATEFA (2017)	AMTEC test stand for single cell development	small	~ 2	Na ~ 4 l	< 1300	
SOLTEC 1 (2022)	8-shape loop for long term tests up to 1000 K, low cycle fatigue	small	~ 40	Na ~ 14 l	< 1000	Material/parts qualification
SOLTEC 2 (2018)	8-shape loop for long term tests up to 1000 K, fast transients	small	~ 40	Na ~ 14 l	< 1000	Material qualification
SOLTEC 3 (2022)	Single loop for long term tests up to 1000 K, receiver and AMTEC	small	~ 40	Na ~ 10 l	< 1225	Material/parts qualification
KASOLA (2018)	Large scale experimental infrastructure with three test ports	Mid-size	~ 400	Na, ca. 7000 l	< 820	Multipurpose NuSAFE, CSP,..
KARIFA (2022)	Small scale experimental facility for Na boiling tests	Small	~ 2	Na, ~ 2 l	< 1225	Na boiling

KASOLA facility (1)

- KARlsruhe SOdium LAboratory contributes to safety oriented EU-programs: ENSII+, SESAME, ESFR_ *smart*
- Total electric power: ~ 2 MW
- Sodium temperature range: 150°-550°C
- Sodium maximum flow rate: 150 m³/h
- Test-section: up to 6 m long
- Sodium amount: 7m³
- Backbone of KIT-sodium infrastructure (Na-storage, purification, distribution)
- Component and safety tests under real conditions
- Qualification of CFD and system codes



KASOLA facility (2)



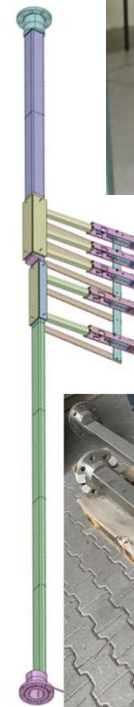
**KASOLA buildings
(aerial view)**



**Convection test section
Height ~ 6m**

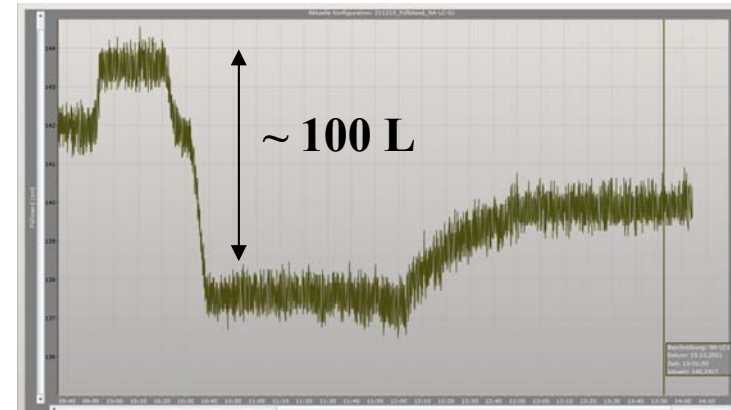


Machine room



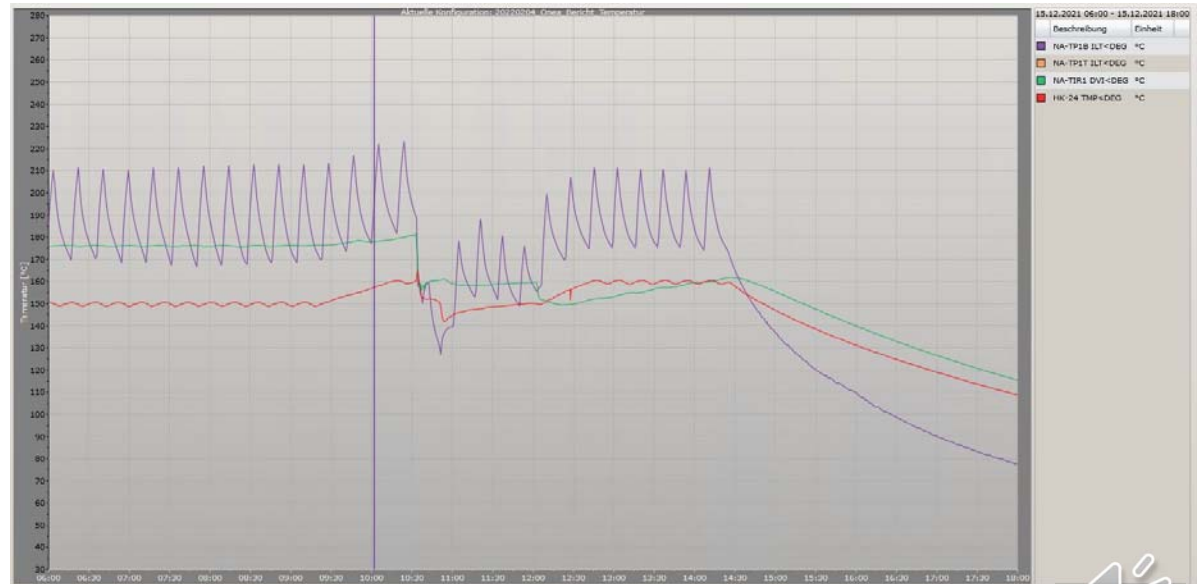
Backward facing step

KASOLA facility (3)

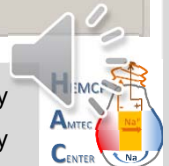


Na level (storage tank)

Na pressure level (storage tank)



Na temperature level



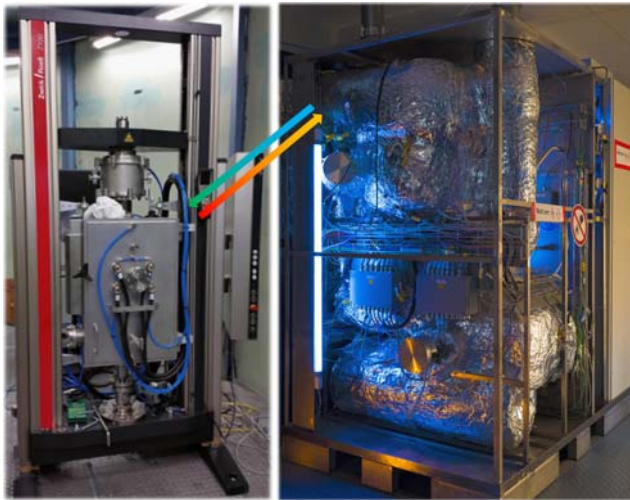
SOLTEC – Sodium Loop to Test materials and Corrosion



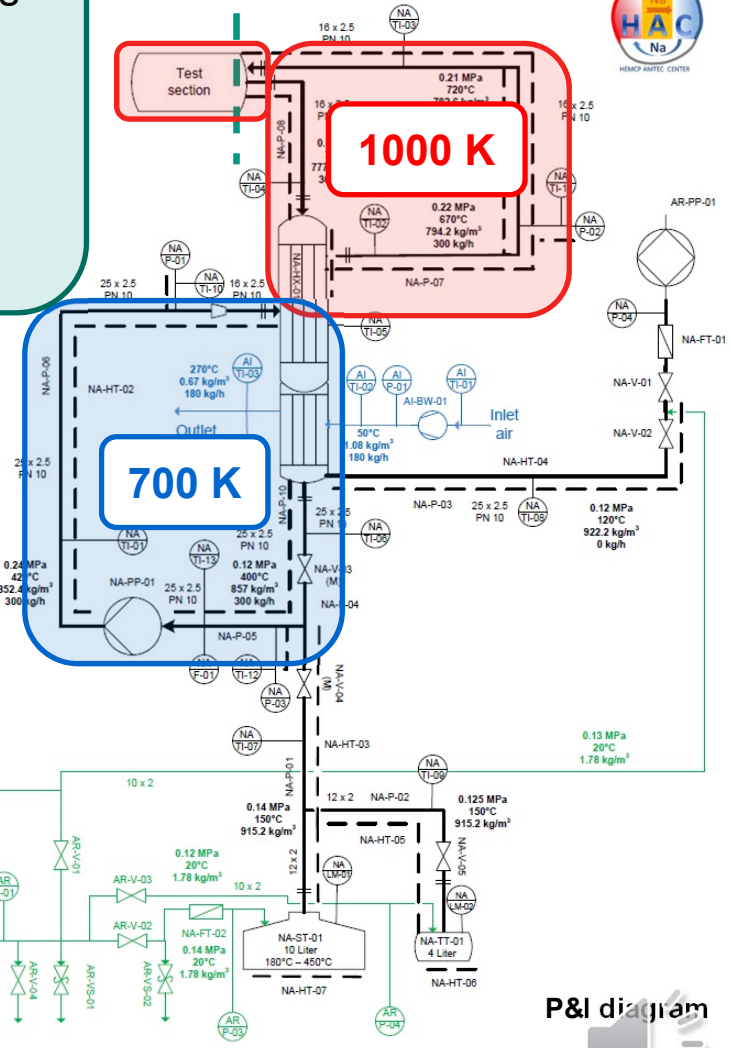
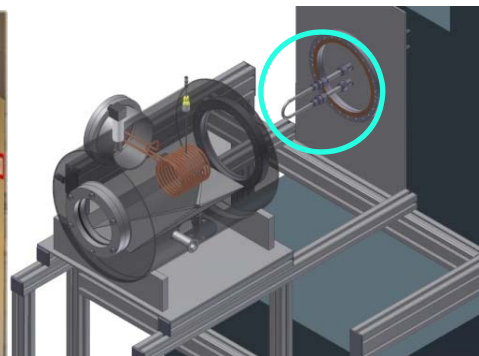
- Material qualification for high temperature applications:
- SOLTEC-1: Creep fatigue tests of innovative materials in hot Na (**unique**)
- SOLTEC-2: Corrosion/erosion tests for new steels
- SOLTEC-SOLAM: Long term tests for new thermoelectrical converters
- Set into operation: Mid 2018

Test sections:

Traction facility



Material test chamber



SOLTEC - Technical data

- Mass flow rate: 300 kg/h
 - S1: 4.8 m/s in test sample
 - S2: 1.0 m/s in test sample ($Re = 28600$, $300^{\circ}C$)
- Temperature: cold loop $450^{\circ}C$; hot loop $720^{\circ}C$, SOLTEC-3 SOLAM: $950^{\circ}C$
- Na inventory: ~ 14 L
- Max. pressure: 3.5 bar g
- Compact configuration: $1.2 \times 1.6 \times 1.9$ m³
- Main components:
 - Na-pump (3kW permanent magnet pump)
 - 7.5 kW Na-air HX & 27 kW Na-Na heat recuperator,
 - Storage tank (15 L) = expansion tank (particular feature)
 - 6.7 kW HT heater



LIMTECH Alliance
HEMCP: Helmholtz Energy Materials
Characterization Platform

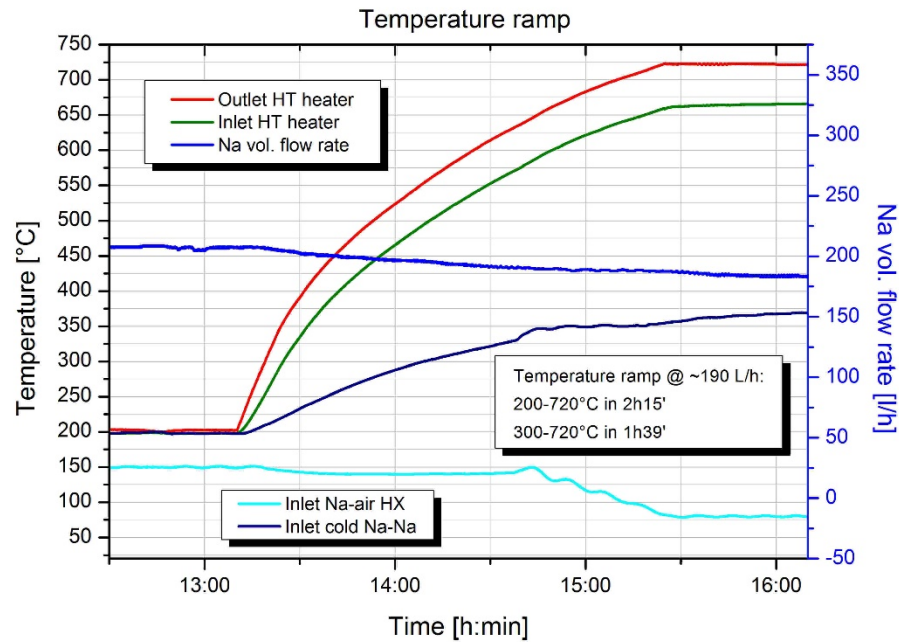


SOLTEC-2

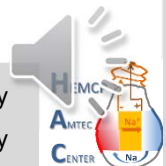
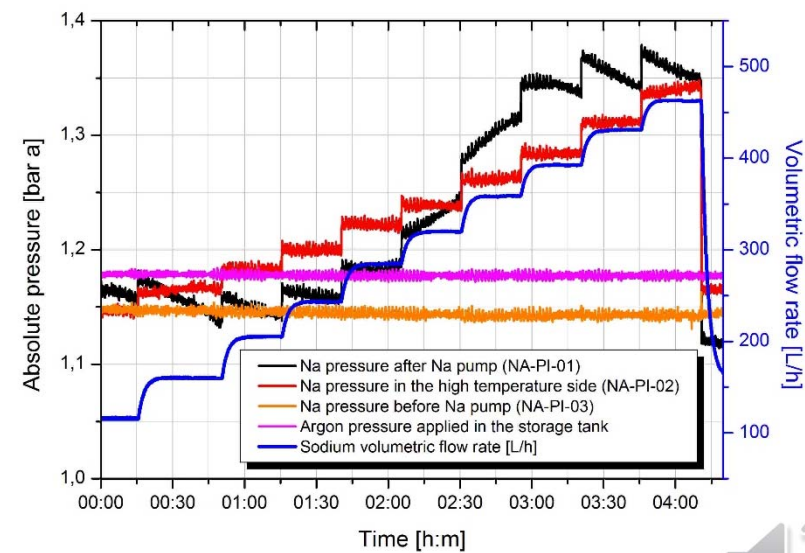
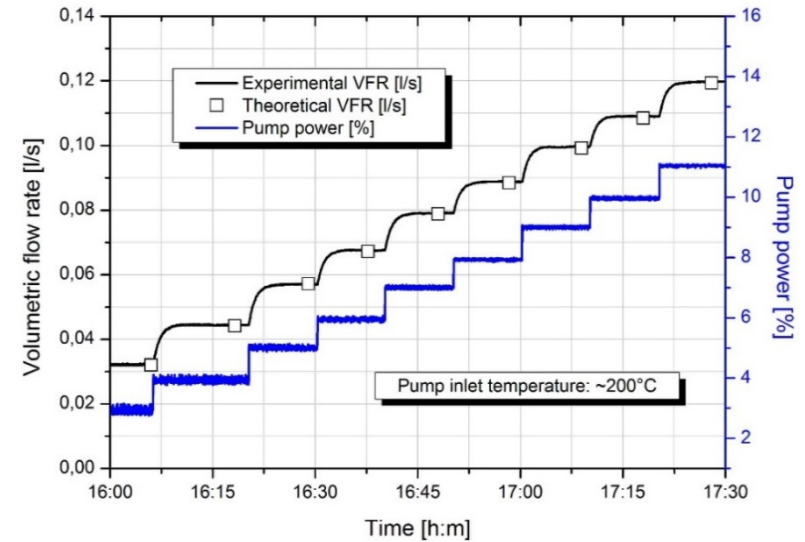
Manufacturing: SAAS GmbH, SOWEC GmbH



SOLTEC – Experimental data

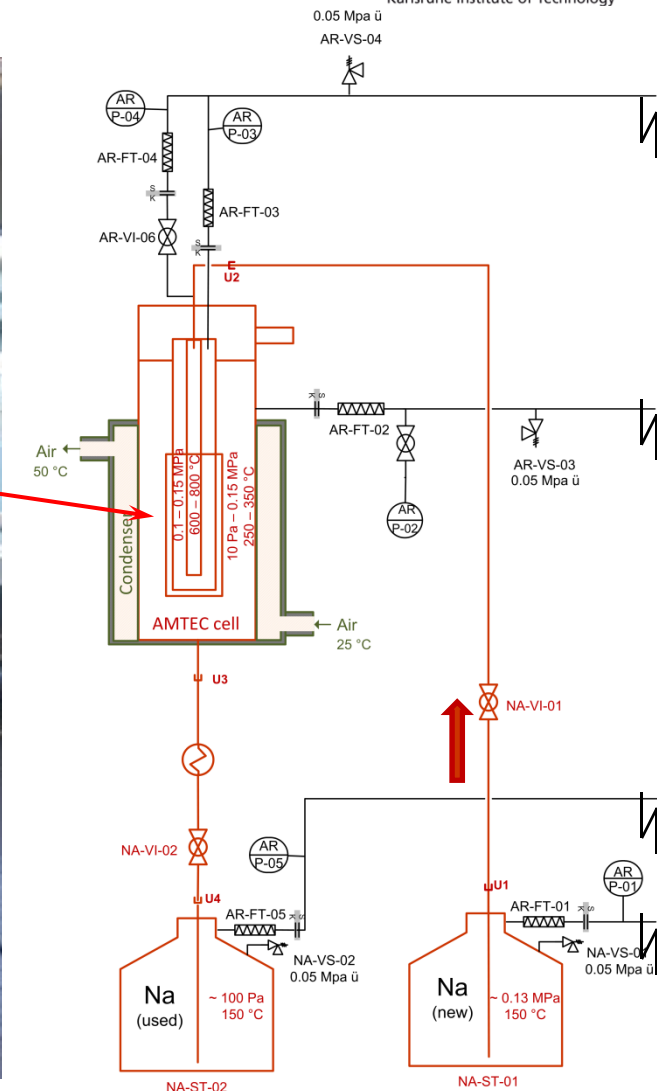


- Temperature ramp @ 190 L/h
 - 200 – 720°C in 2h 15'
 - 300 – 720°C in 1h 39'

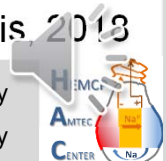


AMTEC Test Facility (ATEFA) *

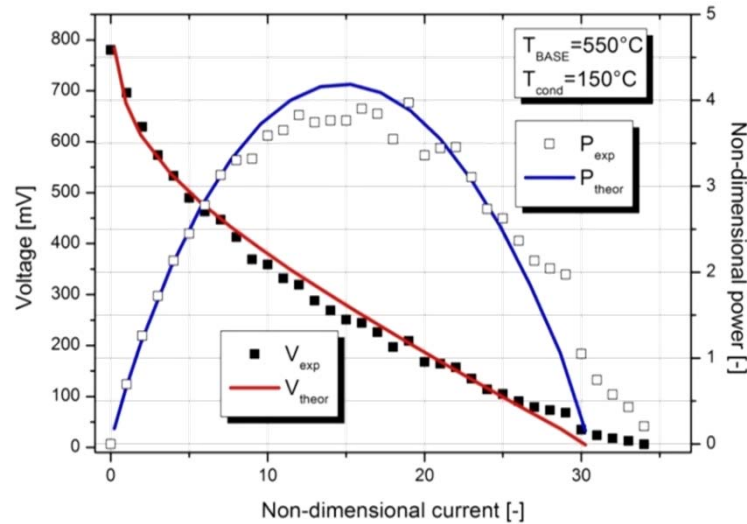
- AMTEC: Alkali-Metal Thermal-to-Electric Converter
- Ar pressurized induced Na flow
- Temperature range:
 - Loop: up to 300°C
 - Test cell: up to 1000°C
- Na flow rate determined by gravity and electrical power of the cell
- Na inventory: ~ 4 L
- Max. overpressure: 0.5 bar
- Compact configuration: 0.6 × 0.9 × 2.0 m³
- Main components:
 - Two storage tanks (~ 4,5 l)
 - Air cooled AMTEC test cell with inner heater



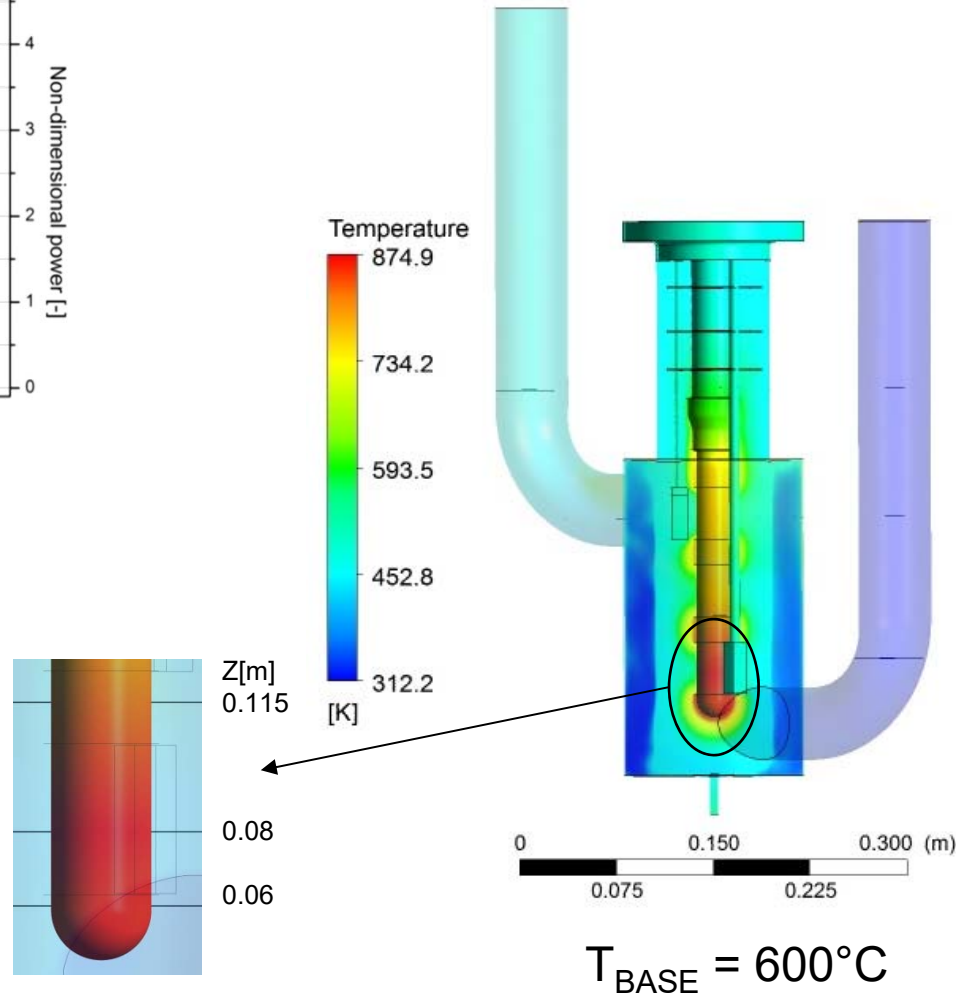
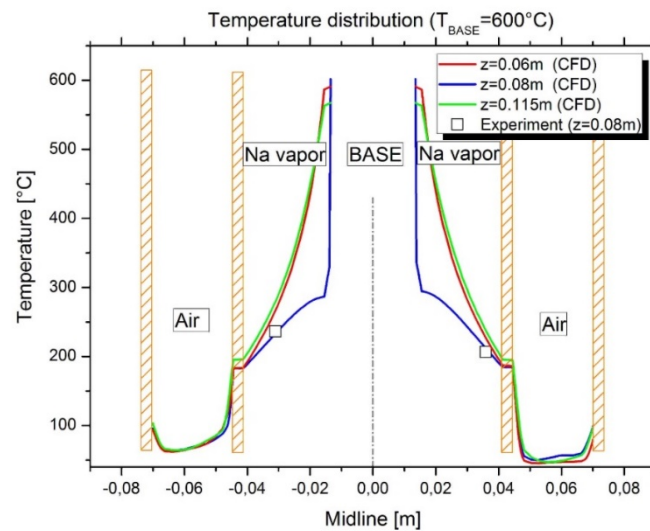
* N. Diez., PhD Thesis, 2013



ATEFA – Experimental and numerical data



AMTEC characteristic line



* A. Onea, PAMIR 11, 2019

Experimental tests of Na transport by capillarity

- Test of passive sodium transport in porous structures by capillarity
- Sample: powder sintered stainless steel (AISI 316L)
 - Porosity: 42 %
 - Pores: 20 μ m
 - 2 samples: 70 x 10 mm²



Experimental mockup



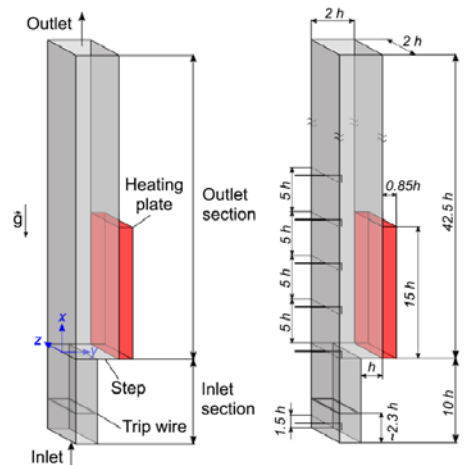
Insertion depth: 1cm

Sample before (left) and after (right) insertion in hot Na bath

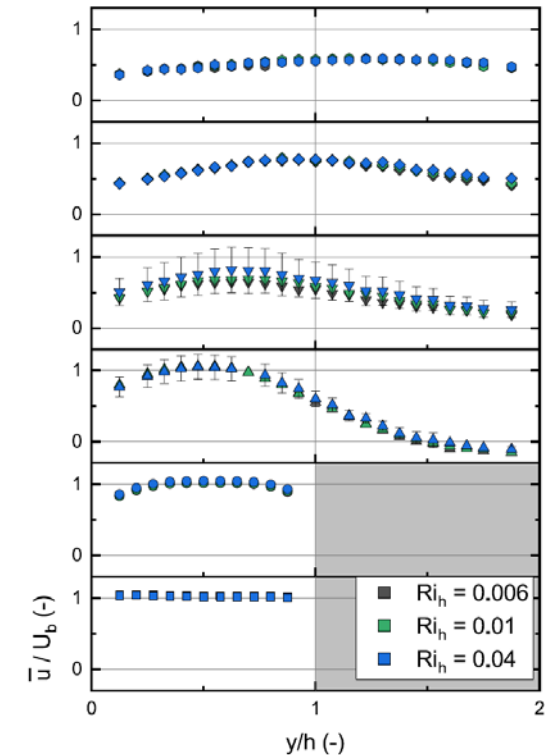
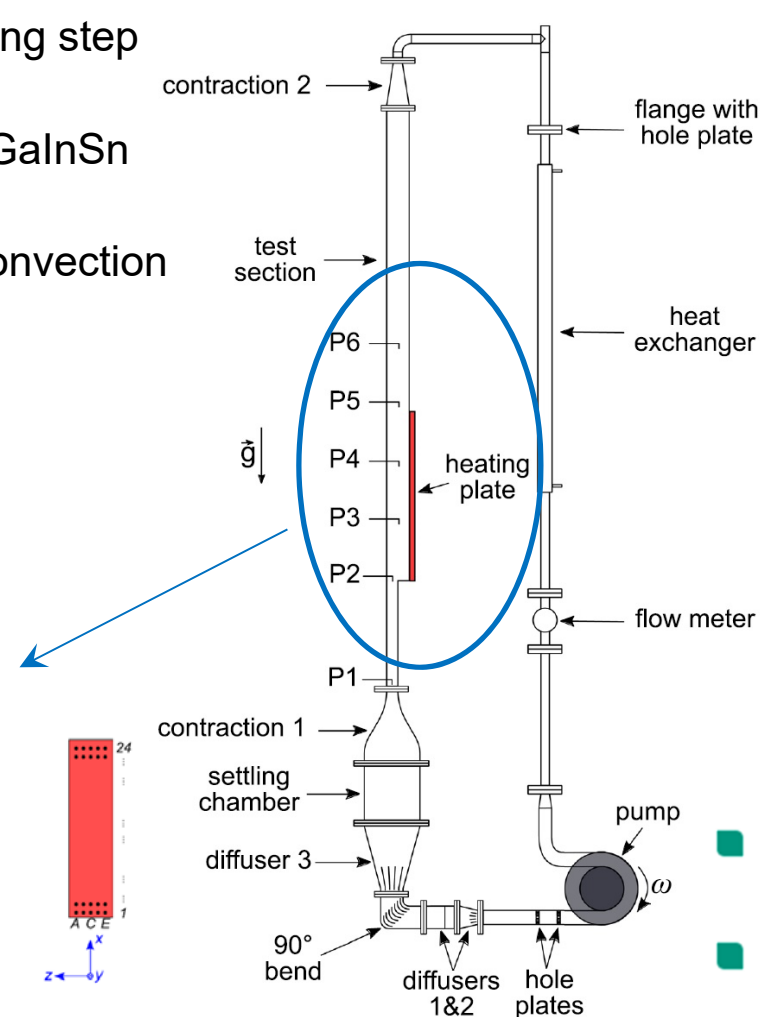
Mass [g]	Sample with inner TE channel	Sample without inner channel
Before experiment	58.87	57.712
After experiment	62.418	61.532
Mass gain	3.55 (~80% filling)	3.82 (~84% filling)

DITEFA *

- Test of backward facing step geometry
- Fluid: eutectic alloy GaInSn ($Pr \sim 0.03$)
- Forced and mixed convection regimes ($Ri_h < 0.3$)
- Re : 3800-76000
- Ri_h : 0.0028 – 1.14



Backward facing step test section



Vel. distribution $Re \sim 20000$

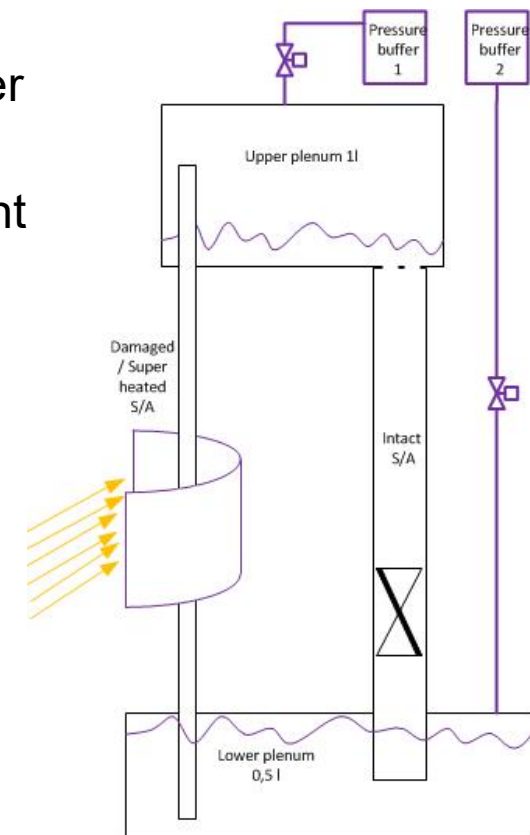
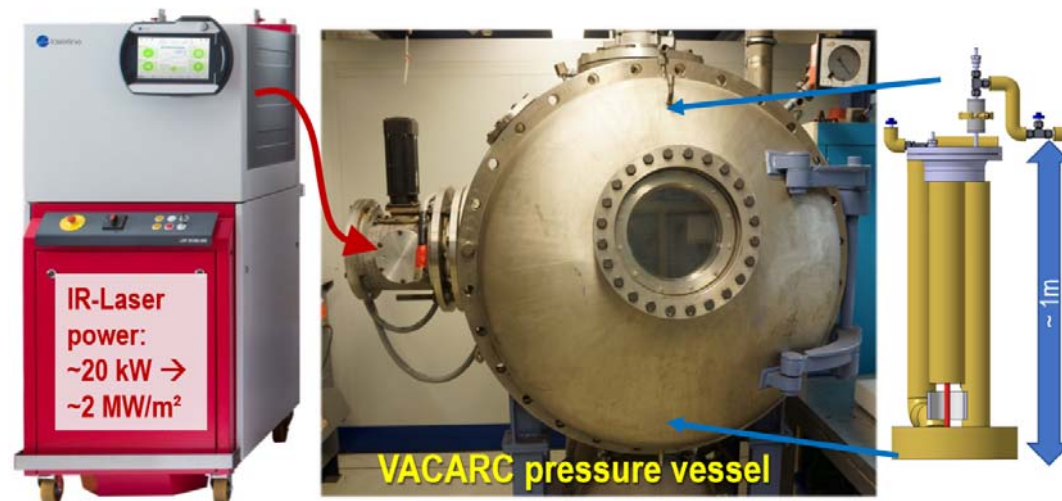
- Re independent vel. profiles ($10000 \leq Re_h \leq 30000$)
- Qualification of new permanent magnet probes

* Th. Schaub, Exp. Fluids, 2021



KARIFA – Karlsruhe Receiver test FAcility

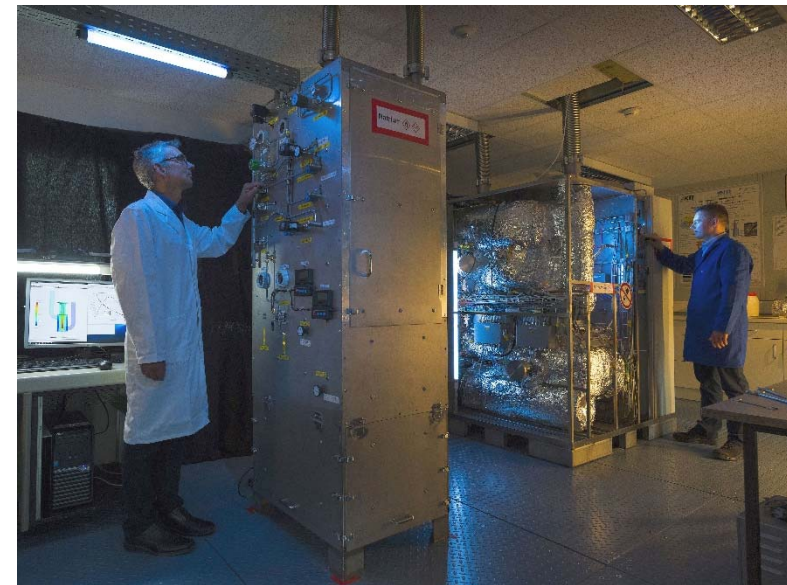
- Local Na boiling and dry-out experiments in single tubes
 - Detection of bubble formation & movement
 - Bubble collapse in upper plenum
 - Qualification of materials/components under power densities of 0,5 – 3 MW/m²
 - Heat pipe tests for DEMO divertor cooling segment
- 20 kW IR-laser beam



Conclusions

- KASOLA family -> large spectrum of sodium facilities to cover applications from basic physics (few liter Na) up to medium scale demonstrators (tonnes of Na)
- Wide temperature range, from RT (GaInSn) up to $\sim 1000^{\circ}\text{C}$ (Na)
- KASOLA facility ready for component tests with respect to core safety (flow transitions, passive shut down system)
- DITEFA and ATEFA adequate for education & training
- Robust safety concept, proven during last years of operation with no incident to be reported
- Successful qualification of new instrumentation sensor developed to measure turbulence quantities
- Code family used: TRACE, SAS-SFR, ANSYS CFX

Thank you for your attention!



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