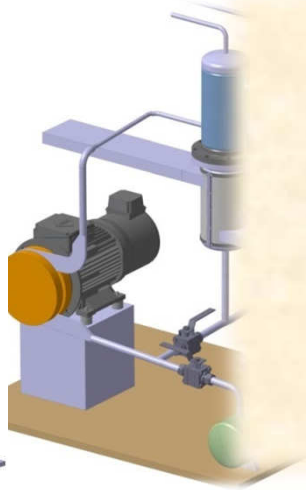
The Karlsruhe Sodium Laboratory KASOLA

17.03.2016

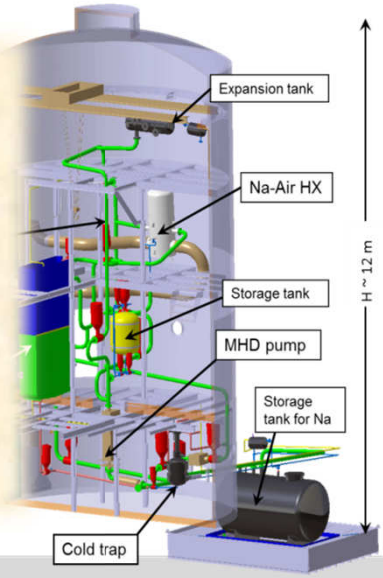
Wolfgang Hering, Angela Jianu, Sara Scherrer, Alexandru Onea, Martin Lux, Wadim Jäger, Maxime Haselbauer, Christoph Homann, Oliver Albrecht, Alexander Brecht, Robert Stieglitz

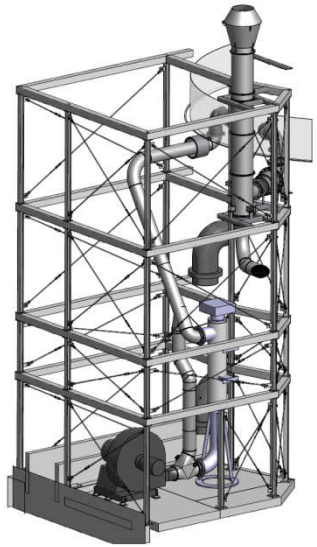
Generation IV International Forum, 14th SFR Safety & Operation PMB Meeting, 15-18 March 2016

Institute for Neutron Physics and Reactor Technology



KASOLA
- Objectives
- Facilities
- Experiments
- Summary





Objectives

Early Phase (2009-10)

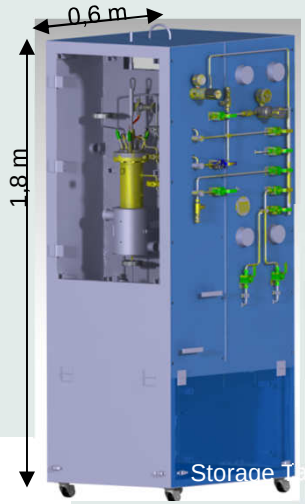
- Reestablish sodium technology at KIT (initially started in 1965)
- High quality data for CFD qualification
- Primary/secondary system behavior starting from full power (7-19 pins)
- Pool flow pattern in slab geometry (4x4x0,4 m, scale 1:2 - 1:3)

Modified after “phase out decision”

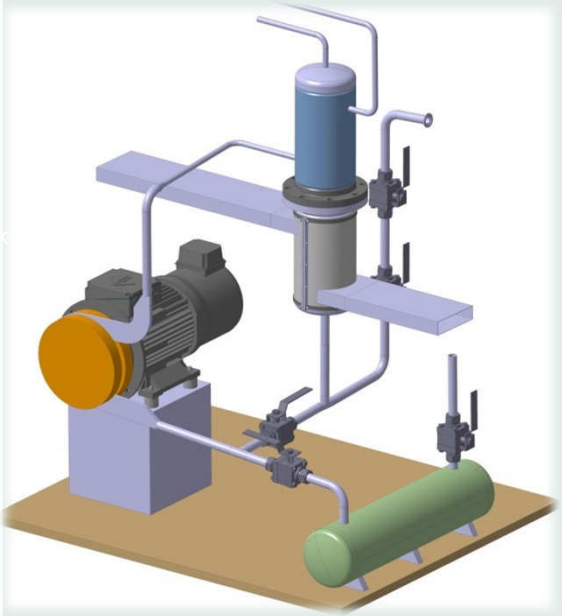
- General thermal hydraulics of liquid metals
- High temperature materials for energy technology
- Direct energy conversion using sodium
- Component development
- Sodium for concentrating solar power (CSP)

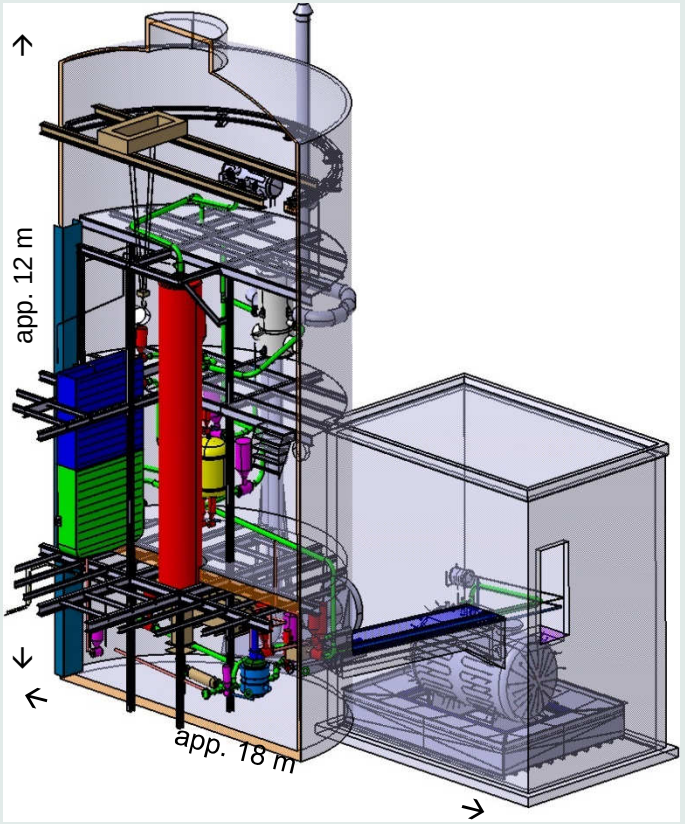
Facilities within KASOLA

Basic physics (Electro-chemistry)	System level (Materials)	Medium Scale / Demonstrator (Systems)
AMTEC ATEFA	**Innovative materials** SOLTEC I – III	**System dynamics** KASOLA facility



← DITEFA



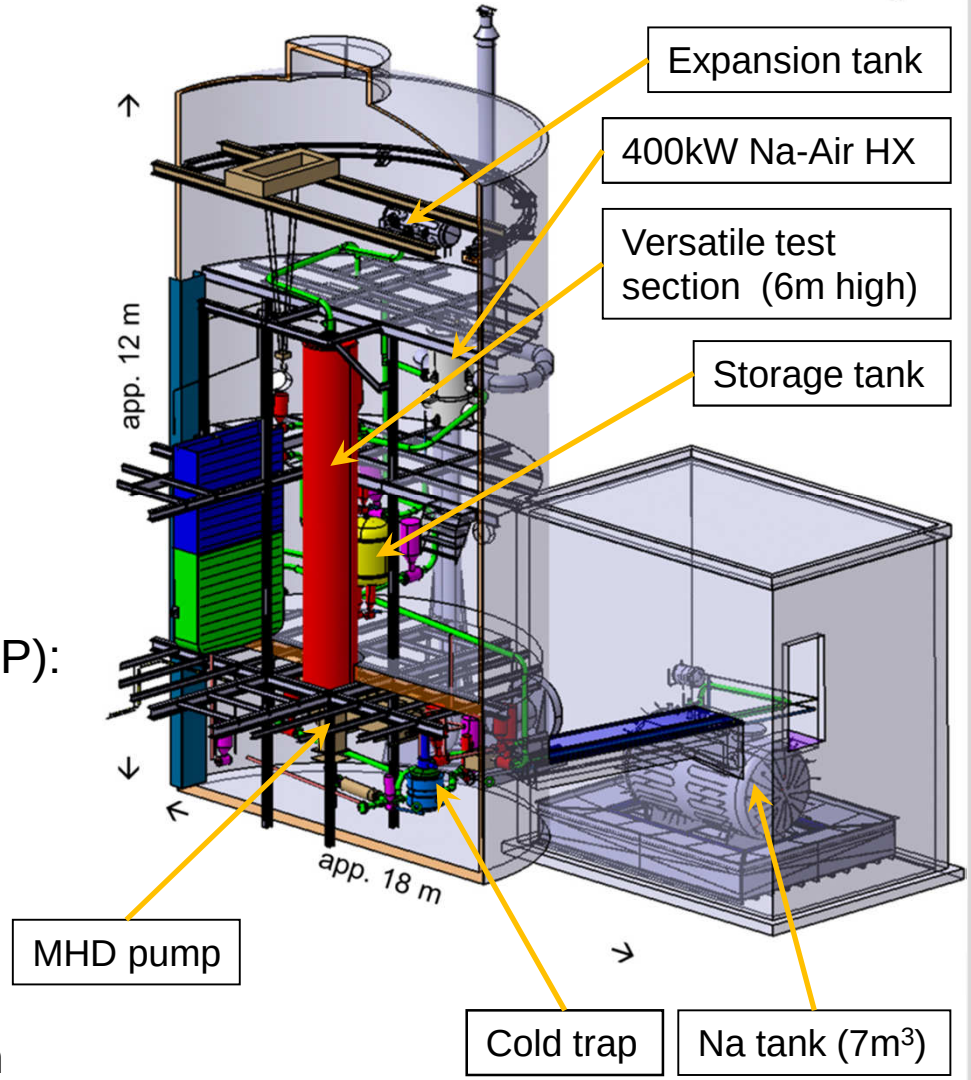


KASOLA- KArlsruhe SOdium Laboratory

http://www.inr.kit.edu/258.php

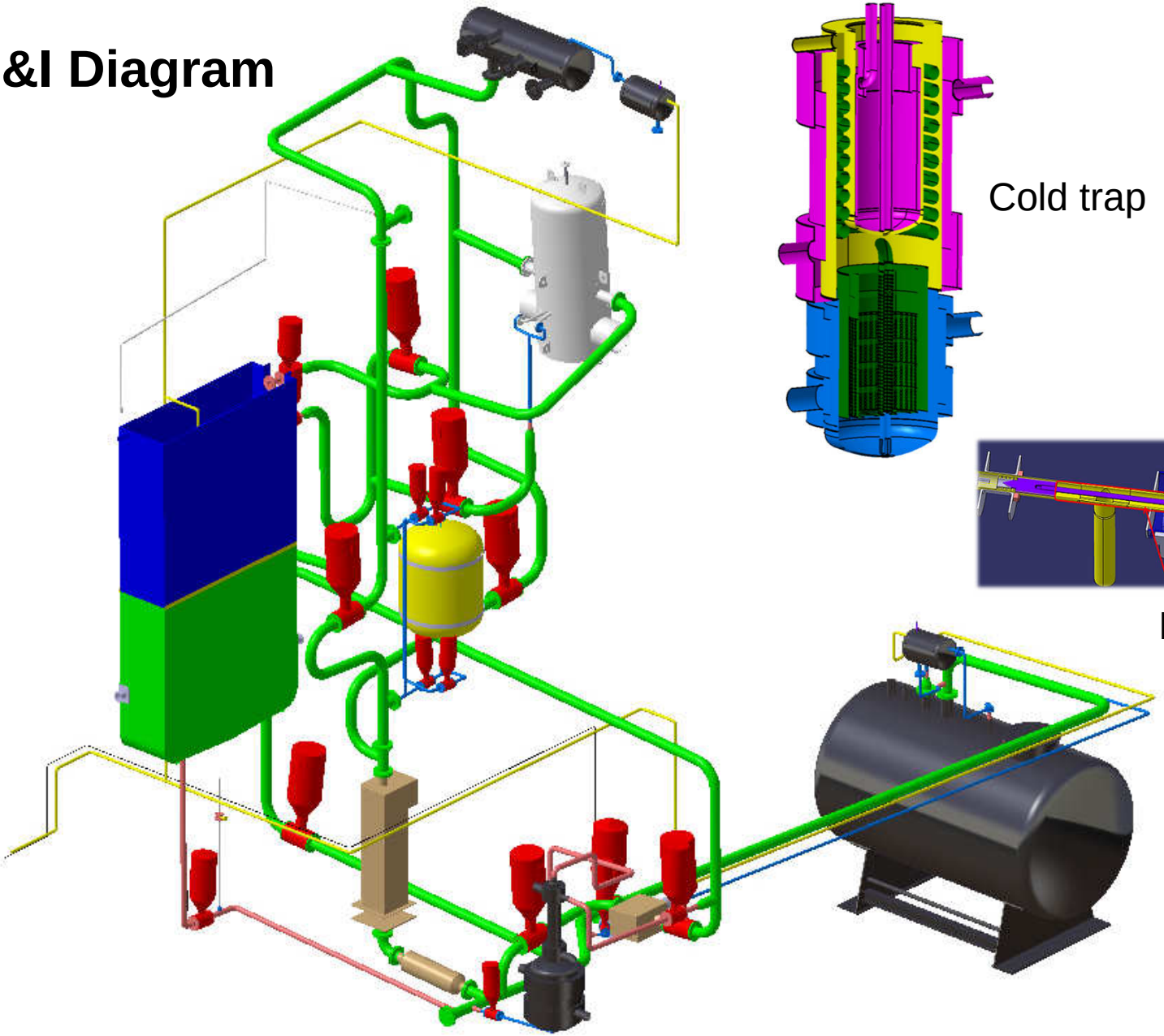
- Medium scale facility: ~7 m³ Na
- Na temperature range: 150°-550°C
- Na maximum flow rate: 150 m³/h
- Cooling power: ~ 400 kW
- Three test ports:
  - long test section: 6 m height
  - versatile port
  - auxiliary port

- Experimental tasks (LIMTECH, HEMCP):
  - Flow in a backward facing step
  - Model development and validation:
    - anisotropic heat transfer
    - transition between free, mixed, and forced convection
  - High temperature energy storage
  - AMTEC integration into an energy system

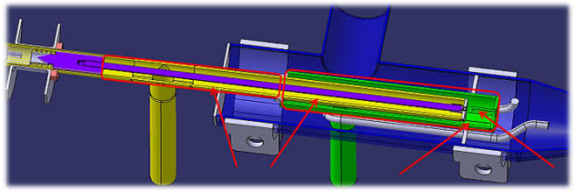


Institute for Neutron Physics and Reactor Technology
Facility design, System dynamics and Safety (ASS)

P&I Diagram



Cold trap



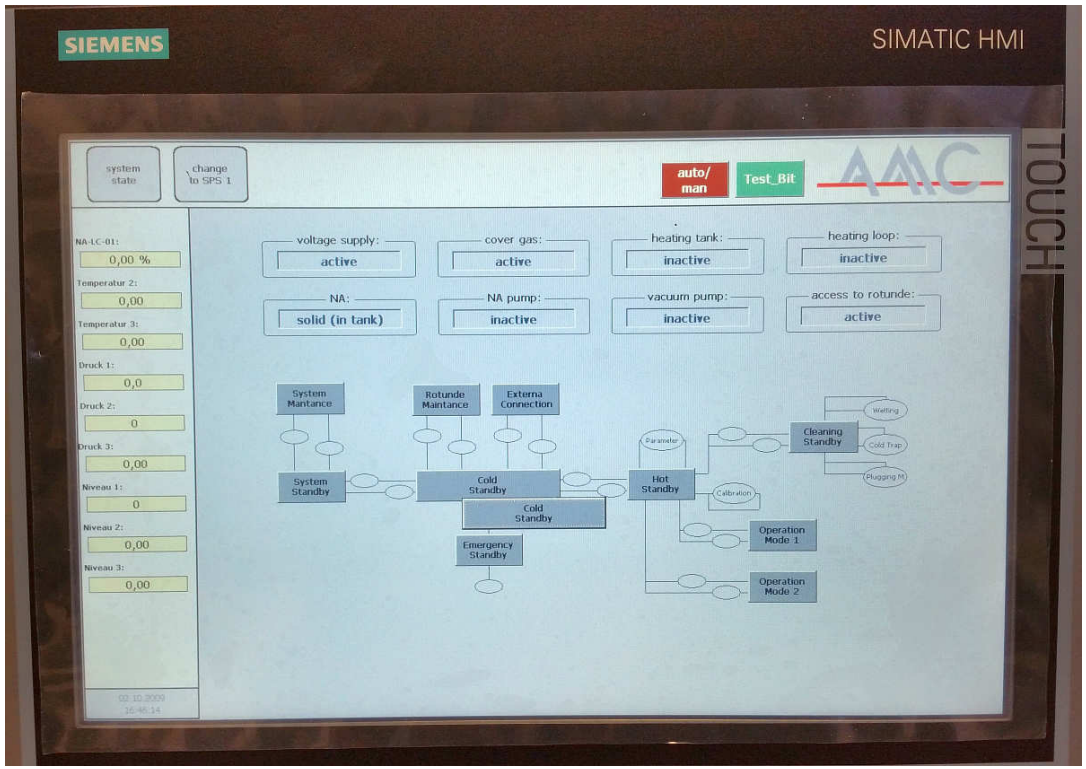
Plugging meter

KASOLA machinery level

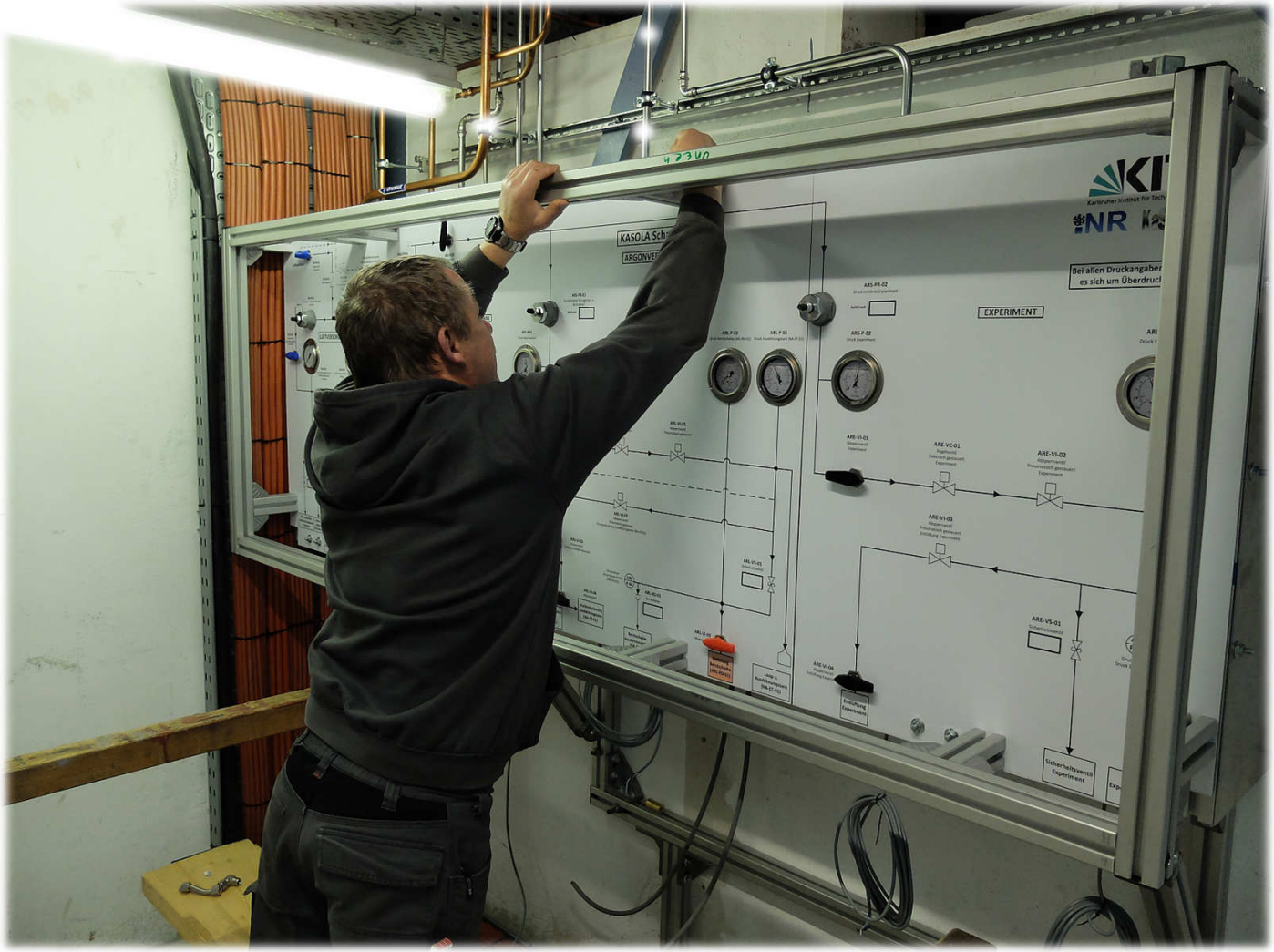
Red color: Seismic improvements

Test section ready

- Full length test section installed incl. heater system (lower end)
- I&C with installed recommended safety system



Status of Facilities: KASOLA

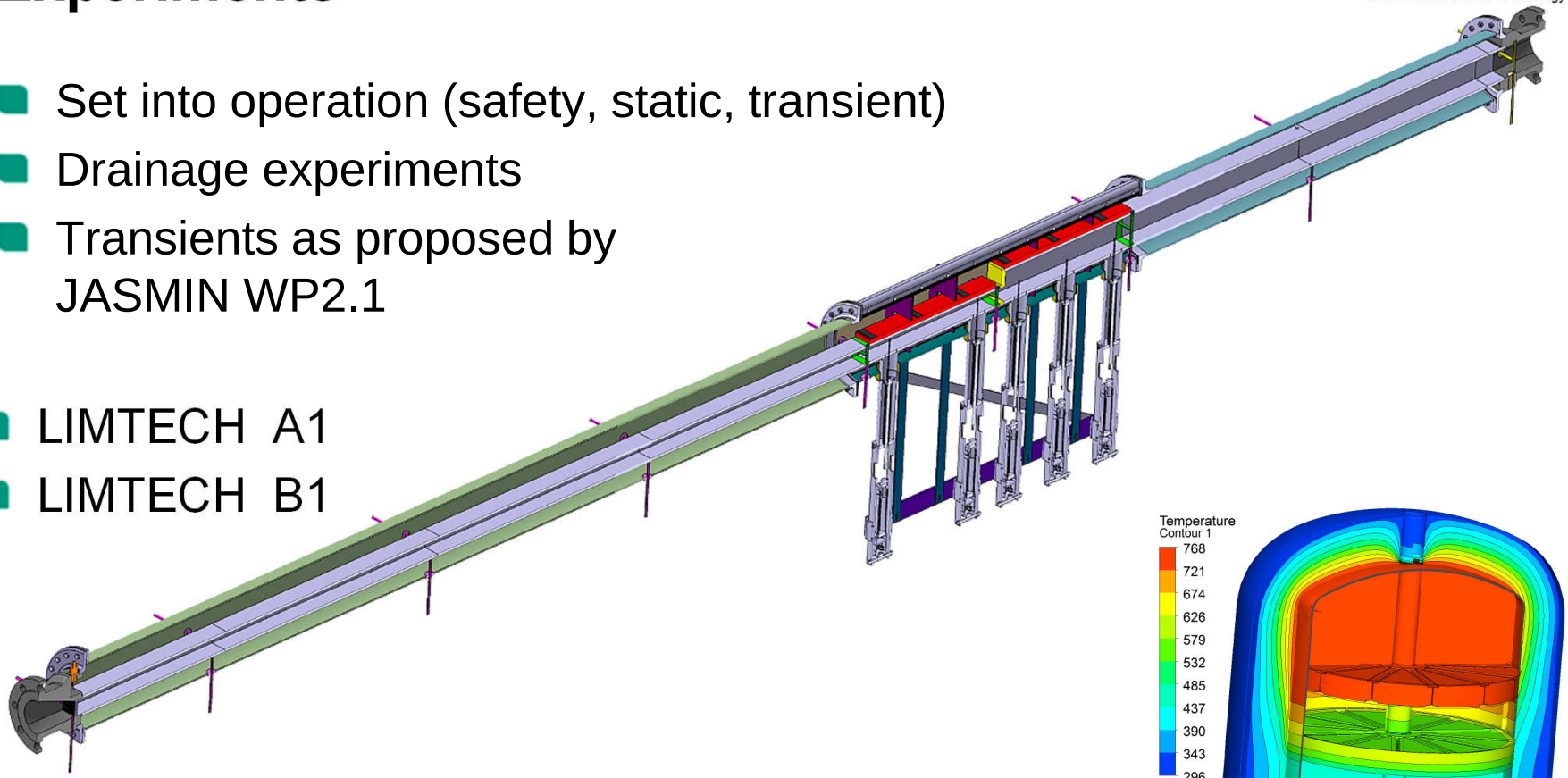


Control panel:

- Cover gas Ar
- Pressurized air
- Experimental supply

Experiments

- Set into operation (safety, static, transient)
- Drainage experiments
- Transients as proposed by JASMIN WP2.1



- LIMTECH A1
- LIMTECH B1

- LIMTECH: B4 Dynamic behavior of single tank high temperature energy storage system

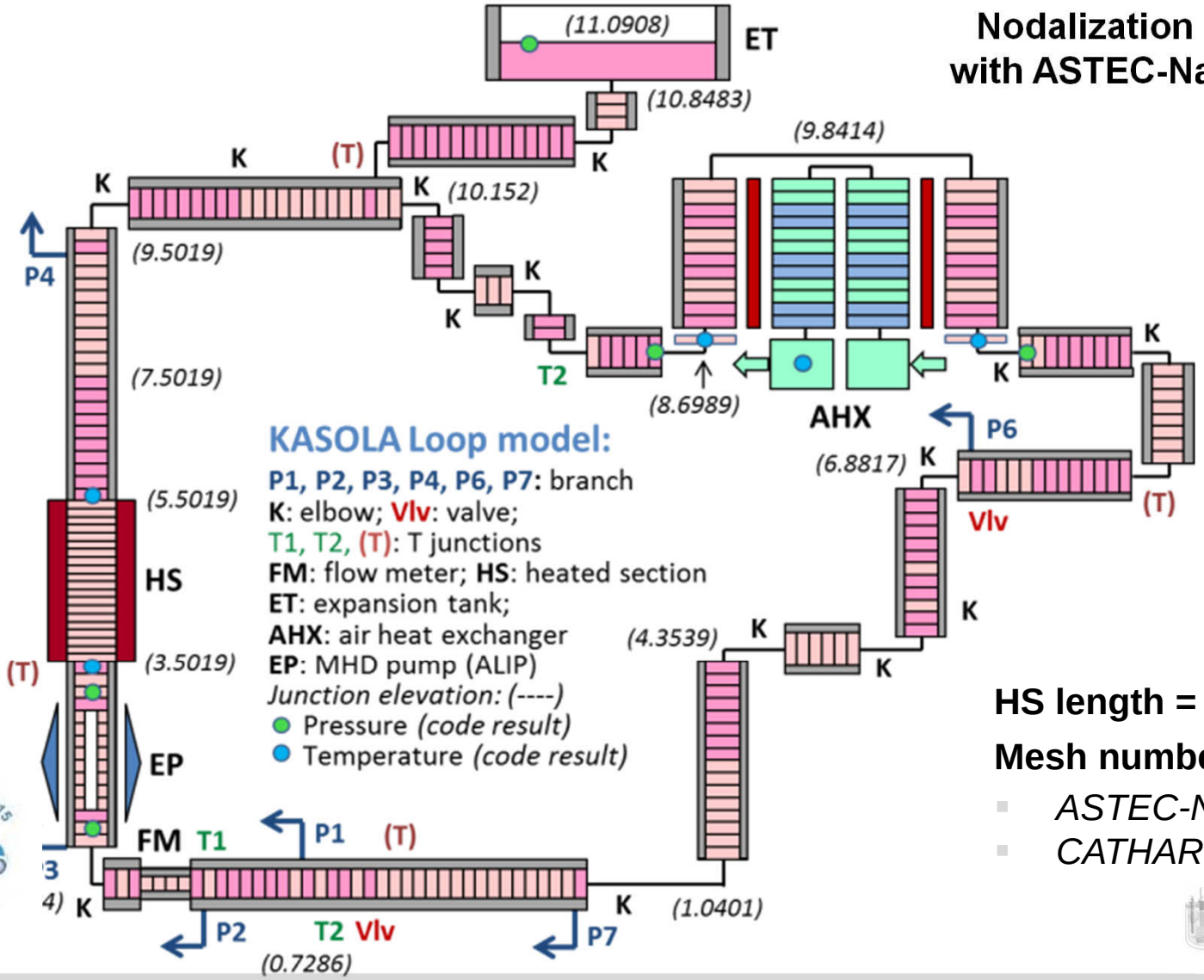
KASOLA: Analytical support

- Start with TRACE-Na (inhouse)
  - verification of pressure drop calculations
  - drainage of the sodium (fast release)

- Extension to ASTEC-Na
  → PHD in the frame of JASMIN:
  "Evaluation and improvement of thermal hydraulic models"
  code-to code comparison
- Integration of GRS with ATHELT-Na
- Various Benchmarks on:
  - drainage behavior
  - convection transitions
  - pump transitions
  → comparison postponed to follow up programme
  due to delays.

KASOLA–TH: Base-loop simulation

More reliable loop system description in Na (counterpart to LACANES ,PbBi)



Nodalization scheme used with ASTEC-Na & CATHARE by ENEA

HS length = 2 m

Mesh number (Pri + Sec):

- *ASTEC-Na = 65 + 14*
- *CATHARE = 243 + 26*

KASOLA: Extension of Infrastructure

New buildings

- New power supply of 2 MW
- Building with subterranean location of storage tank of 7 m³ sodium
- Auxiliary building for heating and cooling
  - Compressor for air – sodium heat exchanger
  - Circulators for air cooling chains for cold trap and MHD pump
  - Air heater to provide “trace” heating to heat exchanger tubes

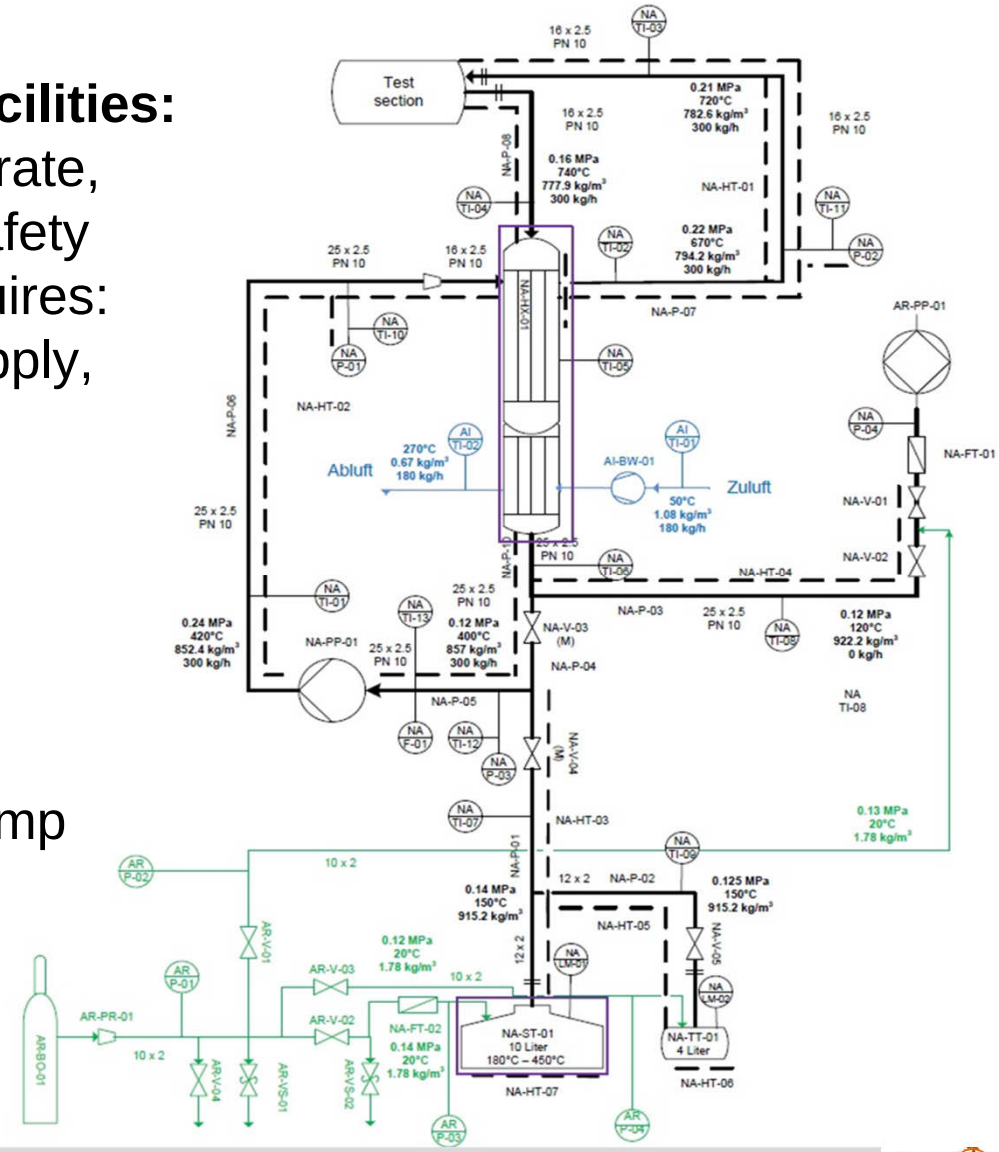
New laboratories

- AMTEC sodium laboratory located on INR-flight deck
- Sodium lab for material investigation at IHM thermal stress tests
- Sodium lab for material interaction at IAM-AWP

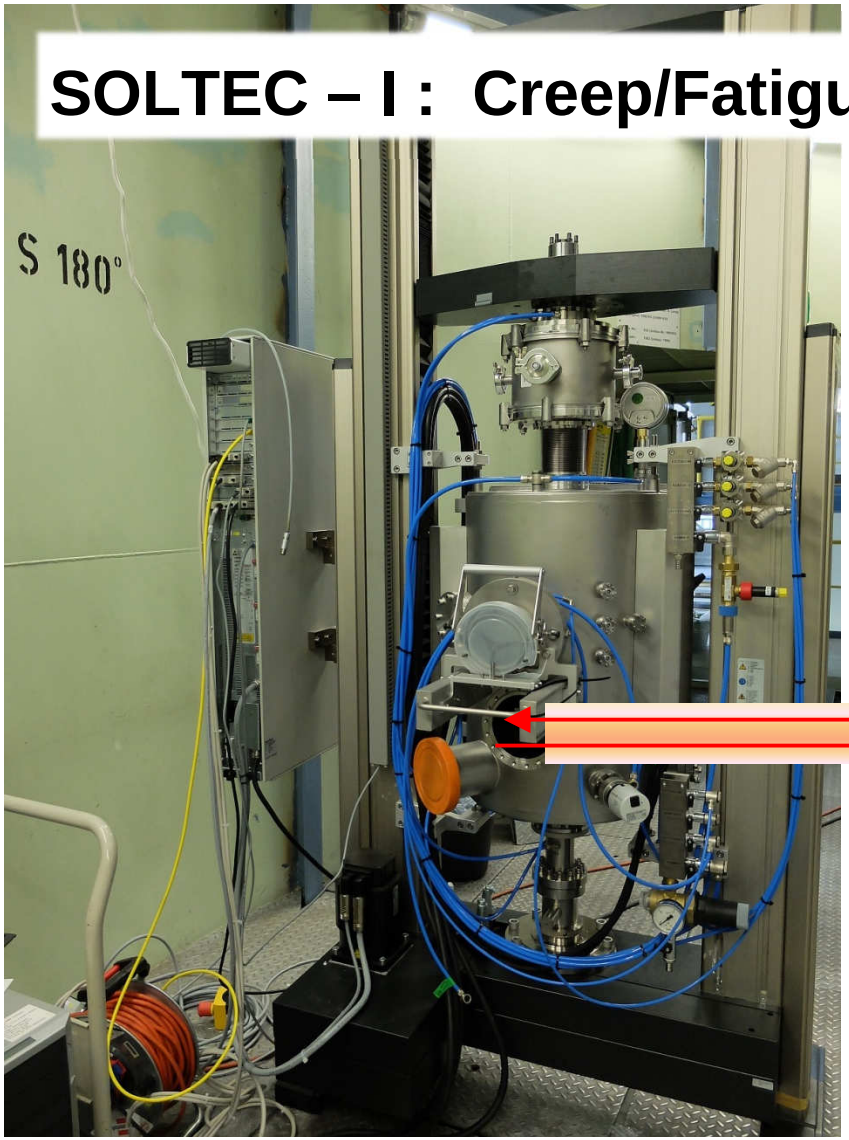
➔ **More tomorrow in reality**

Status of Facilities: SOLTEC I-III

- **Family of three small scale facilities:**
  1. compact and versatile to operate,
  2. fully housed (no additional safety measures in laboratory), requires:
     - power, - air cooling, - Ar supply,
  3. fail safe design
- **Communalities:**
  - integrated safety system
  - Inventory: ~ 8 l Na,
  - heating power: 10 kW
  - 400 < T < 720 / 900 °C,
  - $flow_{(max)}$: 0.3 m³/h by MHD pump
- **Differences:**
  - SOLTEC-I & -II have an IHX
  - SOLETC-III high and low temperature cooler



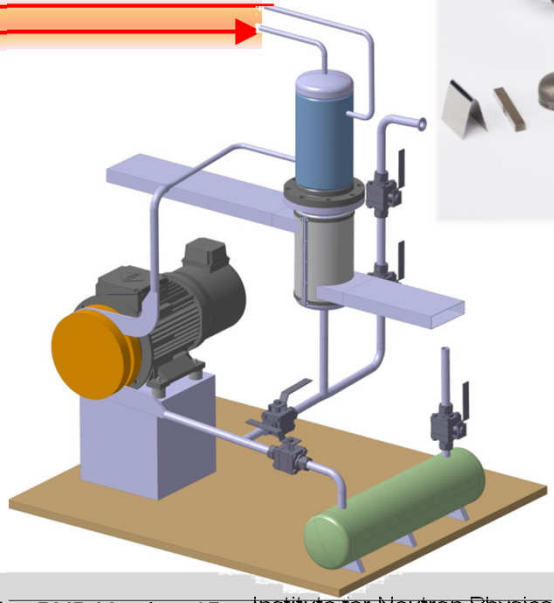
SOLTEC – I : Creep/Fatigue Tests



- Axial flowing sodium up to 8m/s
- Stress corrosion cracking (LCF)
- Up to 800°C in vacuum furnace

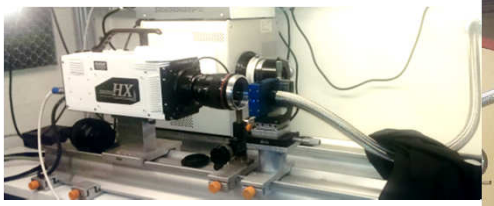
Materials:

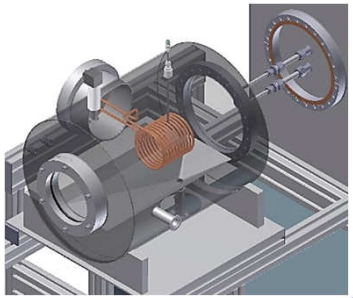
- ODS,
- Laminates,
- Ni-base alloys

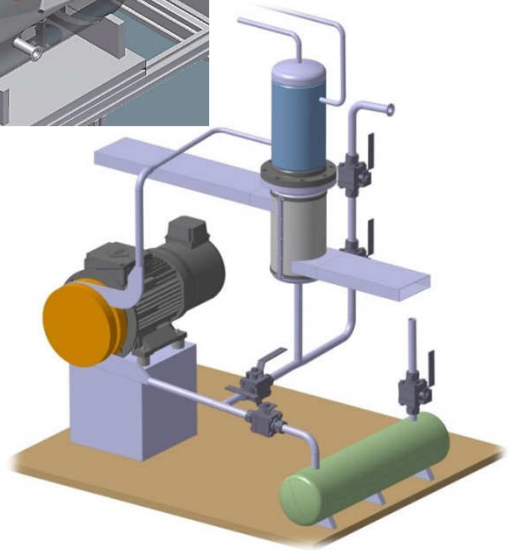


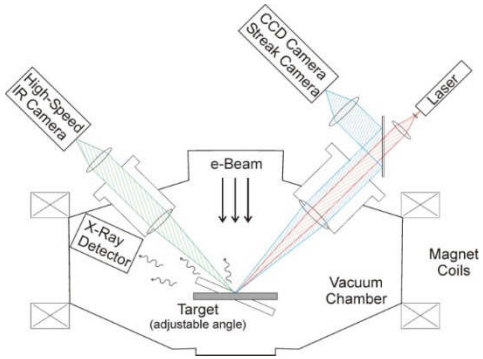
SOLTEC-II: protective coatings

- Material compatibility at high temperatures in contact with liquid PbBi, Sn and **Na**
- and under rapid temperature transients (SOLTEC-II)
- Thermal cycling tests at high temperature - ΔT: 650 – 900°C
- Long term stability of protective surface coatings (in/outer surface) using pulsed electron beams (GESA-SOFIE) – **S**urface **O**ptimization facility with **F**ast **I**n-situ diagnostic **E**quipment



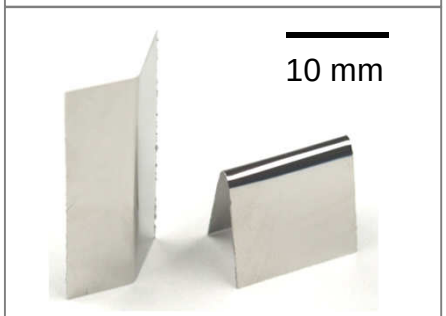




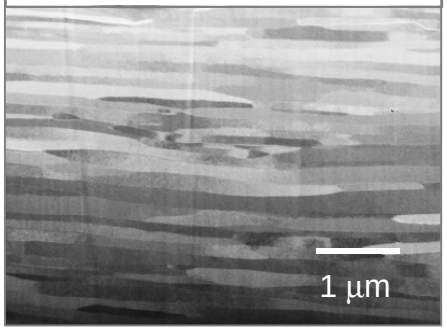


W laminates made of UFG W foils

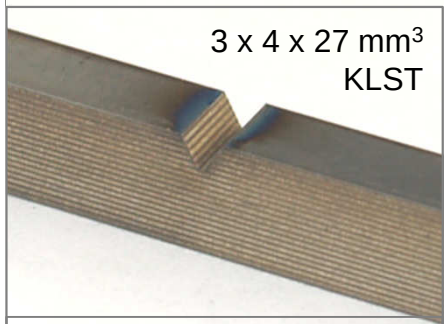
W-foil



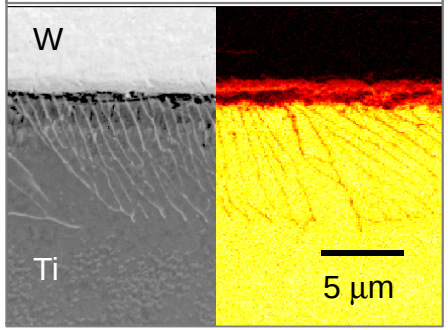
- Metal physics



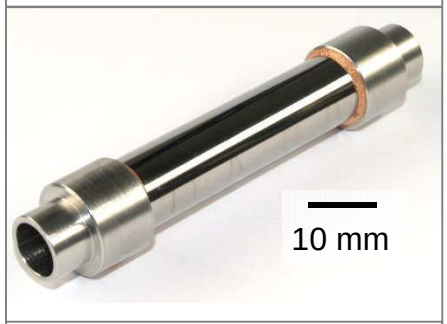
W laminate plate



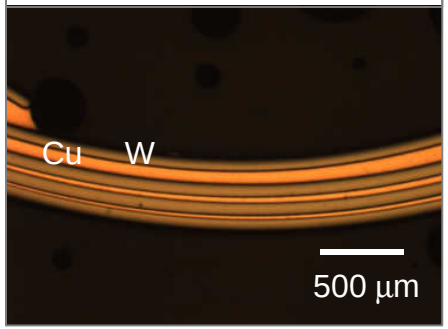
- Bonding and ageing



W laminate pipe

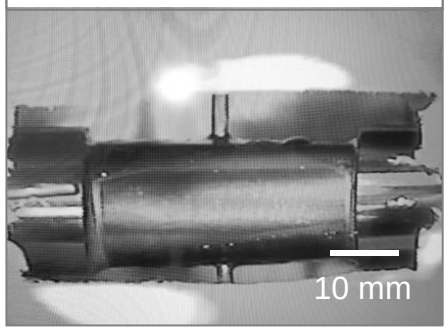


- Joining technology



Applications

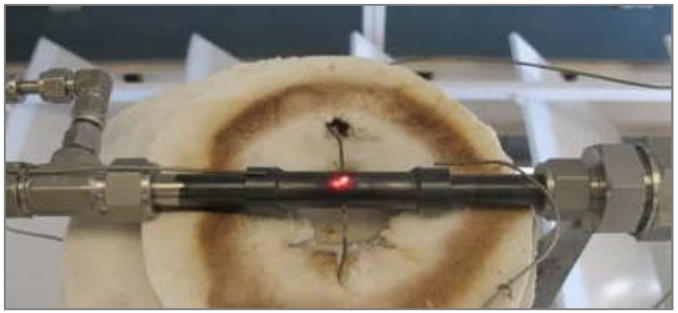
- Fabrication and testing



Challenge: fabrication/qualification

- **Foils, laminate plates, laminate pipes**
- **Qualification at Concentrated Solar Power plant in Almeria**

instrumented mockup



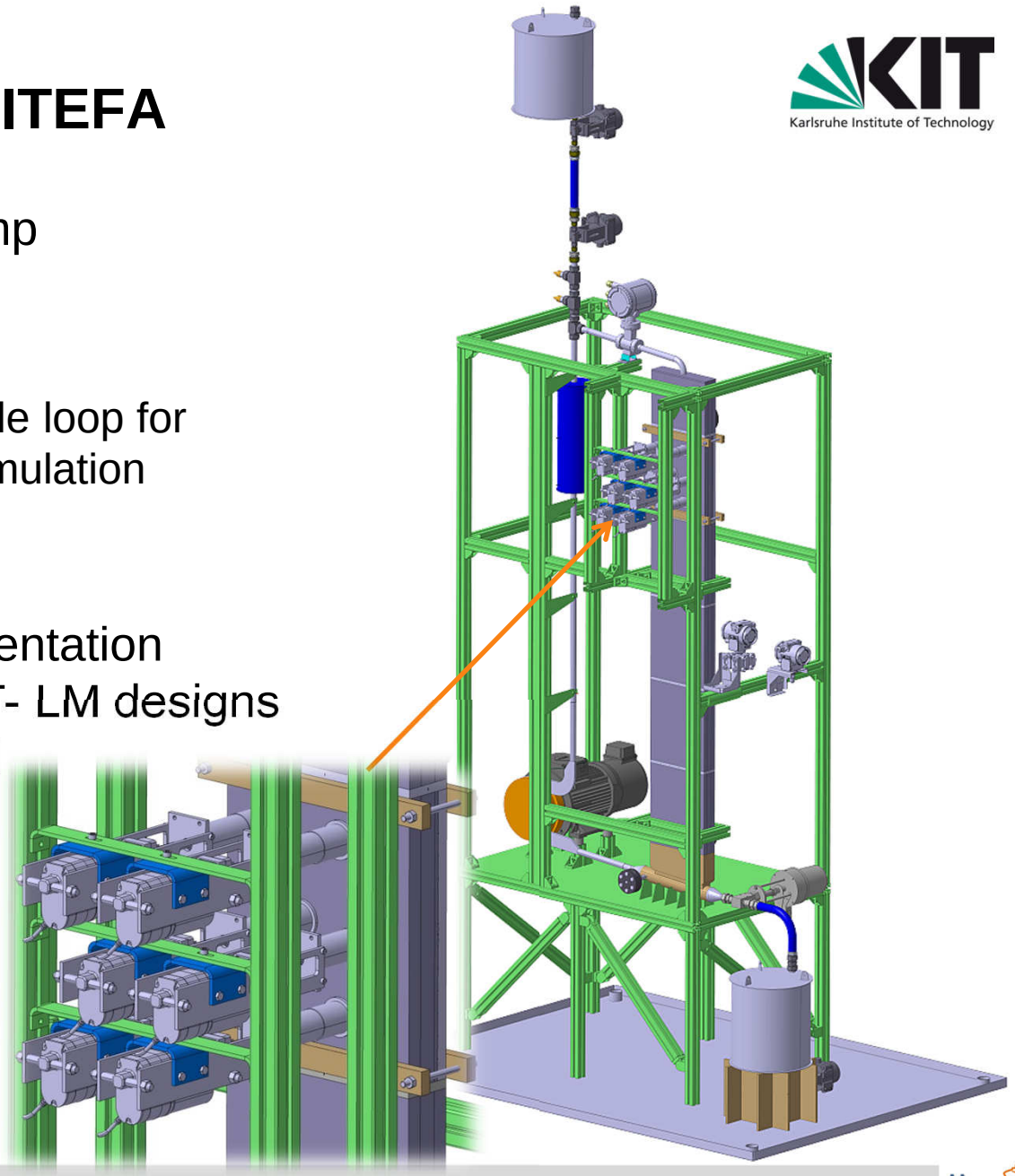
Status of Facilities: DITEFA

GaInSn loop with MHD pump

- Total height: 3,5 m
- Flow rate ~ 0,6 m³/h
- Free inclination of whole loop for different convection simulation

- Experimental objectives:
  - test bed for HT instrumentation
  - proof of principle for HT- LM designs
  - pre-test bed for thermal hydraulic experiments
  - validation experiment for operational and safety systems

- Education & training



International integration

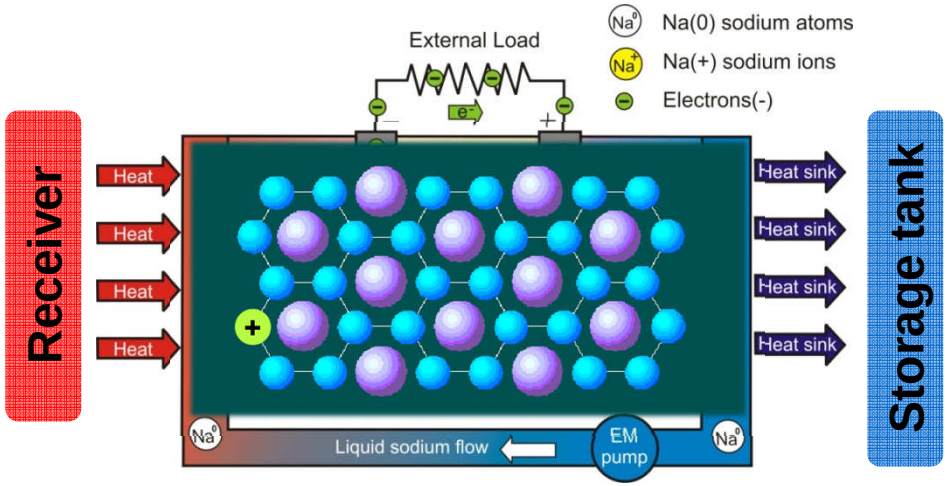
7th FWP:

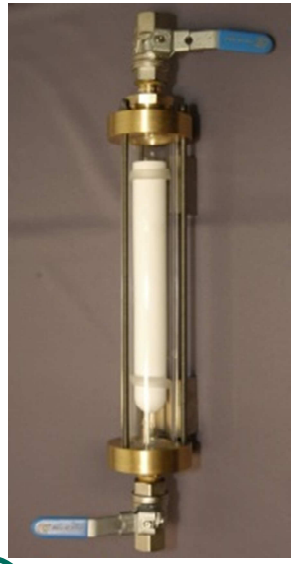
- JASMIN
- ESNII*plus*
- **SESAME: experimental data (2017)**

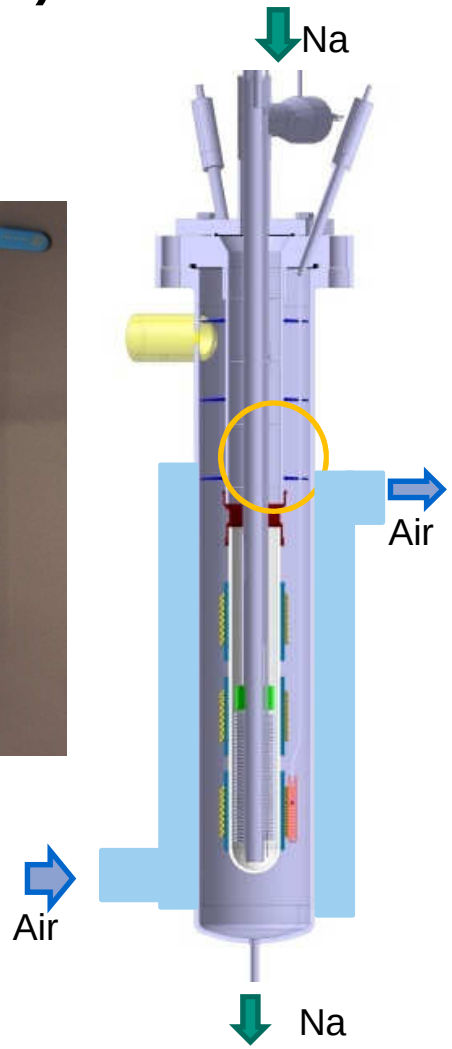
Horizon 2020:

- *JASMIN-Follow up:* ***SALM-IV***
- *Delivered to commission:* ***STARDUST***

Direct Energy Conversion:
Alkali-Metal Thermal-to-Electric Converter (AMTEC)







- BASE: β''-Alumina Solid Electrolyte (Al_2O_3 ~90%, Na_2O ~10%)
- Key process: Na-ionization ($Na \rightarrow Na^+ + e^-$)

<u>Main advantages</u>:
- Achieved efficiency ~ 30%
- Power-weight ratio (< ~500 W/kg)
- Low maintenance: no moving parts
- Flexible regarding the heat source

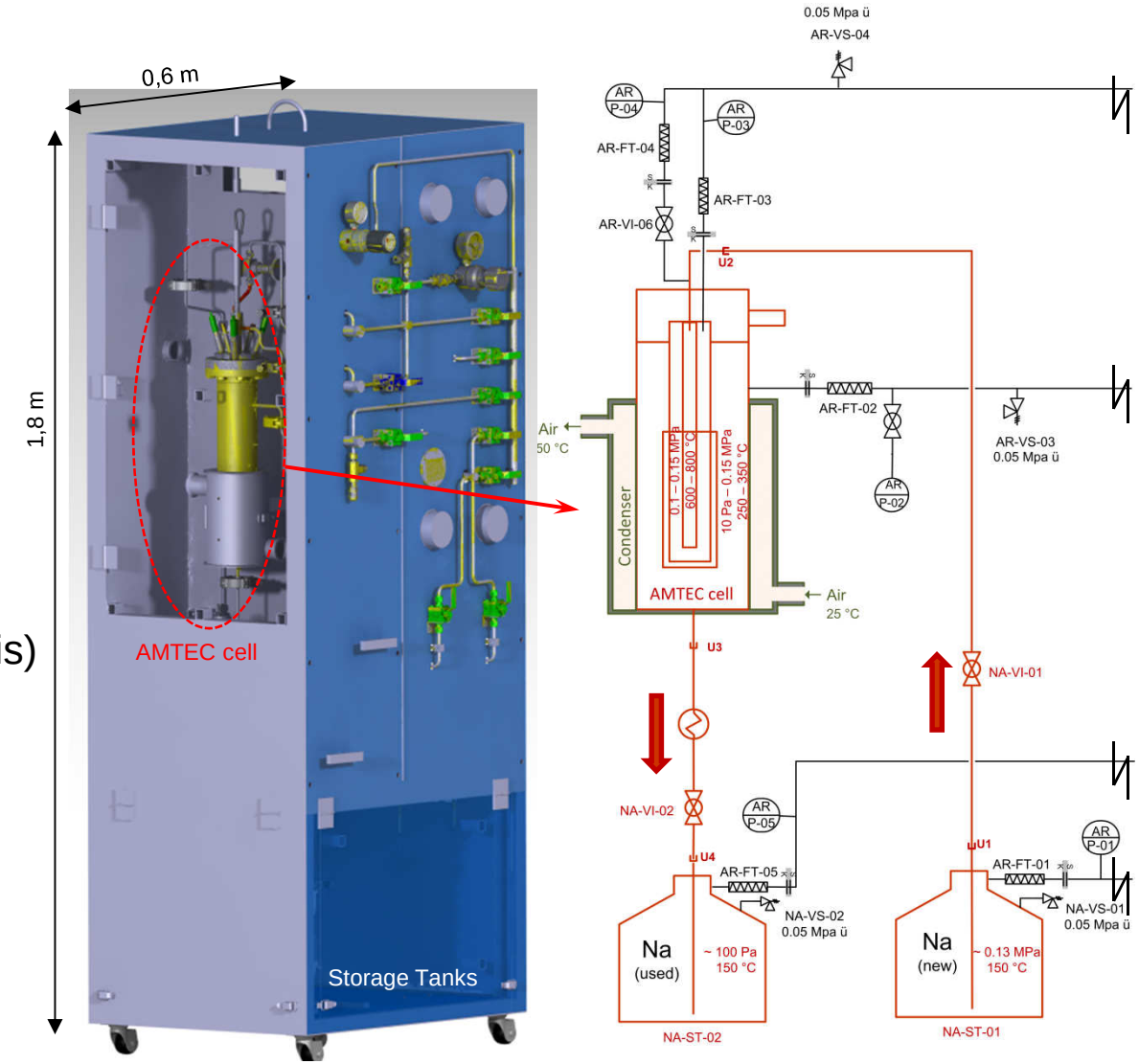
<u>Main disadvantages</u>:
- Large power loss
- Lower real η

* Onea et al. Magnetohydrodynamics 15, 2015

Institute for Neutron Physics and Reactor Technology
Facility design, System dynamics and Safety (ASS)

AMTEC TEst FAcility (ATEFA)

- **Thermal dynamics**
- **Electrochemistry**
- **Control and supervision of AMETC process**
- **Materials, metal–ceramic joints (600 – 100°C)**
- **Safety provision**
- **Education and training** (PHD, several BA and MA thesis)



Progress in 2015 (1/2)

INR

- Sodium/AMTEC laboratory in operation, safety systems installed
- First sodium compatibility tests performed
- Storage and transport casks build and tested
- ATEFA facility ready for implementation of AMTEC device
- Development of LM - CSP 2.0 at KASOLA ongoing

2015: HEMCP Kick-off meeting:
"A high temperature technology: AMTEC – Challenges and Perspectives within the HGF-energy research

Progress in 2015 (2/2)

IAM-AWP

- CORTINA Laboratory (IAM-AWP) in preparation and refurbishment
- Glovebox for local sodium and sample handling delivered
- Samples of innovative materials (W-Cu laminates) available

IHM

- Technology for soldering of ceramics and niobium operational
- Laboratory modifications to safely handle sodium finsihed
- Laboratory devices for protective coatings delivered
- Waiting for SOLTEC-II

Summary

- **KASOLA is on track**
  - Facilities: 1. **KASOLA** waiting for I/C finishing and licensing
    2. **ATEFA** ready for start, operation delayed due to ceramic damages
    3. **SOLTEC** depending on time schedule of selected manufacturer
    4. **CORTINA/ANCONA** to be finalized in 2016
  - **Scientific publications**: 2015: >10 journal and conference papers
  - **Education**: 2 PHDs, several bachelor & master thesis + internships
  - **Industry:** technological help requested from VAST SOLAR (Australia)

- **HEMCP**
  - Roadmap to “Demonstrator” still in time
  - Proposal for HORIZON-2020 **STARDUST** on LM-CSP delivered to EU commission on February 16, 2016
- **LIMTECH**
  - Start of experimental campaign mid 2016
- **Risks:**
    - Human resources reduction!
    - HEMCP and LIMTECH ends in 2017

Something else?

Recover of ancient sodium experiments performed in out institute (1966: IRE → 1994: IRS → 2004: INR → ???)

- Thermal hydraulics: KNS
  → now used for ASTEC-Na validation
- FAUNA
- FAUST
- NACOWA aerosol experiments
- NALA
- THINA (Thermite – Na interaction)
  SINBAD

Inherited:

- AOW: Vaporisation in thermal fragmentation

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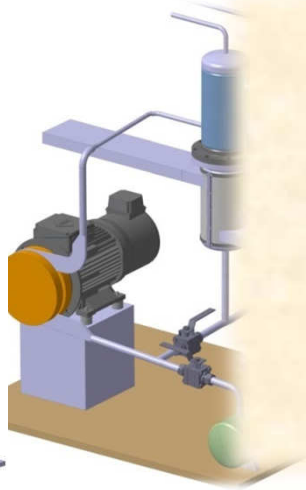

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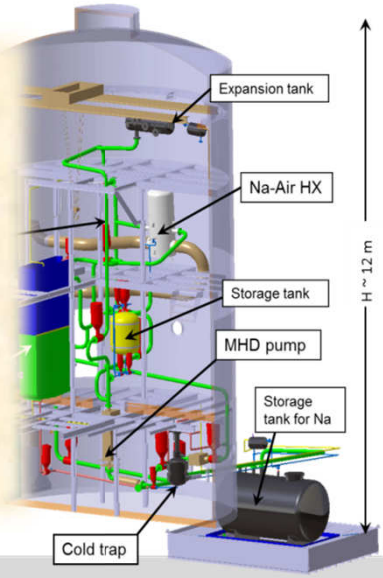

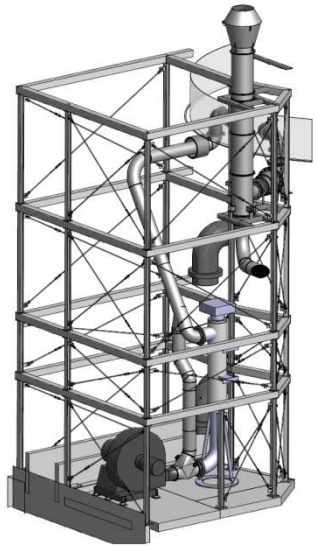

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- High quality data for CFD qualification
- Primary/secondary system behavior starting from full power (7-19 pins)
- Pool flow pattern in slab geometry (4x4x0,4 m, scale 1:2 - 1:3)

Modified after “phase out decision”

- General thermal hydraulics of liquid metals
- High temperature materials for energy technology
- Direct energy conversion using sodium
- Component development
- Sodium for concentrating solar power (CSP)

Facilities within KASOLA

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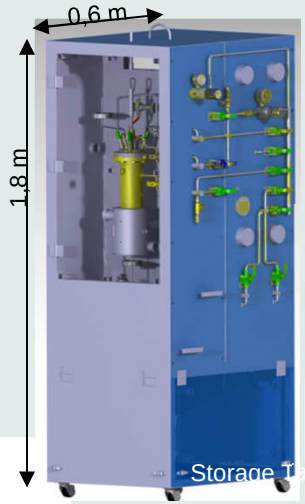

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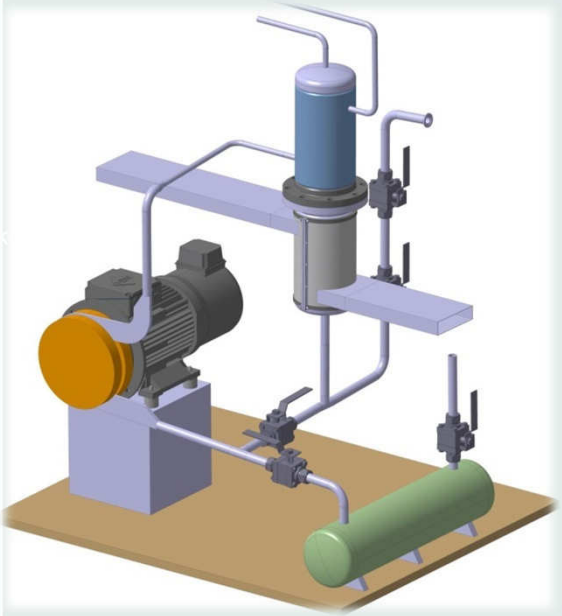

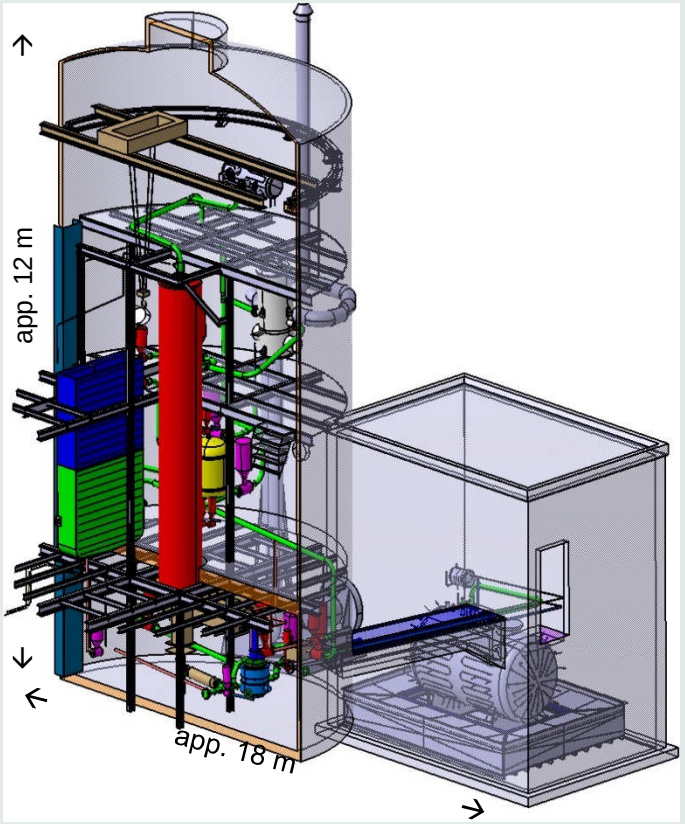

KASOLA- KArlsruhe SOdium Laboratory

http://www.inr.kit.edu/258.php

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- Na temperature range: 150°-550°C
- Na maximum flow rate: 150 m³/h
- Cooling power: ~ 400 kW
- Three test ports:
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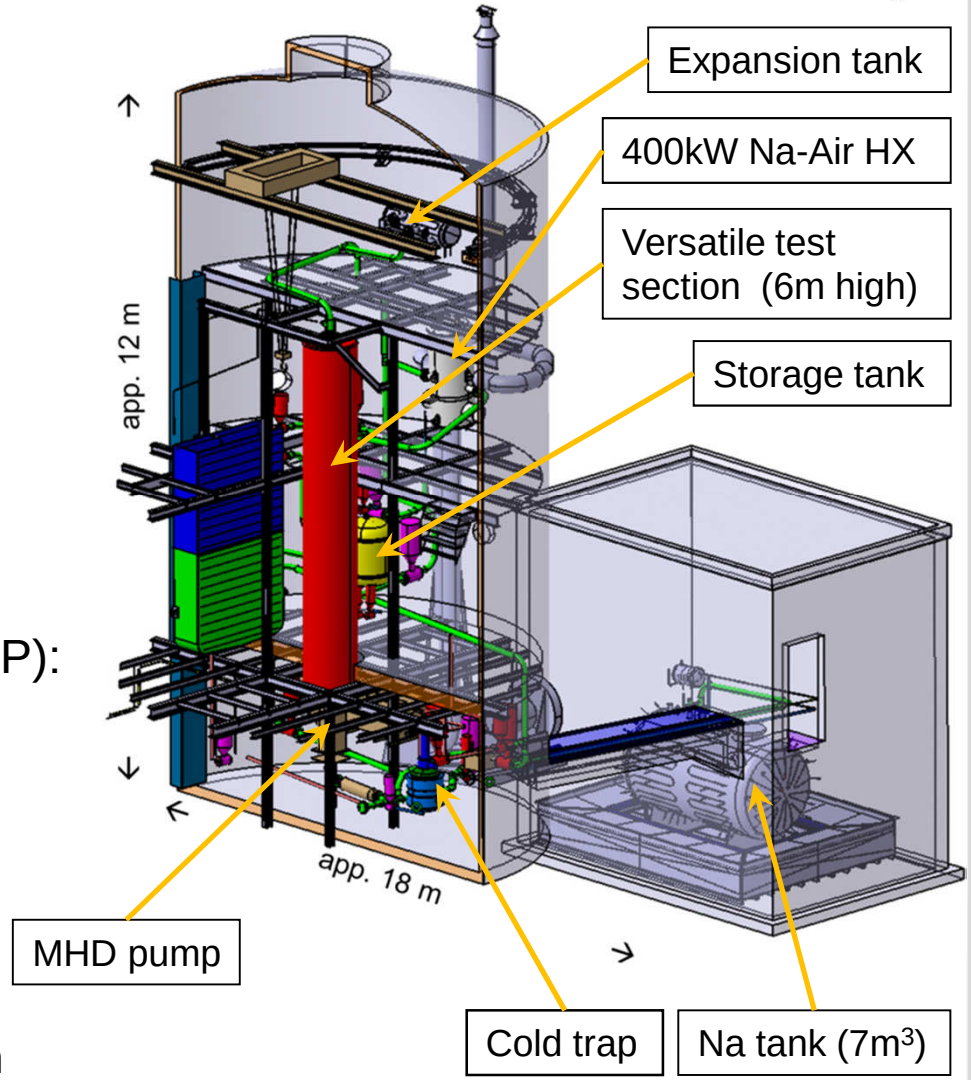
  - auxiliary port

- Experimental tasks (LIMTECH, HEMCP):
  - Flow in a backward facing step
  - Model development and validation:
    - anisotropic heat transfer
    - transition between free, mixed, and forced convection
  - High temperature energy storage
  - AMTEC integration into an energy system



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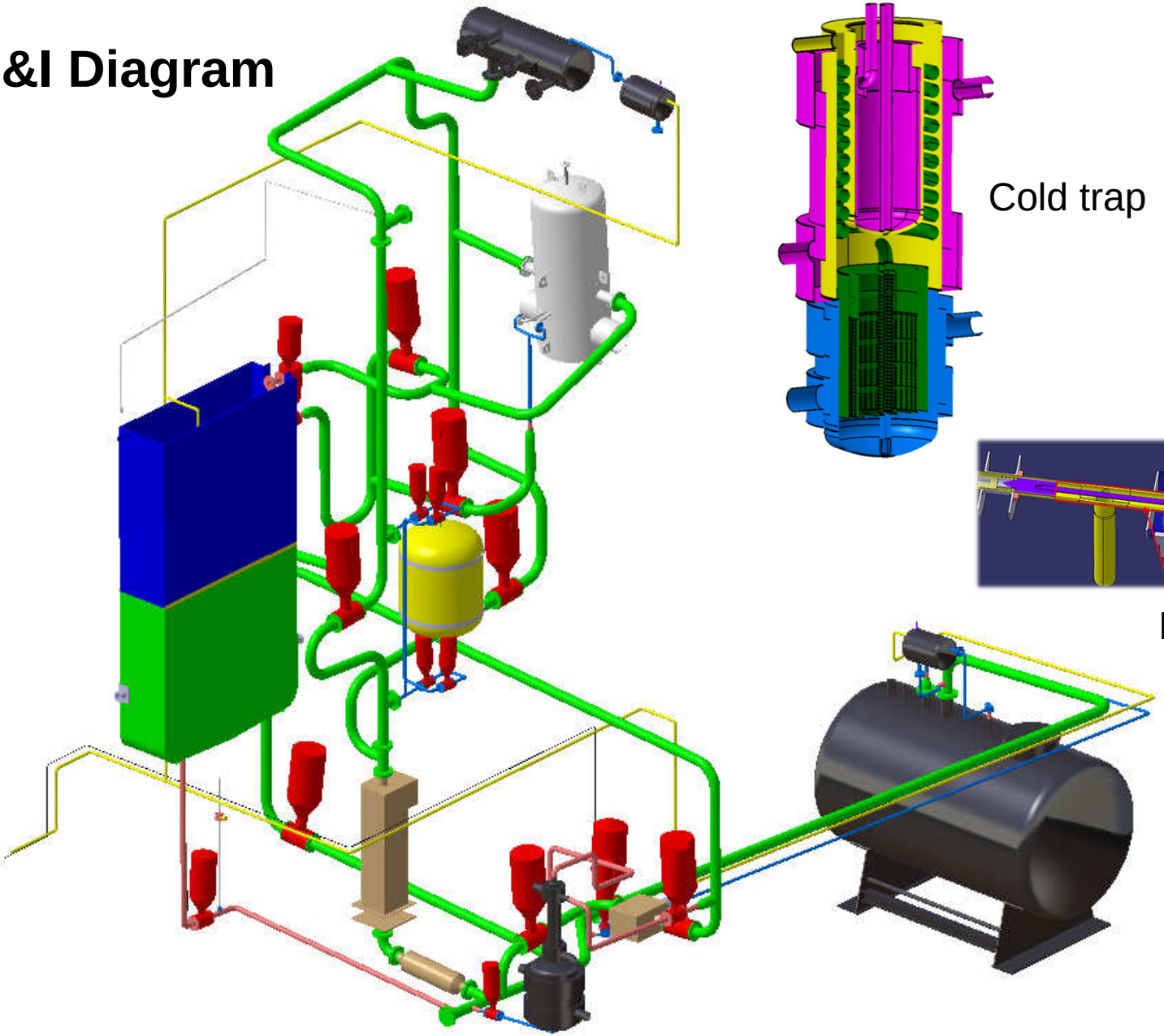
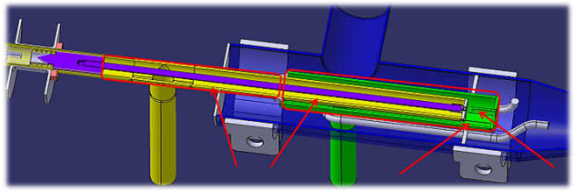
Facility design, System dynamics and Safety (ASS)

P&I Diagram



Cold trap



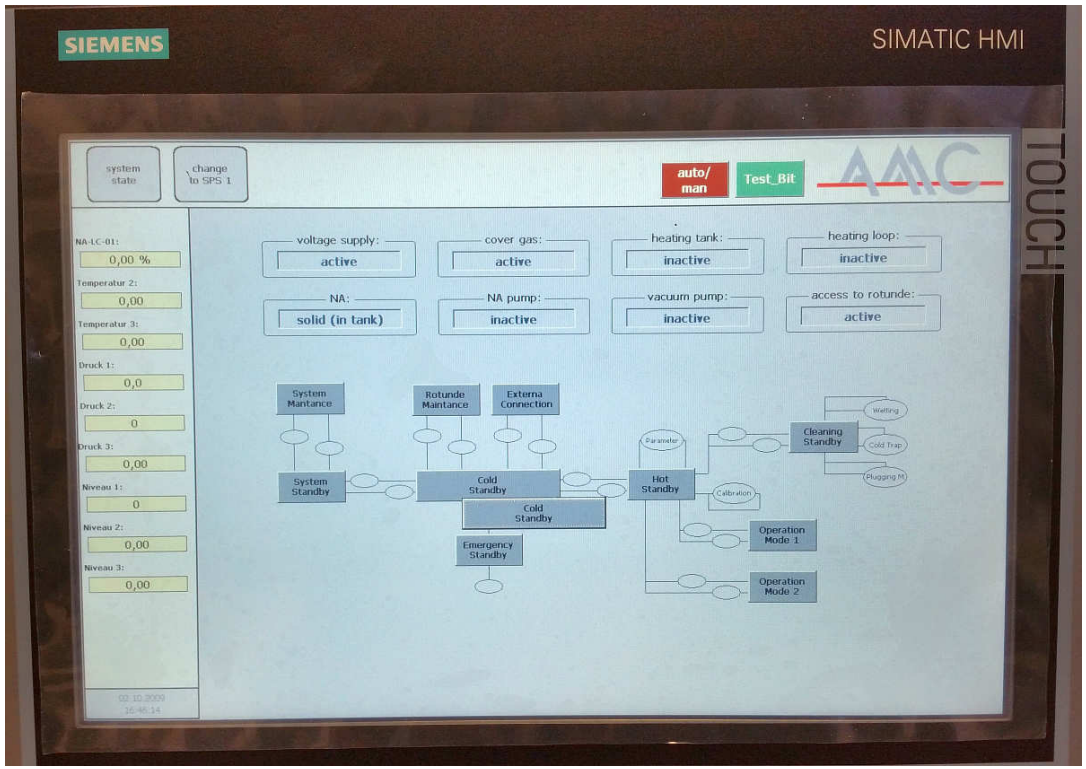
Plugging meter

KASOLA machinery level

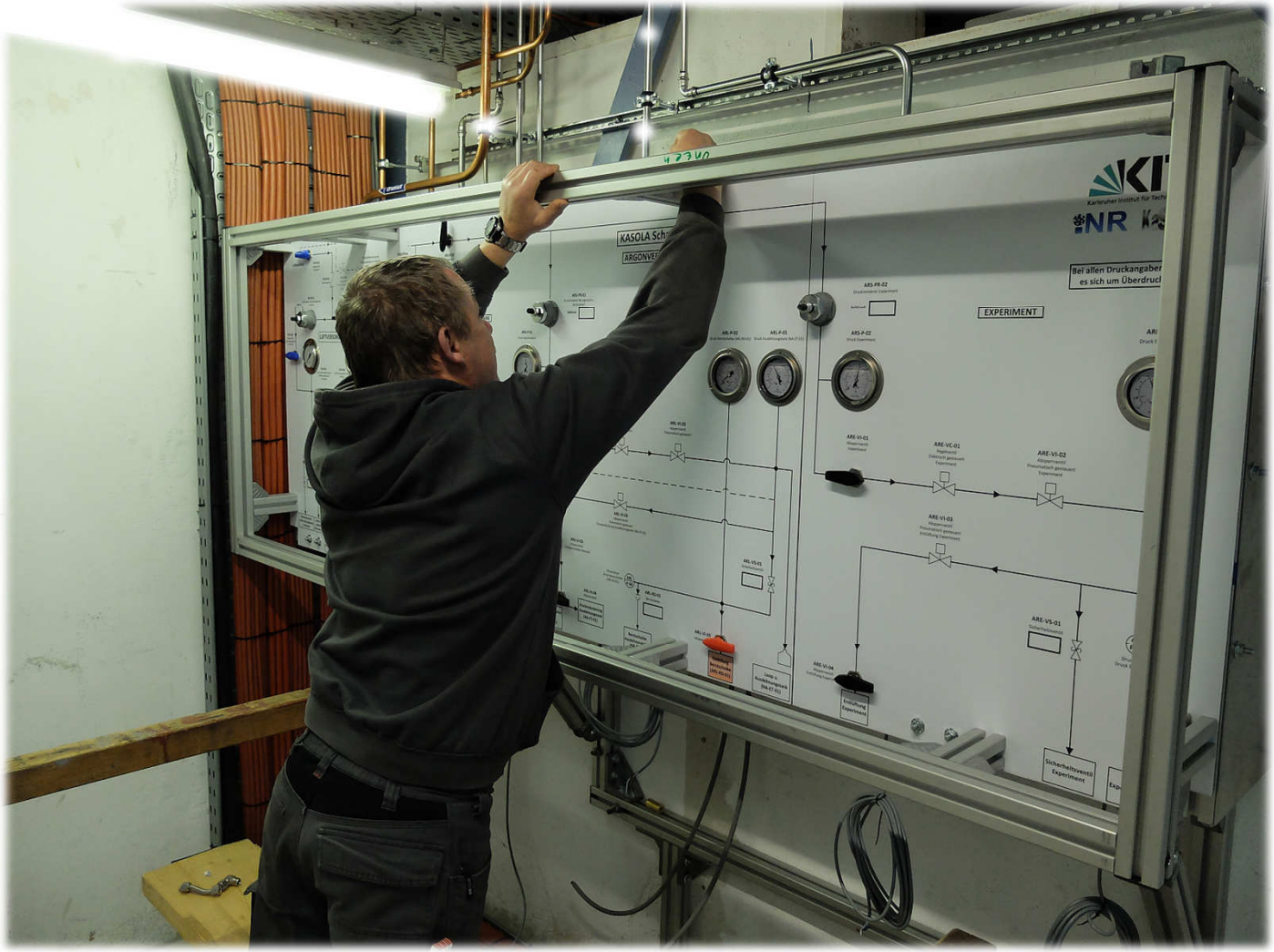
Red color: Seismic improvements

Test section ready

- Full length test section installed incl. heater system (lower end)
- I&C with installed recommended safety system



Status of Facilities: KASOLA

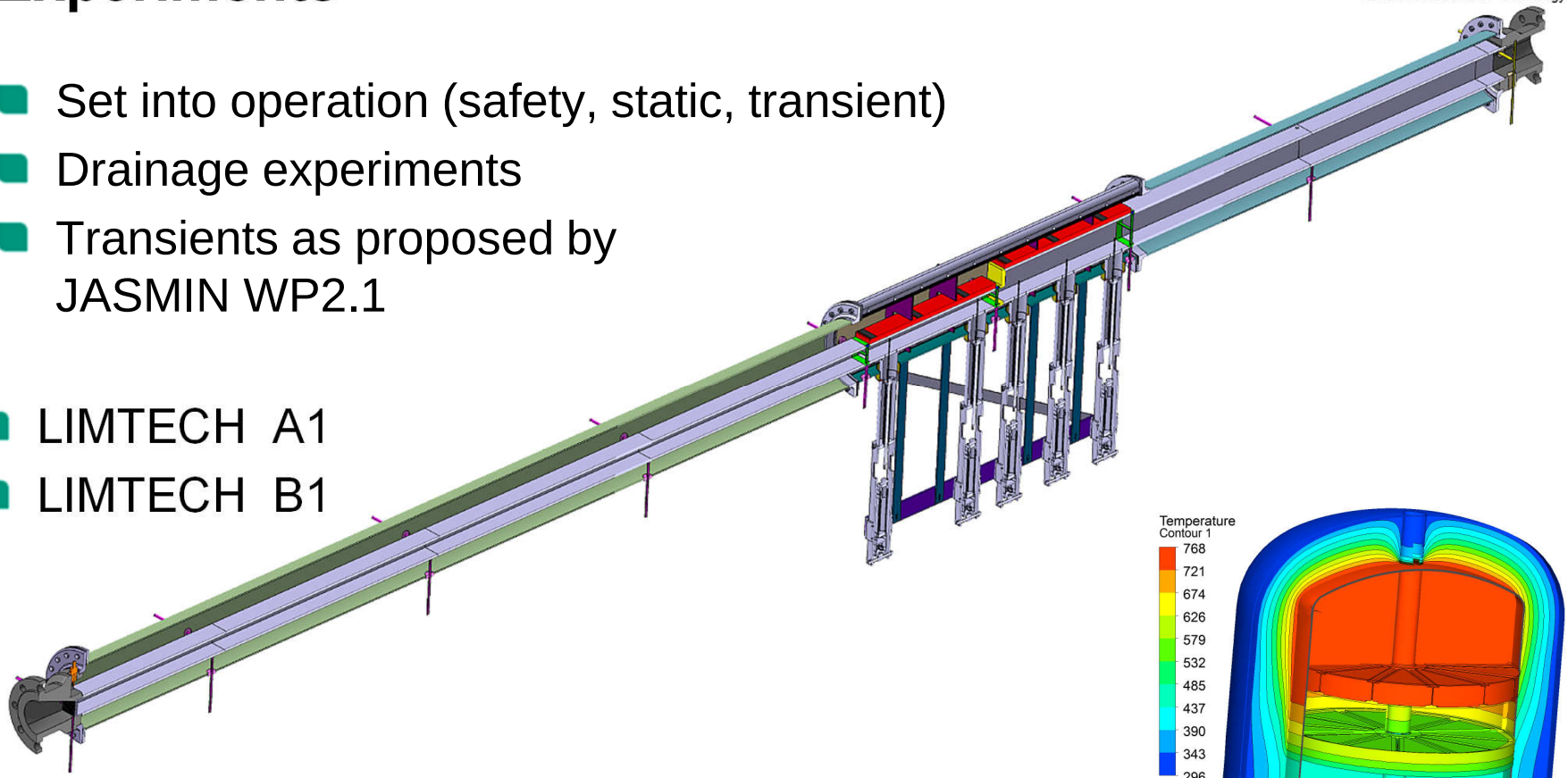


Control panel:

- Cover gas Ar
- Pressurized air
- Experimental supply

Experiments

- Set into operation (safety, static, transient)
- Drainage experiments
- Transients as proposed by JASMIN WP2.1



- LIMTECH A1
- LIMTECH B1

- LIMTECH: B4 Dynamic behavior of single tank high temperature energy storage system

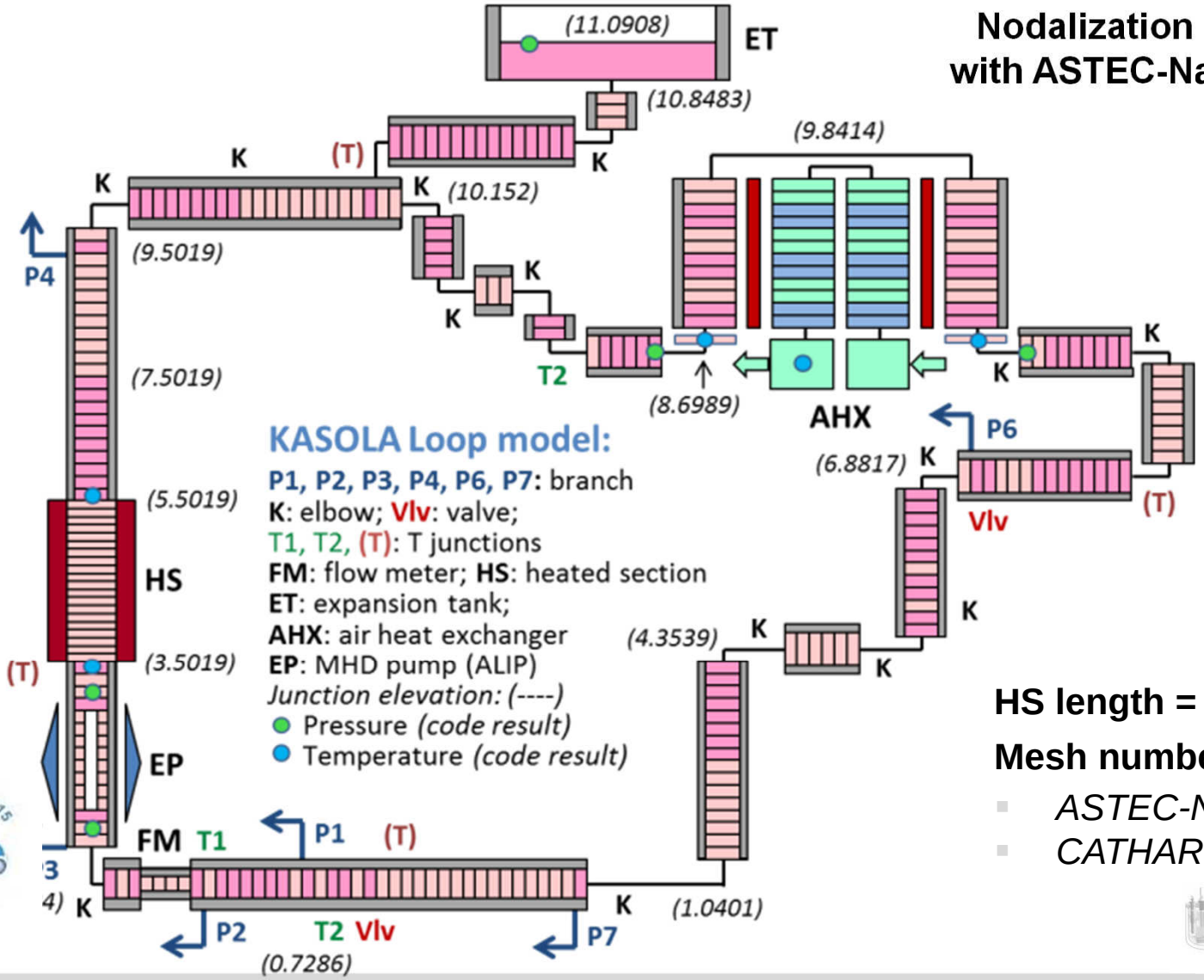
KASOLA: Analytical support

- Start with TRACE-Na (inhouse)
  - verification of pressure drop calculations
  - drainage of the sodium (fast release)

- Extension to ASTEC-Na
  → PHD in the frame of JASMIN:
  "Evaluation and improvement of thermal hydraulic models"
  code-to code comparison
- Integration of GRS with ATHELT-Na
- Various Benchmarks on:
  - drainage behavior
  - convection transitions
  - pump transitions
  → comparison postponed to follow up programme
  due to delays.

KASOLA–TH: Base-loop simulation

More reliable loop system description in Na (counterpart to LACANES ,PbBi)



Nodalization scheme used with ASTEC-Na & CATHARE by ENEA

HS length = 2 m

Mesh number (Pri + Sec):

- *ASTEC-Na = 65 + 14*
- *CATHARE = 243 + 26*

KASOLA: Extension of Infrastructure

New buildings

- New power supply of 2 MW
- Building with subterranean location of storage tank of 7 m³ sodium
- Auxiliary building for heating and cooling
  - Compressor for air – sodium heat exchanger
  - Circulators for air cooling chains for cold trap and MHD pump
  - Air heater to provide “trace” heating to heat exchanger tubes

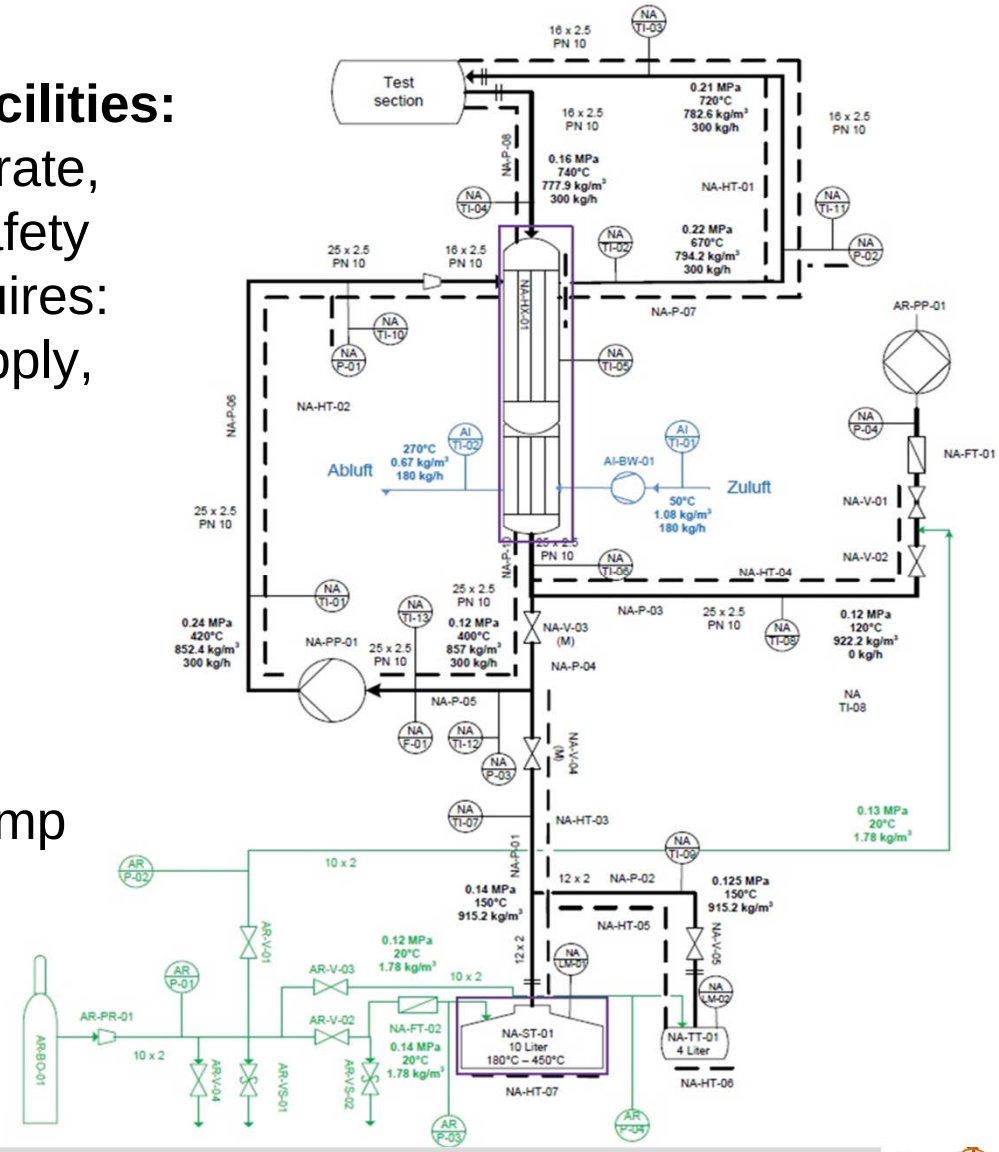
New laboratories

- AMTEC sodium laboratory located on INR-flight deck
- Sodium lab for material investigation at IHM thermal stress tests
- Sodium lab for material interaction at IAM-AWP

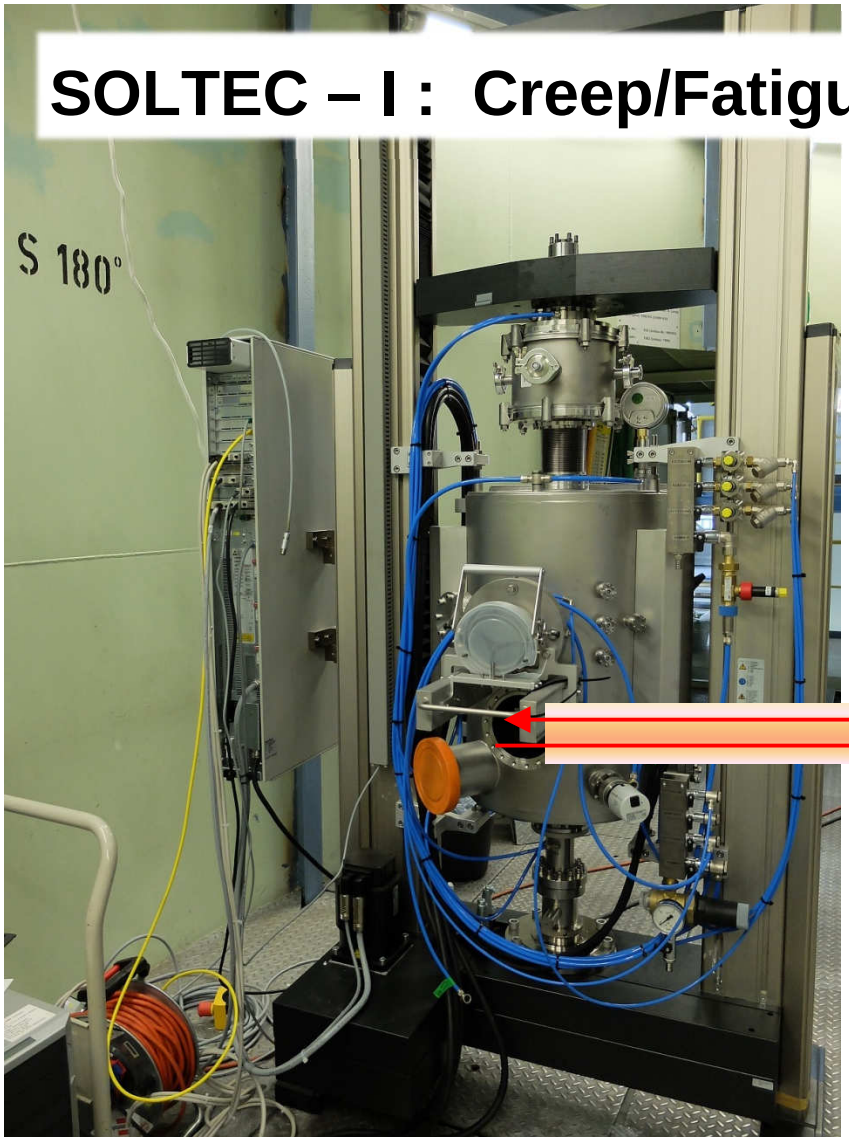
➔ **More tomorrow in reality**

Status of Facilities: SOLTEC I-III

- **Family of three small scale facilities:**
  1. compact and versatile to operate,
  2. fully housed (no additional safety measures in laboratory), requires:
     - power, - air cooling, - Ar supply,
  3. fail safe design
- **Communalities:**
  - integrated safety system
  - Inventory: ~ 8 l Na,
  - heating power: 10 kW
  - 400 < T < 720 / 900 °C,
  - $flow_{(max)}$: 0.3 m³/h by MHD pump
- **Differences:**
  - SOLTEC-I & -II have an IHX
  - SOLETC-III high and low temperature cooler



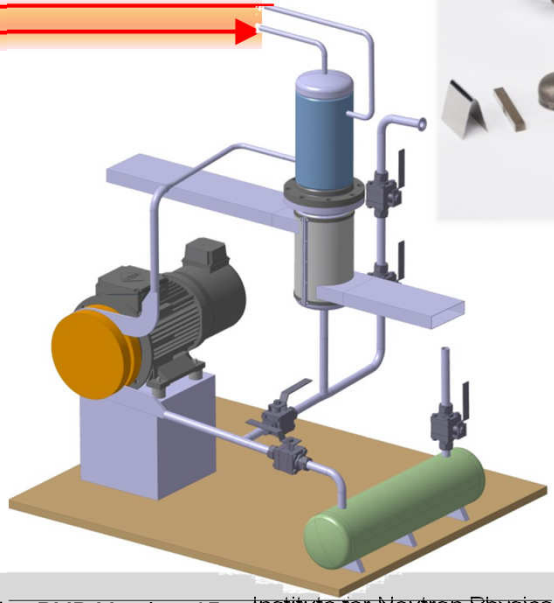
SOLTEC – I : Creep/Fatigue Tests



- Axial flowing sodium up to 8m/s
- Stress corrosion cracking (LCF)
- Up to 800°C in vacuum furnace

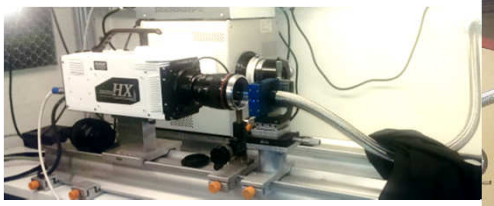
Materials:

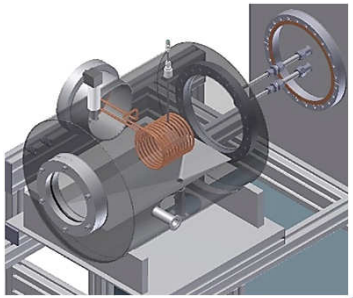
- ODS,
- Laminates,
- Ni-base alloys

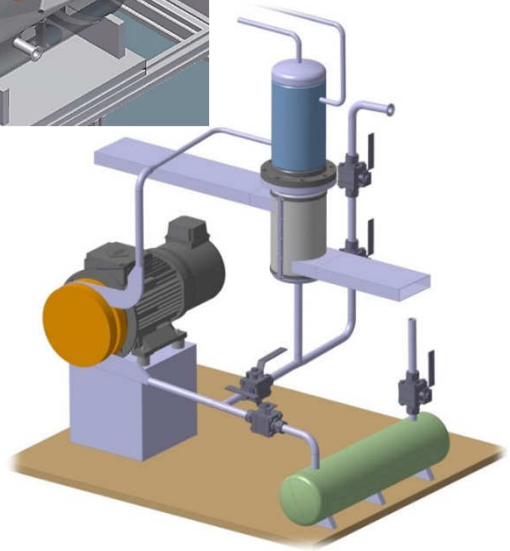


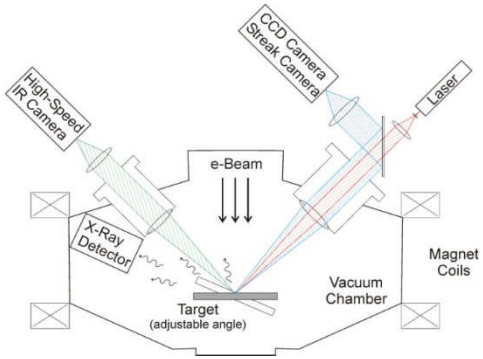
SOLTEC-II: protective coatings

- Material compatibility at high temperatures in contact with liquid PbBi, Sn and **Na**
- and under rapid temperature transients (SOLTEC-II)
- Thermal cycling tests at high temperature - ΔT: 650 – 900°C
- Long term stability of protective surface coatings (in/outer surface) using pulsed electron beams (GESA-SOFIE) – **S**urface **O**ptimization facility with **F**ast **I**n-situ diagnostic **E**quipment



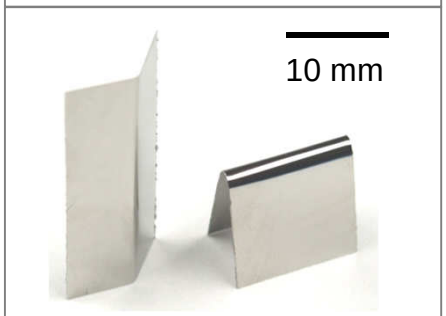




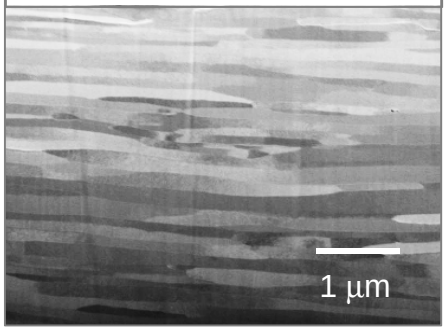


W laminates made of UFG W foils

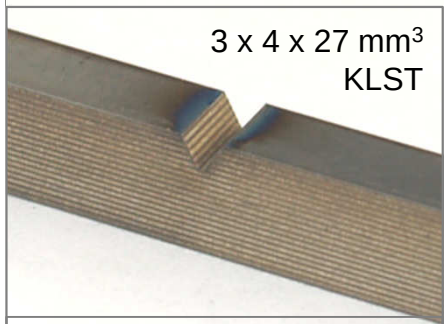
W-foil



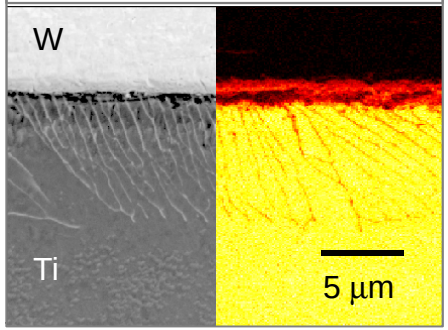
- Metal physics



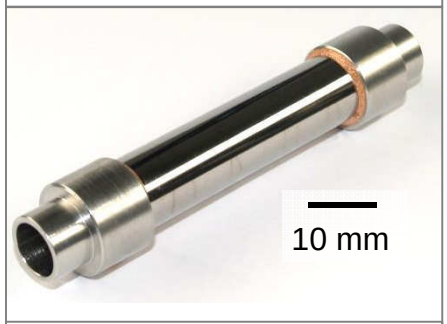
W laminate plate



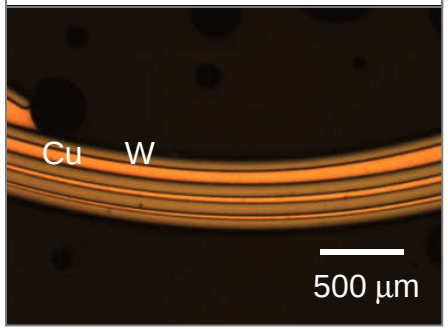
- Bonding and ageing



W laminate pipe

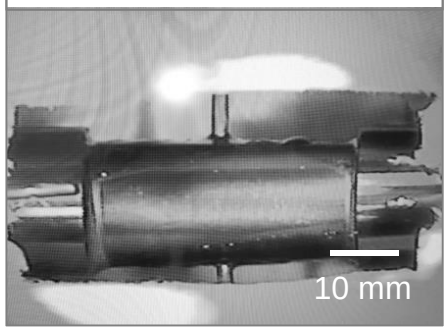


- Joining technology



Applications

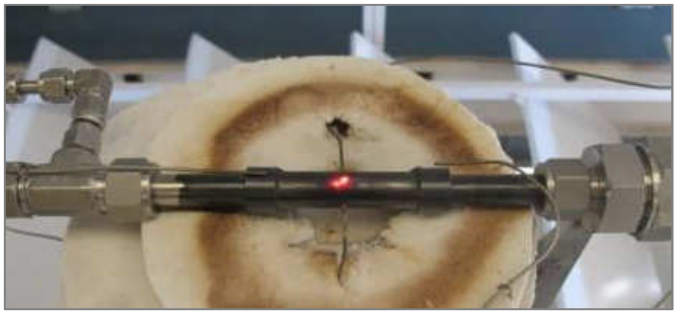
- Fabrication and testing



Challenge: fabrication/qualification

- **Foils, laminate plates, laminate pipes**
- **Qualification at Concentrated Solar Power plant in Almeria**

instrumented mockup



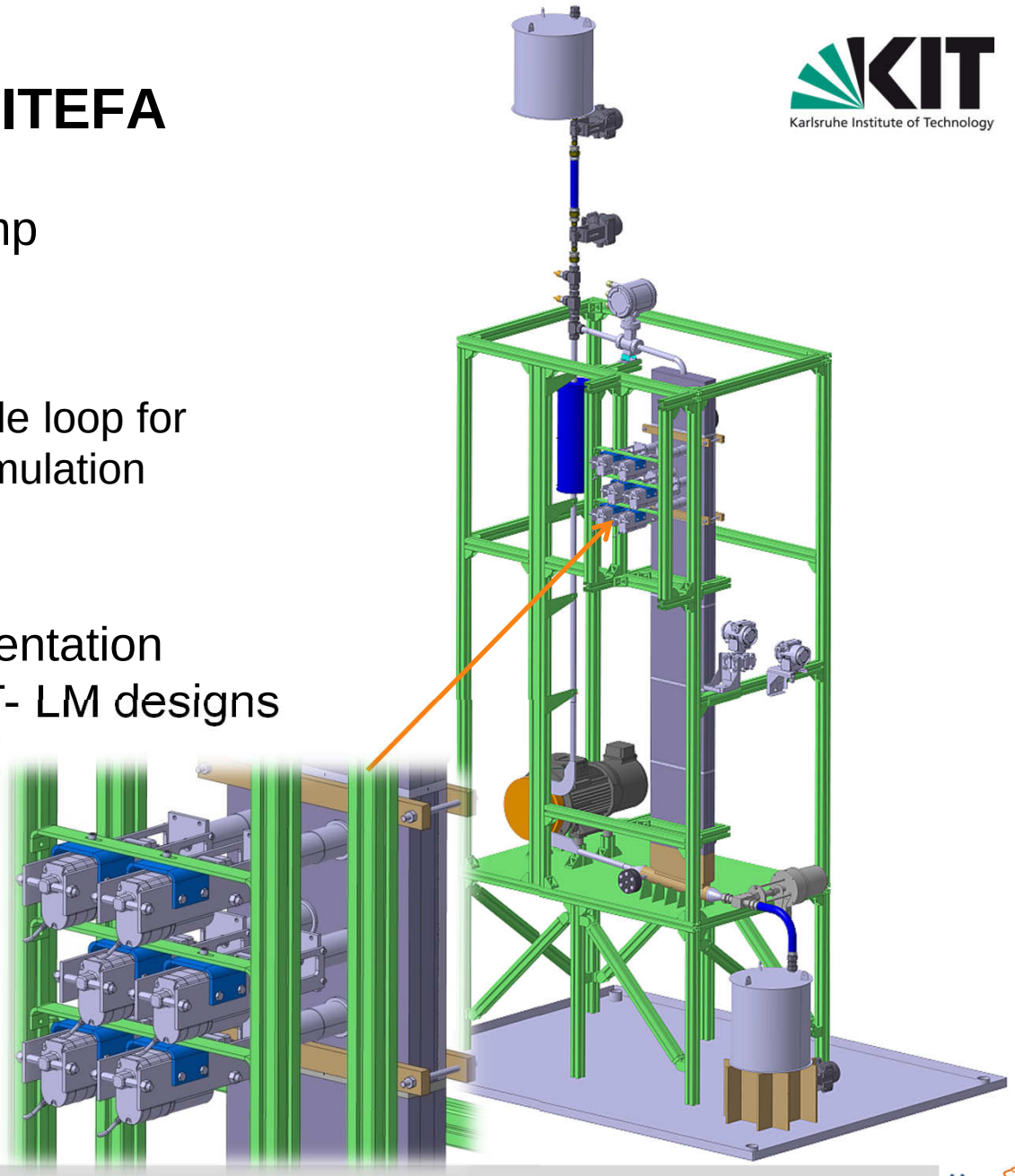
Status of Facilities: DITEFA

GaInSn loop with MHD pump

- Total height: 3,5 m
- Flow rate ~ 0,6 m³/h
- Free inclination of whole loop for different convection simulation

- Experimental objectives:
  - test bed for HT instrumentation
  - proof of principle for HT- LM designs
  - pre-test bed for thermal hydraulic experiments
  - validation experiment for operational and safety systems

- Education & training



International integration

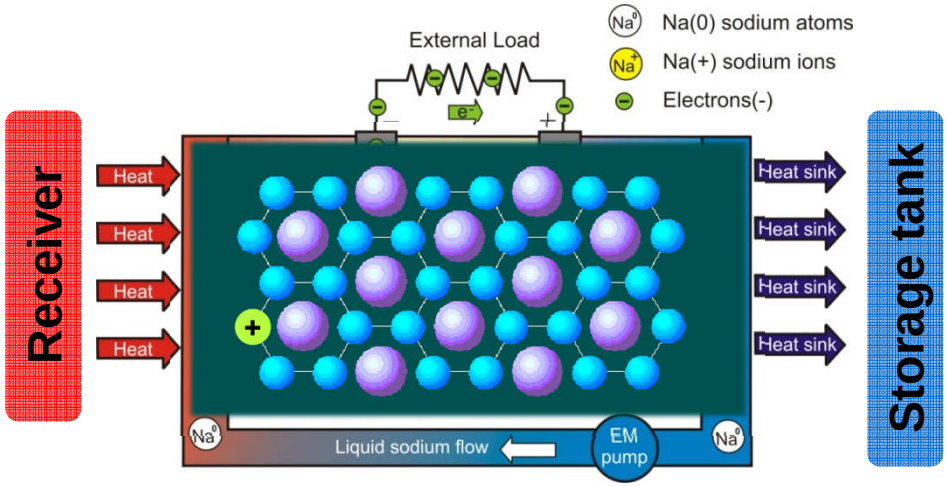
7th FWP:

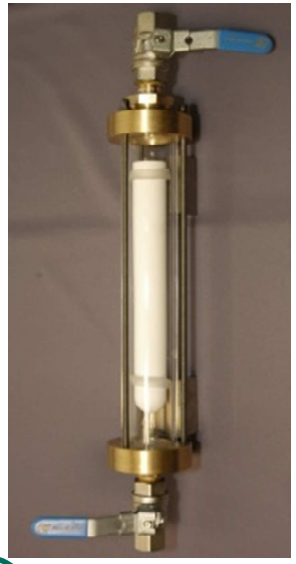
- JASMIN
- ESNII*plus*
- **SESAME: experimental data (2017)**

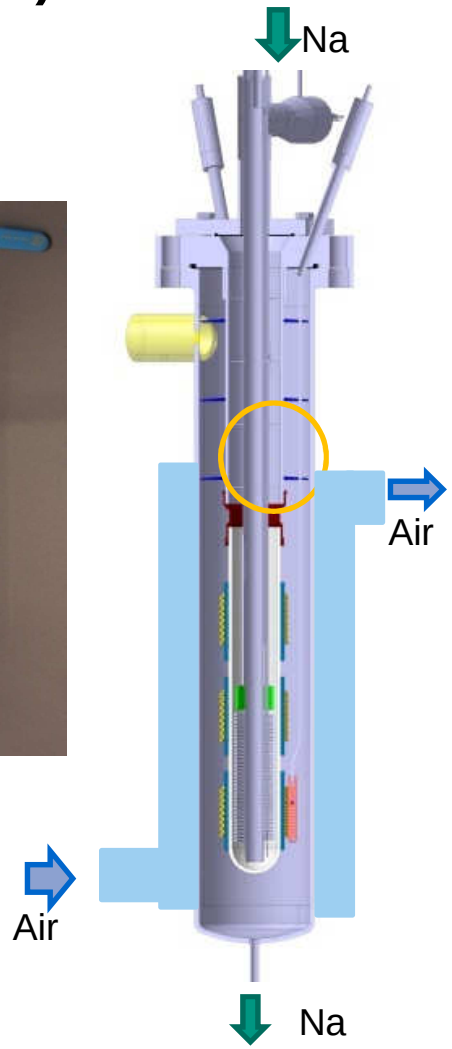
Horizon 2020:

- *JASMIN-Follow up:* ***SALM-IV***
- *Delivered to commission:* ***STARDUST***

Direct Energy Conversion:
Alkali-Metal Thermal-to-Electric Converter (AMTEC)







- BASE: β''-Alumina Solid Electrolyte (Al_2O_3 ~90%, Na_2O ~10%)
- Key process: Na-ionization ($Na \rightarrow Na^+ + e^-$)

<u>Main advantages</u>:
- Achieved efficiency ~ 30%
- Power-weight ratio (< ~500 W/kg)
- Low maintenance: no moving parts
- Flexible regarding the heat source

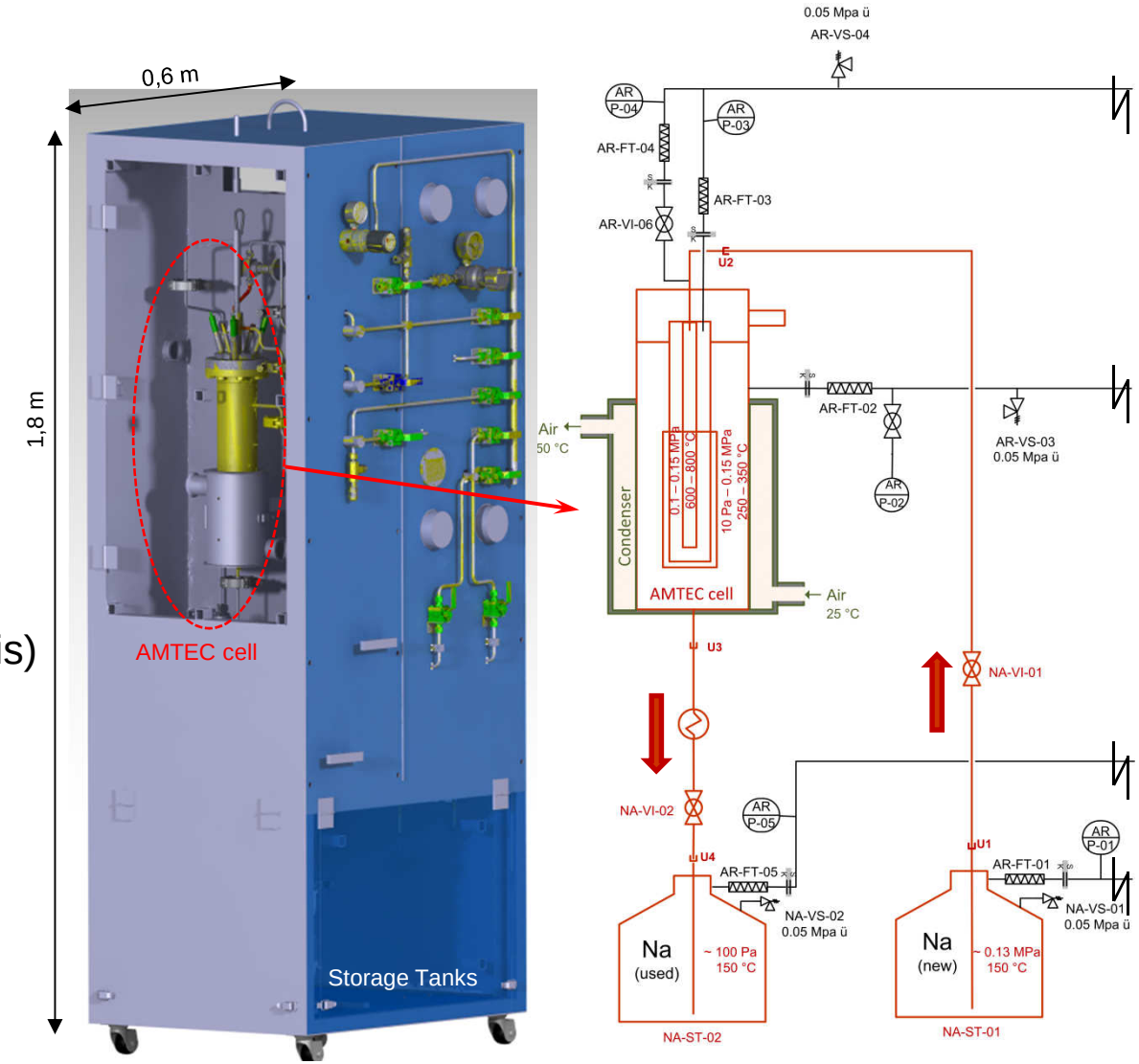
<u>Main disadvantages</u>:
- Large power loss
- Lower real η

* Onea et al. Magnetohydrodynamics 15, 2015

Institute for Neutron Physics and Reactor Technology
Facility design, System dynamics and Safety (ASS)

AMTEC TEst FAcility (ATEFA)

- **Thermal dynamics**
- **Electrochemistry**
- **Control and supervision of AMETC process**
- **Materials, metal–ceramic joints (600 – 100°C)**
- **Safety provision**
- **Education and training** (PHD, several BA and MA thesis)



Progress in 2015 (1/2)

INR

- Sodium/AMTEC laboratory in operation, safety systems installed
- First sodium compatibility tests performed
- Storage and transport casks build and tested
- ATEFA facility ready for implementation of AMTEC device
- Development of LM - CSP 2.0 at KASOLA ongoing

2015: HEMCP Kick-off meeting:
"A high temperature technology: AMTEC – Challenges and Perspectives within the HGF-energy research

Progress in 2015 (2/2)

IAM-AWP

- CORTINA Laboratory (IAM-AWP) in preparation and refurbishment
- Glovebox for local sodium and sample handling delivered
- Samples of innovative materials (W-Cu laminates) available

IHM

- Technology for soldering of ceramics and niobium operational
- Laboratory modifications to safely handle sodium finsihed
- Laboratory devices for protective coatings delivered
- Waiting for SOLTEC-II

Summary

- **KASOLA is on track**
  - Facilities: 1. **KASOLA** waiting for I/C finishing and licensing
    2. **ATEFA** ready for start, operation delayed due to ceramic damages
    3. **SOLTEC** depending on time schedule of selected manufacturer
    4. **CORTINA/ANCONA** to be finalized in 2016
  - **Scientific publications**: 2015: >10 journal and conference papers
  - **Education**: 2 PHDs, several bachelor & master thesis + internships
  - **Industry:** technological help requested from VAST SOLAR (Australia)

- **HEMCP**
  - Roadmap to “Demonstrator” still in time
  - Proposal for HORIZON-2020 **STARDUST** on LM-CSP delivered to EU commission on February 16, 2016
- **LIMTECH**
  - Start of experimental campaign mid 2016
- **Risks:**
    - Human resources reduction!
    - HEMCP and LIMTECH ends in 2017

Something else?

Recover of ancient sodium experiments performed in out institute (1966: IRE → 1994: IRS → 2004: INR → ???)

- Thermal hydraulics: KNS
  → now used for ASTEC-Na validation
- FAUNA
- FAUST
- NACOWA aerosol experiments
- NALA
- THINA (Thermite – Na interaction)
  SINBAD

Inherited:

- AOW: Vaporisation in thermal fragmentation