

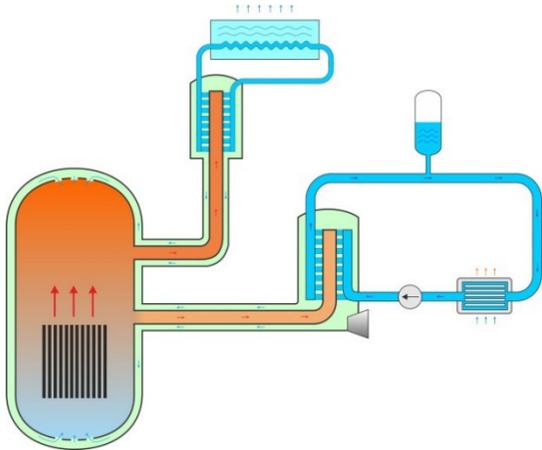
Centrum výzkumu Řež s.r.o.

Candidate materials for GFR concept ALLEGRO and R&D related activities

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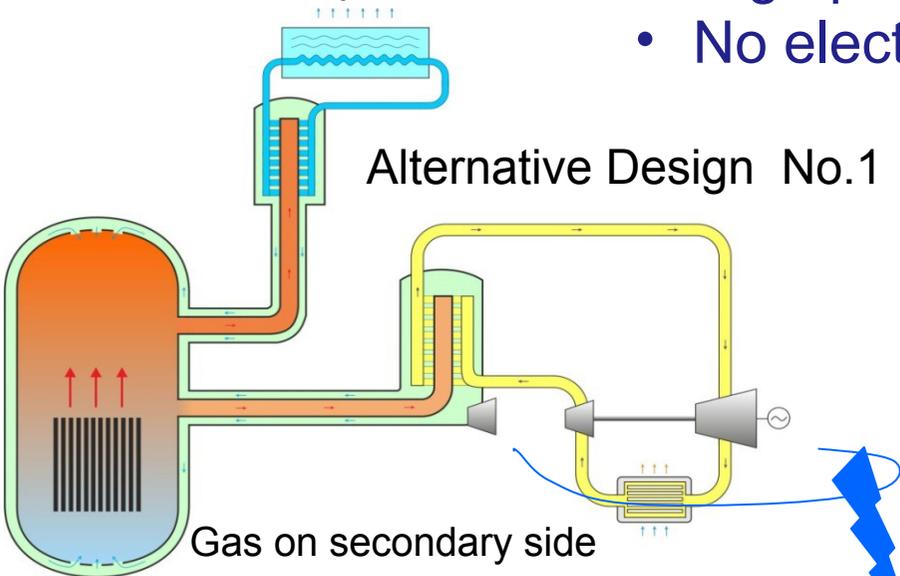
November 25-26th, 2015, Matisse Workshop, Petten

ALLEGRO Design & Modification



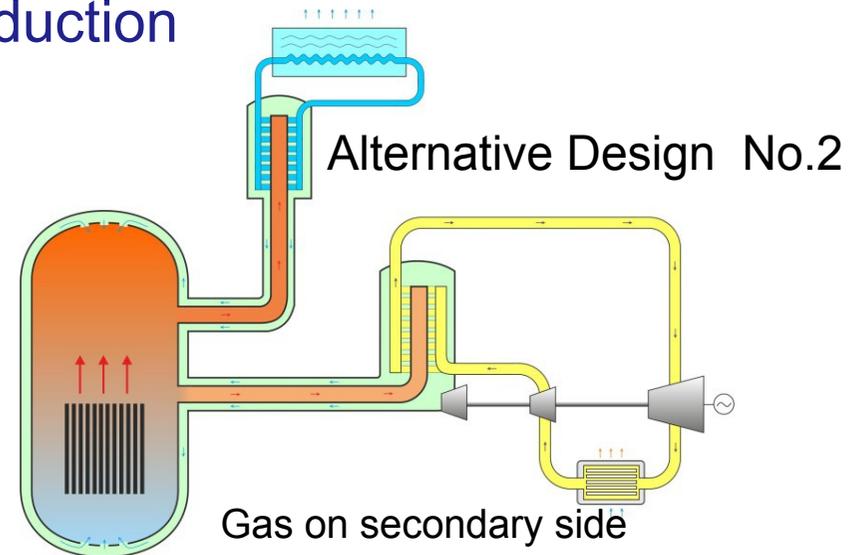
Reference Design of ALLEGRO
Water on secondary side

- Fast-neutron spectrum and closed fuel cycle for efficient conversion of rich uranium and management of long-lived minor actinides
- Coolant: helium
- Outlet temperature up to 850 °C
- Fuel: MOX/composite ceramic clad elements
- Compact core (no moderator)
- High power density $\sim 100\text{-}400 \text{ MW/m}^3$
- No electricity production



Alternative Design No.1

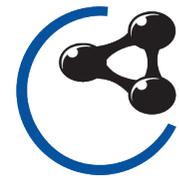
Gas on secondary side
Secondary blower and secondary turbine in one shaft
electrically connected to primary blower



Alternative Design No.2

Gas on secondary side
Primary and Secondary blower,
secondary turbine in one shaft





New ALLEGRO strategy

- To reduce ALLEGRO power from 75 MWth to cca. 10 MWth and to find the optimum core configuration
- To optimize nitrogen injection (launch time, duration) and the backup pressure in guard containment
- To increase main blowers inertia to avoid short term peak temperature for the LOCA+ blackout case and/or to develop a design with a gas turbine in the secondary side coupled to the primary blowers
- Initial core: UO₂ pellets in AIM1 (15-15Ti) cladding instead of MOX pellets; replaced by ceramic fuel
- A new systematic Roadmap is prepared to cover all design, safety and experimental aspects of ALLEGRO development. 75 tasks were shared by the partners: VUJE, UJV, NCBJ and MTA EK. Participation of CEA.





GFR challenges

- Necessity of **high-temperature resistant (refractory) fuel – cladding** capable to withstand very high temperatures
- **High temperature corrosion resistant materials** (cooling circuit, heat exchanger, **insulation, sealing**)
- Relatively **high pressure** in primary circuit & related highly efficient circulators
- Rapid heat-up of the core following loss-of-forced cooling due to:
 - Lack of thermal inertia (gaseous coolants & the core structure)
 - High power density (100 MW/m³)
- Difficult removal of decay heat in accident conditions (LOCA)
- Relatively **high temperature non-uniformities along fuel rods**
- High coolant velocity in the core (vibrations)
- He leakage from the system & He recycling & He chemistry control



GFR Power conversion system options



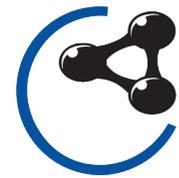
GFR Specific challenges: structural materials

GFR Component	Temperature [°C]*	Material
Fuel - cladding	530	SS 316, 15-15Ti
	850 (1650)	SiCf/SiC
Reflector	530	SS 15-15Ti
	850	ZrC
HT component	530	FM steels HCM12A, Stainless steel 316, 304, 15-15Ti, 12-25Ti
	850	Alloy 800?, IN 617, SS 316, ODS?, Hastelloy X, Hastelloy XR, Hayness 230
Reactor PV	530	2 1/4Cr-1Mo bainitic steel
	850	9Cr-1MoVNb, 7-9Cr2WV (EUROFER), Fe-3Cr-3WV, 12Cr
Power conversion		Alloy 713LC; IN-100;

*pressure 6-7 MPa

Power conversion

ALLEGRO: Reactor Pressure Vessel



Requirements

- Very long term aging and structural integrity (60years)!
- Industrial feasibility: manufacturability & weldability
- Environmental effects (impure He compatibility) on oxidation, fatigue, fatigue crack growth at very high temperature (incl. accidental conditions)
- The database characterizing the effects of neutron irradiation on the nil-ductility transition temperature and the fracture toughness.
- Tensile and very long term creep and creep-rupture properties of the plate, forging, weldments, and heat-affected zones of this class of materials (operating T 400-550°C 100 dpa)
- High temperature bolting (IN718; SS 304; SS 316)

Candidate materials RPV:

9Cr1Mo-**T9**; 9Cr2Mo; 9Cr-MoVNb-**T91**; 9Cr-0.5Mo1.8WVNb-**T92**; 12Cr-1Mo-1WVNb-**HCM12**

Reference material: 316LN

Possible materials (&Xcut fusion): F82H (7.5Cr2WV), JLF1; EUROFER (9Cr2WV); 3Cr-3WV; F/M ODS; P91, P92



ALLEGRO: High Temperature Components



Requirements

- High thermomechanical resistance (temperature 850°C & pressure 7MPa)
 - Good tensile, fatigue characteristics and long-term creep resistance
- Resistance to extreme environments – corrosion/oxidation in impure helium; H₂ and He embrittlement
- Industrial feasibility: manufacturability & joining techniques & compactness

Intermediate Heat Exchanger:

High thermal efficiency (95%), low pressure drop, no leakage, inspectability and lifetime (20 years)

Printed circuit HE

- compact, counter-flow heat exchanger design based on plate sheets into which fluid flow channels are chemically etched and assembled by diffusion bonding

Plate fin HE

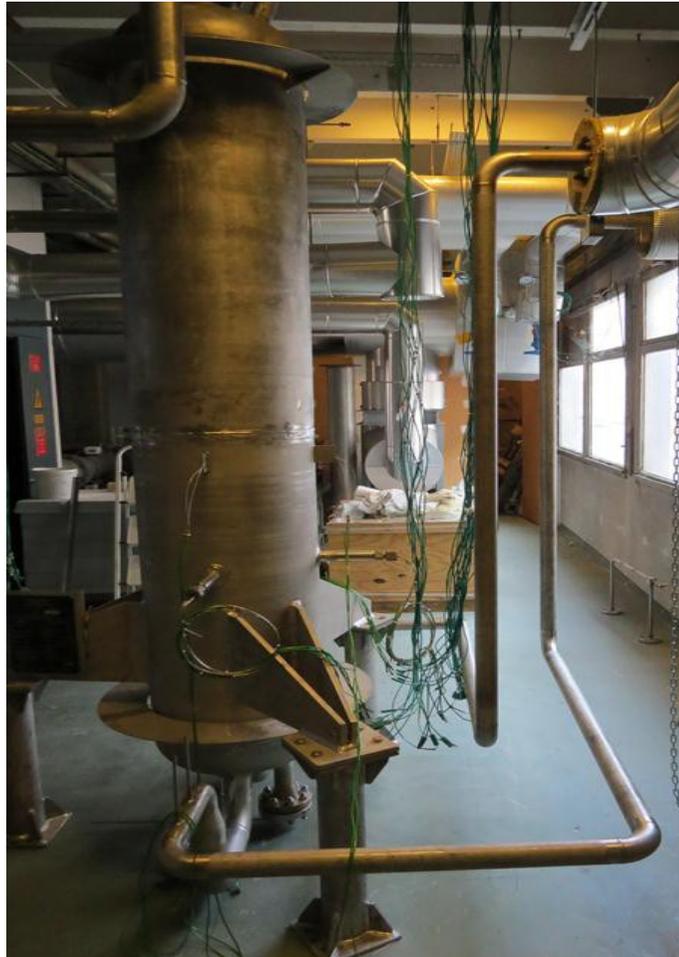
- very thin fins formed by stamping and assembled by brazing on flat foils

Helical tubular HE

- back-up option



Example: High Temperature Components



Compact IHX (Alloy8000 developed within ARCHER project; tested in CEA loop



Helical tubular SG (Alloy 800) HTR-PM reactor China



ALLEGRO: High Temperature Components

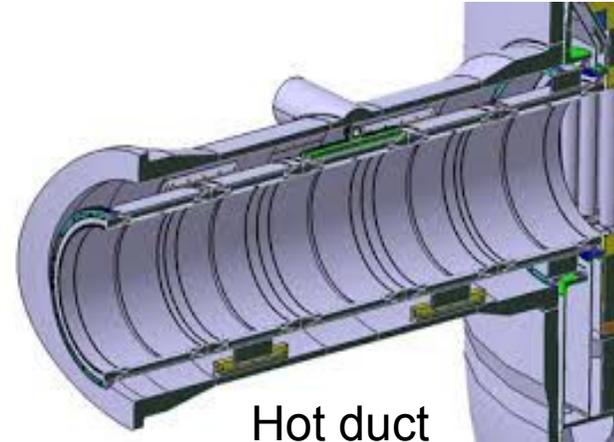


Hot Duct

HT part up to 900C

LT part 400-500C

Insulation material: fibrous C-C



Valves

Specific component- coaxial pipes

Candidate materials HT components:

IN617; Hayness 230; Hastelloy X, 316FR (700C);

Reference material: Alloy 800H (HTR technology)

Possible materials: SAVE 25; 602CA; HR120; Sanicro29

Power conversion system

Turbine

High temperature (850 °C), high mechanical stresses (~ 225 – 266 MPa), low corrosion by He impurities

Candidate materials:

Ni-base alloy for disk and coated DS Ni- base alloys or single crystals for blades



ALLEGRO: Fuel & cladding

Requirements of the fuel cladding:

- leak-tightness barrier to fission products & to coolant
- good mechanical behaviour up to 1 600°C (integrity up to 2 000°C): ductility, fracture toughness; irradiation creep; thermal shock under accident conditions
- thermal conductivity ($> 10 \text{ W.m}^{-1}\text{.K}^{-1}$); low thermal expansion
- chemical compatibility with fuel and cooling gas (helium); protection against potential oxidation & **erosion**.

Candidate materials: 3 distinct phases of operation- 3 different core configurations:

STARTING MOX CORE

- MOX/SS with 25% Pu (metallic hexagonal sub-assemblies).

Core outlet temperature limited to $\sim 530^\circ\text{C}$

INTERMEDIATE MOX CORE (containing 1 to 6 ceramic fuel assemblies)

- Test assembly (U,Pu)C/SiCf-SiC with 29-35% Pu fuel pins bundle within an internally insulated metallic hex-tube.
- Test assembly outlet temperature $\sim 850^\circ\text{C}$ (reduced flow rate at inlet)

Average core outlet temperature limited to $\sim 530^\circ\text{C}$

FINAL CERAMIC CORE (ceramic fuel assemblies only).

- Average core outlet temperature increased to $\sim 850^\circ\text{C}$.



ALLEGRO: Control rods & fuel subassembly



Requirements:

- Long-term stability of dimension and physical properties;
- Detrimental irradiation effect on the interphase and its capability of deviating cracks and thus providing reasonable fracture toughness;
- Required high creep strength of the fiber to bear thermal-mechanical loading in long-term service under high temperature and neutron flux;
- Mechanical damage under irradiation and creep
- Good mechanical behaviour at temperatures above 1100°C

Candidate materials:

C/C composites; B_4C ; Eu_2O_3 ; EuB_6 ; SiC/SiC composites; Al₂O₃-SiO₂ ceramic fiber material

Thermal insulation, sealing materials

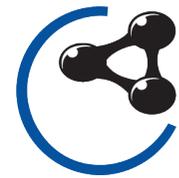
Safety thermal shield; reflector

Candidate materials:

C/C composites; SiC/SiC composites; Al₂O₃-SiO₂ ceramic fiber material; Zr_3Si_2



ALLEGRO related R&D proposed work



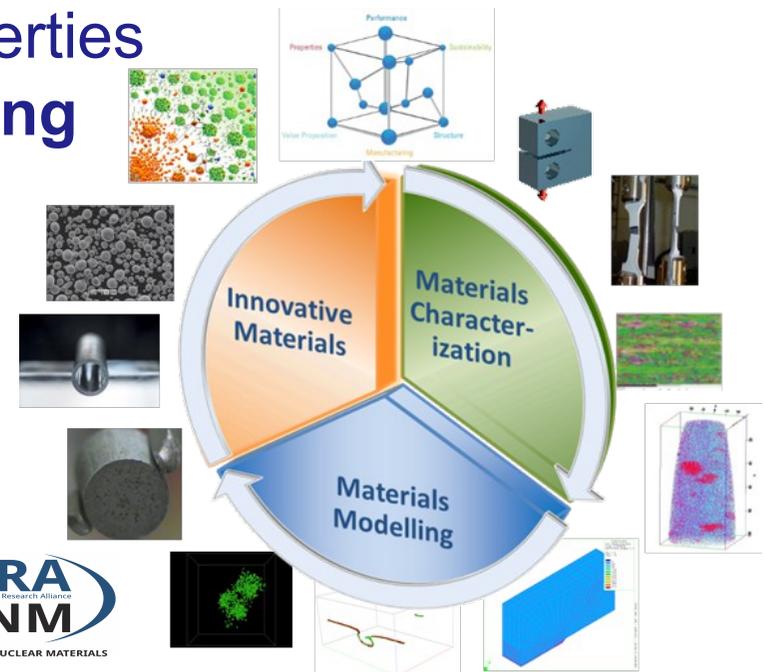
- Regulatory and Codification Requirements, development of codes, norms and methods
- Fabrication issues (joining & post-weld treatment)
- Irradiation damage (RPV, internals, fuel assembly)
- Corrosion/oxidation/erosion resistance of selected materials**
 - long term exposure tests

- Thermal aging; thermal shock degradation of fuel
- Design & Modeling work – mechanical properties
- Components design development & testing**
- Swelling
- Creep behaviour

Materials: F/M steels

HT materials (Ni-alloys)

ceramics



CVR experimental facilities, R&D support: Corrosion/oxidation/erosion resistance of selected materials in HT helium

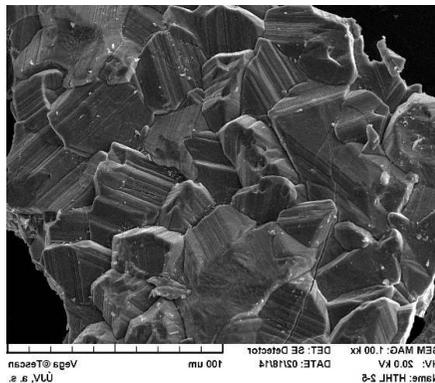
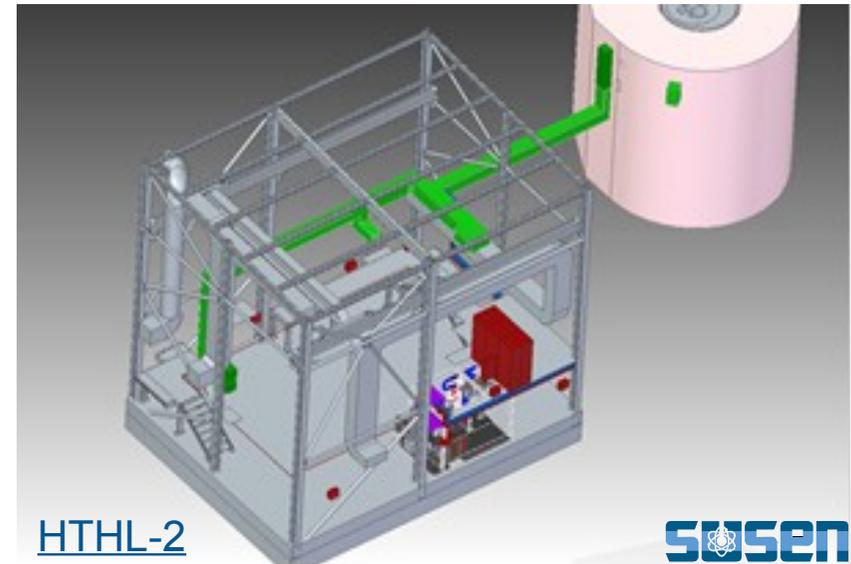


Facilities: High Temperature Furnace (HTF),
High Temperature Helium Loop (HTHL-1),
**HTHL-2, *S-Allegro*

Conditions: T= 850°C; pressure 7MPa, He

Application:

- High temperature corrosion tests of the structural materials in simulated helium coolant environments out of pile and **in pile test – reactor LVR-15*
- Purification of gaseous coolant (He)



Selected materials for testing:

- Steels (FM, austenitic, ODS)
- Nickel alloys
- Graphite
- Ceramics (SiC/SiC, Al-based c.)



CVR experimental facilities, R&D support: Component design development & testing



Inactive experimental equipment with electric heating model active zone

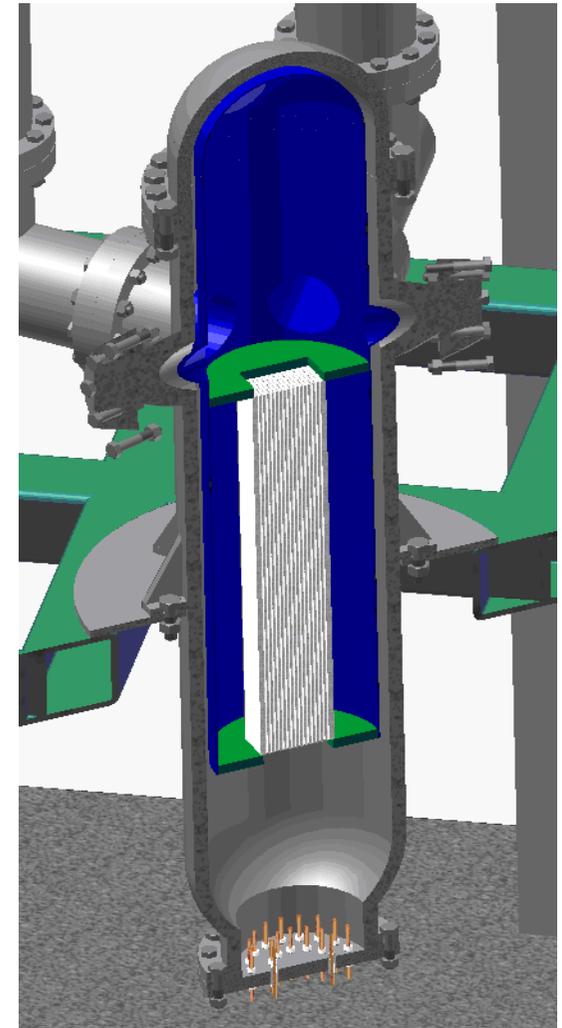


■ Model parameters

- Medium – *helium*
- Pressure – *7 MPa*
- Max. temperature – *900°C*
- Power – *1 MW*
- Flow rate – *0,5 kg/s*
- On-line monitoring: temperature, pressure, power, flow rate

■ Testing

- Piping system, valves – heat transfer internal and external
- Reliability tests
- Construction material and manufacturing technology
- Component testing
- Verification of the inherent and passive safety characteristics under accident conditions including the use of the DHR



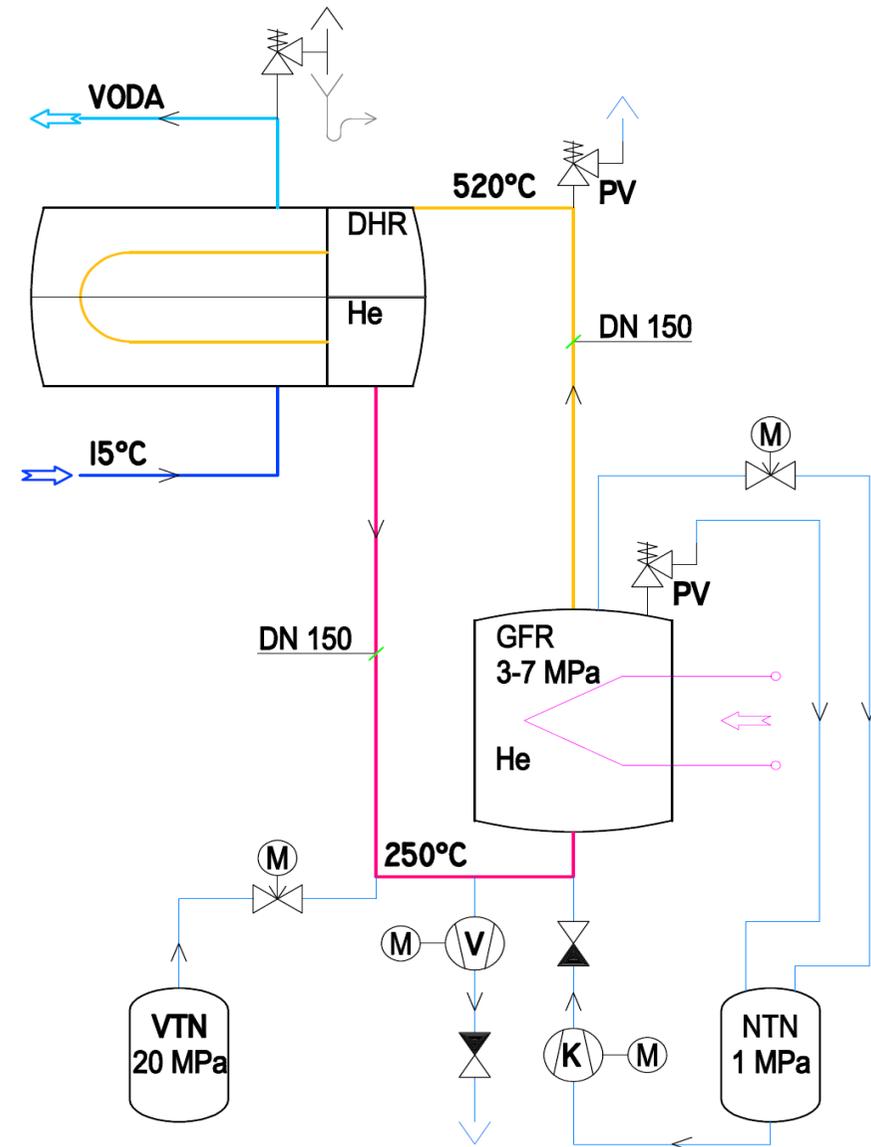
Project „ALLEGRO Research Centre“ in Slovakia



Experimental helium loop

- WP2. Applied research and development in the area of new materials and technologies
- Task 3 Equipment research for ALLEGRO reactor

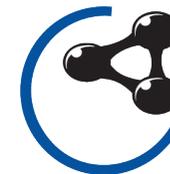
Experimental helium loop, Faculty of Mechanical Engineering, STUBA



Czech companies involved in GFR/HTR related projects



Name	Type; activity	Website	
MICo	Industrial company developing seals and heat exchangers for nuclear power engineering	www.mico.cz	
EVECO	Industrial company developing devices for gas cleaning	www.evecopraha.cz	
Prague Casting Services	Industrial company producing high temperature components by precision castings by the lost wax method.	www.praguecast.cz	
ESTCOM – oxide ceramic	Industrial company producing ceramics based on corundum	www.estcom.cz	
ATEKO	Industrial company, offers turn-key deliveries of complete investment plants in the field of chemical and food industry, refrigeration, power production technologies and environmental protection technologies.	www.ateko.cz	



Thank you for your attention!



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