ÚJV Řež, a. s.

Project ALLEGRO V4G4

French – CZ/SK/HU/PL Collaboration

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using information with courtesy of CEA

2nd French-Czech «Barrande» Nuclear Research Workshop,
Honfleur, France, April 24-26, 2019

Outline

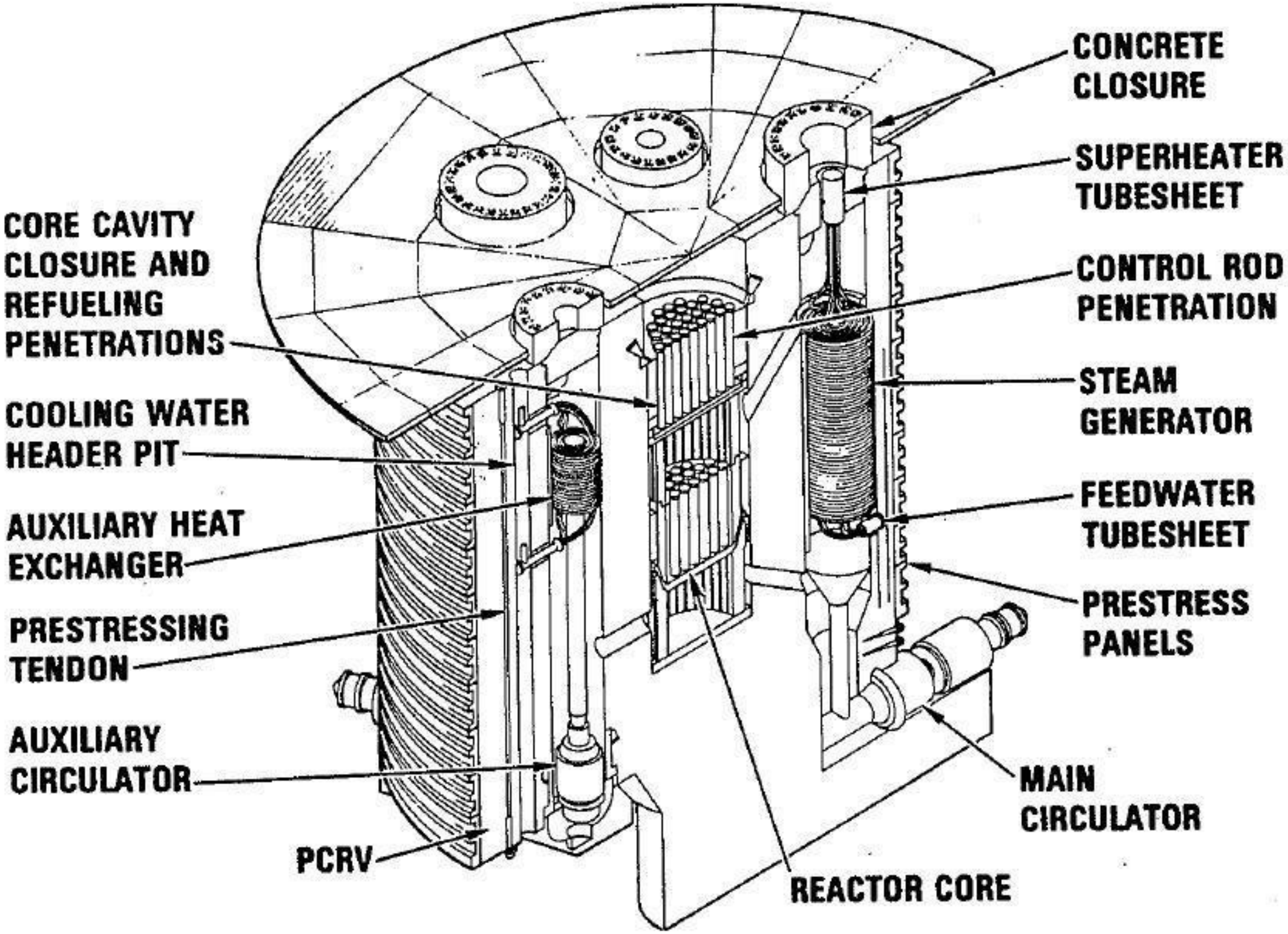
- Gas-cooled Fast Reactors – Main features & Past GFR Projects
- Philosophy by CEA of a Demonstration unit ALLEGRO
- ALLEGRO 2009 – Project of CEA
- ALLEGRO V4G4 – Project of „V4G4 Centre of Excellence“
- R & D for ALLEGRO
- Perspectives & Conclusions

Gas-cooled Fast Reactors (GFR) – Motivation & Concepts

- Helium in Fast reactors: Yet never built alternative to liquid metals
  - Advantages:
    - Transparent for neutrons, inert (no corrosion, no activation),
    - Easy in-service inspection & coolant decommission
    - For temperatures >700 °C
  - Disadvantages:
    - High pumping power & coolant velocity & pressure
    - Difficult decay heat removal in accidents

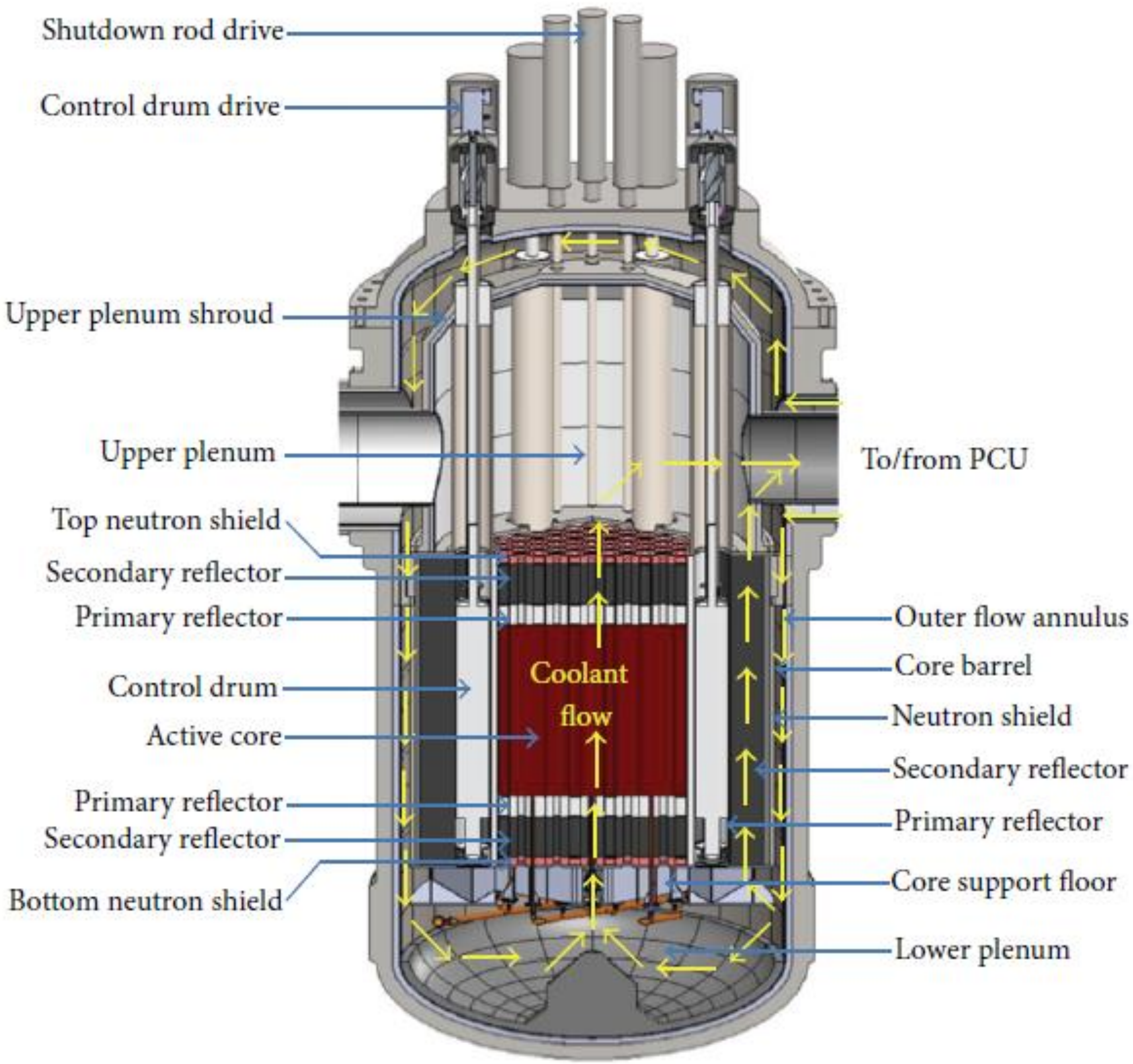
- Past & Recent GFR conceptual designs
  - >1960: Based on MOX/SS (or TRISO), PCRV, max. ~550 °C
    - 1962-1980: General Atomics (GA) 367 MWe, He
    - 1968-1978: European GBR1 to GBR4, ~1000-1200 MWe, He, CO2
    - ~1980 Soviet design, ~1000 MWe, >16 MPa N2O4, U/UO2 in Cr matrix
  - >2000: Refractory fuel (SiC tubes or plates) & steel RV & Guard vessel, max. 800-850 °C
    - CEA – GFR2400 (~1140 MWe), mixed-carbide fuel, 7 MPa He
    - GA – EM2 (~265 MWe SMR), uranium-carbide fuel, 13 MPa He

Example: General Atomics GCFR concept 367 MWe

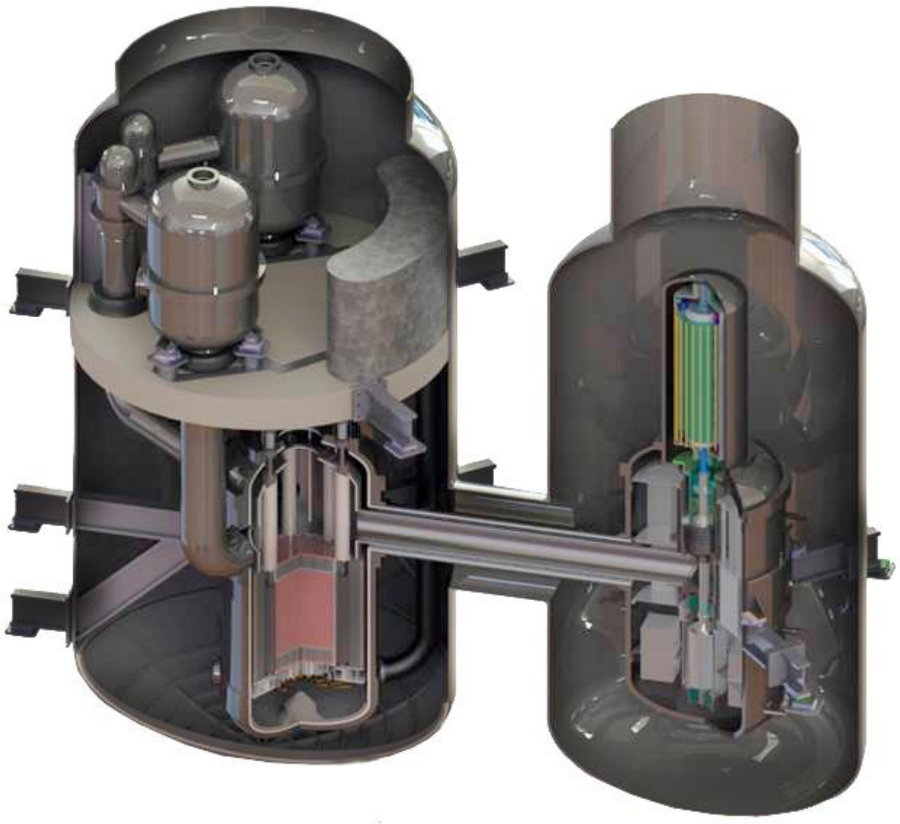


- He 10.5 MPa
- Tin/out = 298/524 °C
- 3 loops with blowers (3 * 10.6 MW)

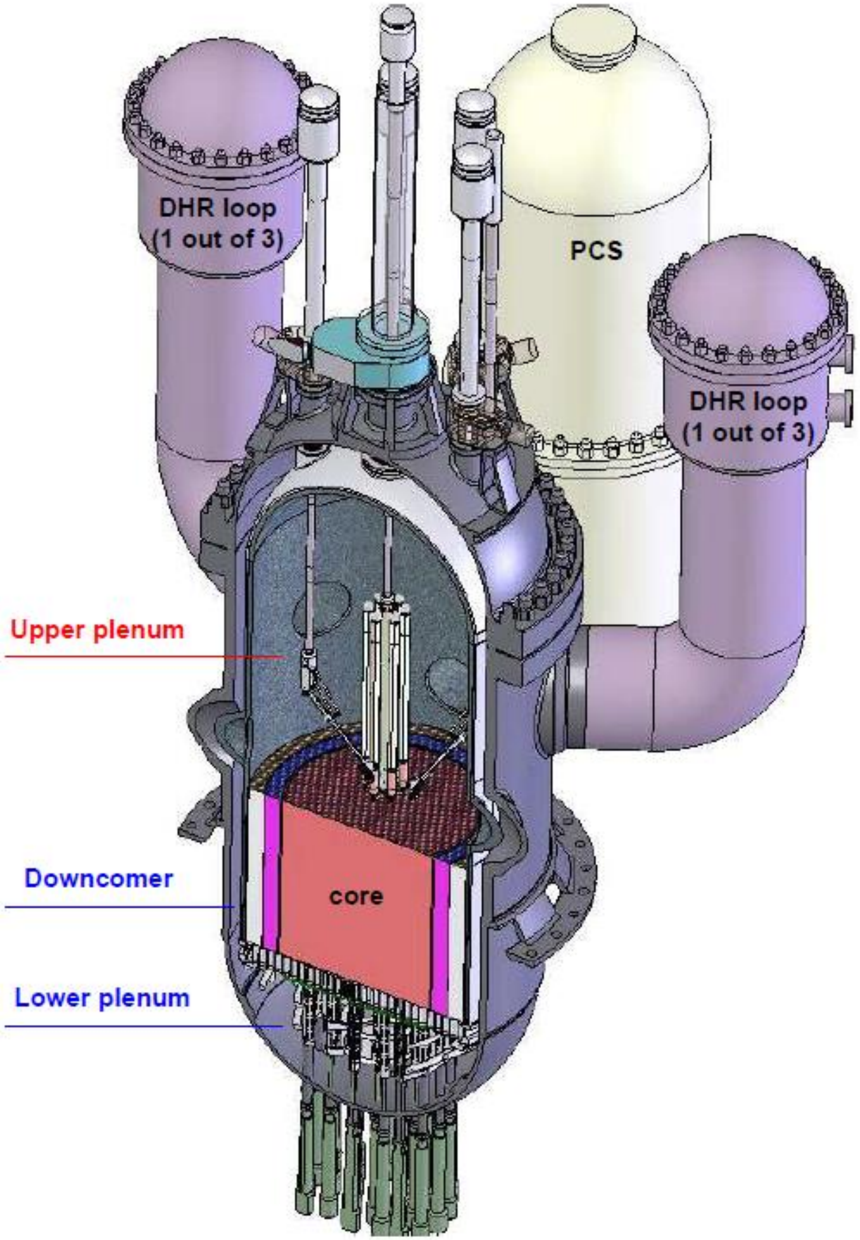
Example: General Atomics GFR concept EM2, 500 MWt, 265 MWe



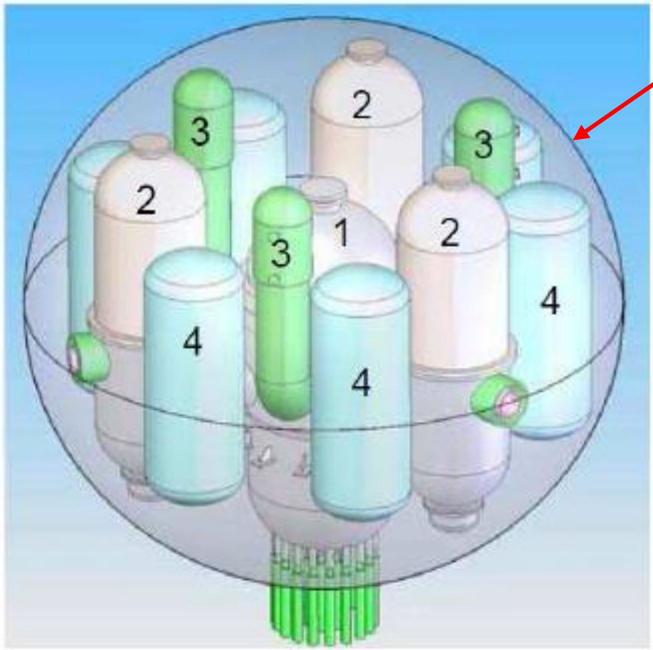
- He 13.3 MPa
- Tin/out = 549/850 °C
- 1 loop Brayton cycle
- I. circuit inside Guard vessel



Example: CEA GFR concept 2400 MWt, 1140 MWe (1)



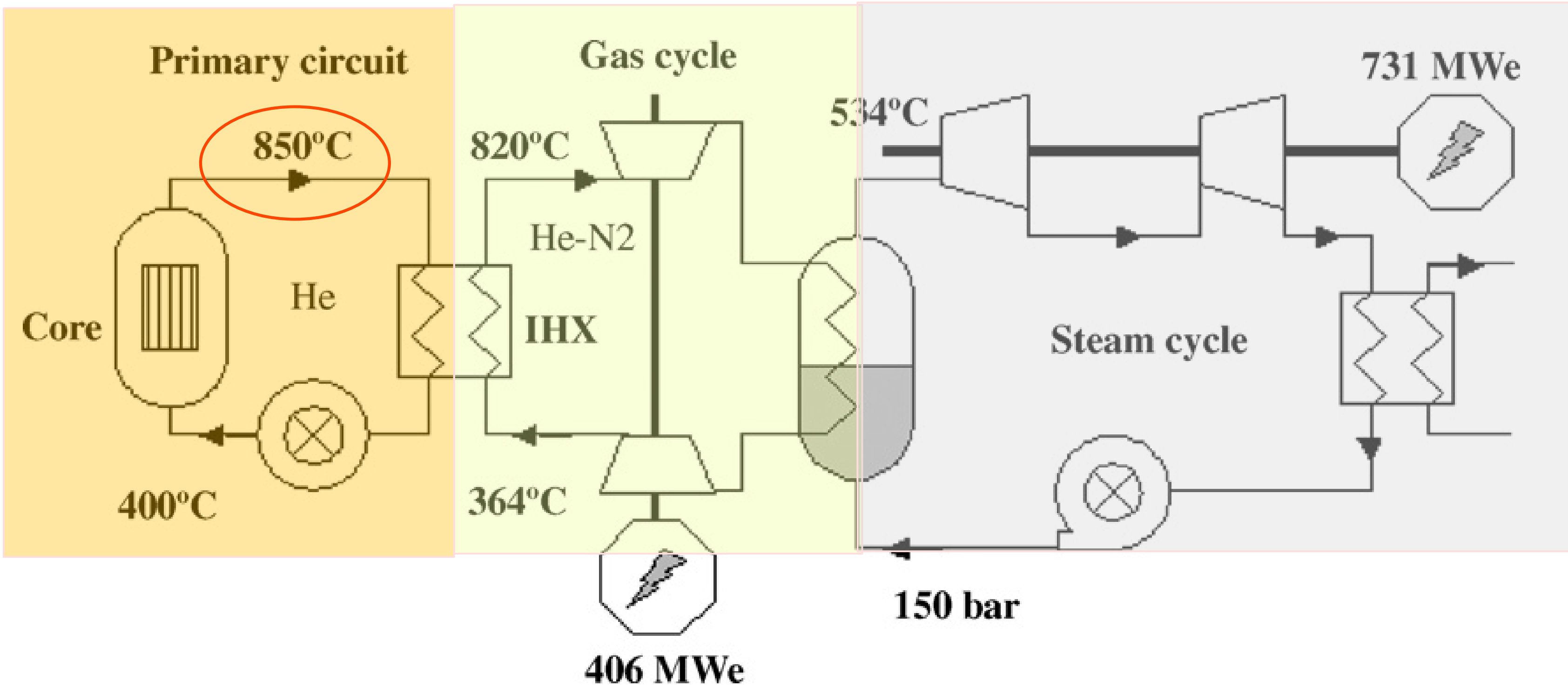
- He 7 MPa
- T in/out = 400 / 850 °C
- 3 loop combined cycle
- I. circuit inside Guard vessel



Guard vessel

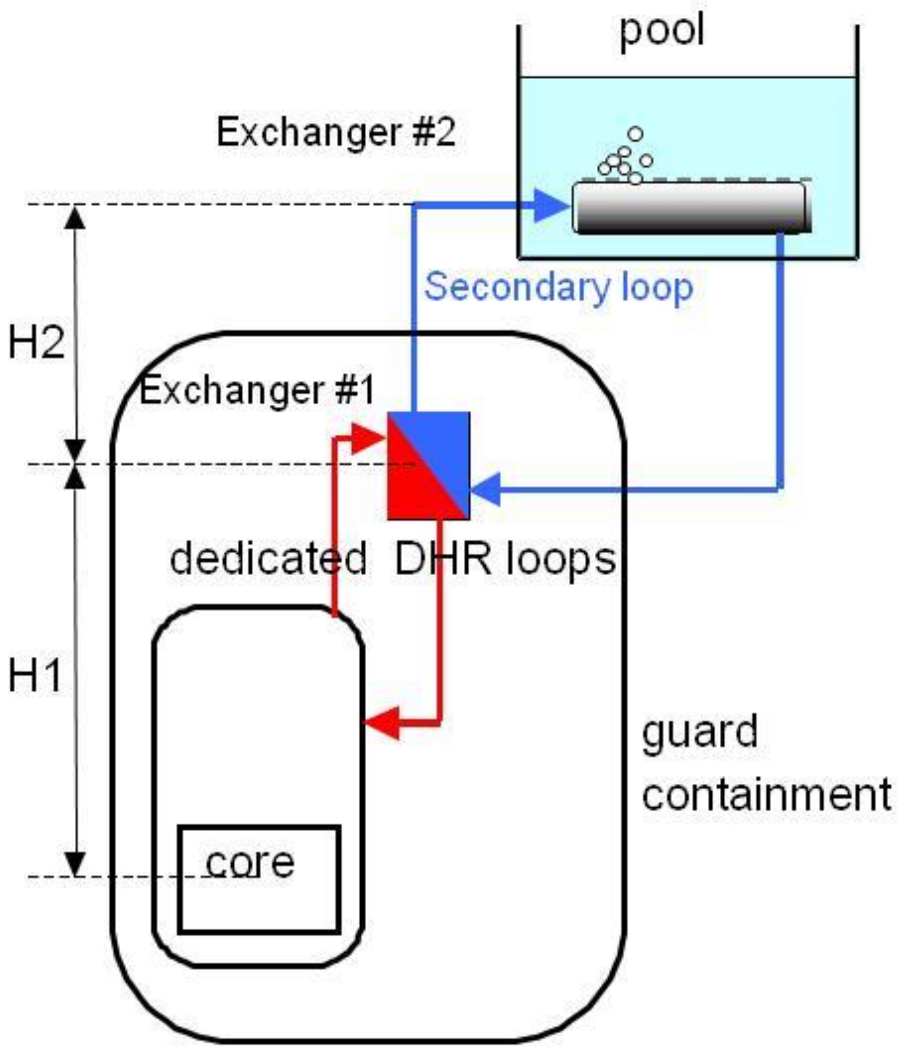
1 RPV
2 MHX
3 DHR
4 He tanks

CEA GFR 2400 MWt: Reference combined cycle (2)



1. **Direct cycle, Tin = 480°C: η ~ 47.5 %**
2. Indirect cycle, Tin = 480°C: η ~ [45.5 – 45.6] %
3. Direct cycle, Tin = 400°C: η ~ 44.8 %
4. **Indirect combined cycle, Tin = 400°C: η ~ [44.4 - 44.7]%**
5. Indirect cycle, Tin = 400°C: η ~ [42.4 – 42.8]%

>2000: Solution for Decay Heat Removal (DHR) from a GFR core



- HTR (~5 MWt/m^3) "conduction cool-down" will not work in a 100 MWt/m^3 GFR
  - High power density, low thermal inertia, poor conduction path and small surface area of the core conspire to prevent conduction cooling.
- A convective flow is required through the core at all times;
  - At pressure:
    Natural convection flow is OK (establishes easily)
  - After depressurization (Guard vessel intact):
    Forced flow is OK (when active systems available)
    - DHR blower pumping power very large at low P

Natural (passive) cooling is OK only, if the gas density (pressure in GV) is high enough (~1 MPa).

ALLEGRO: Concept by CEA of a first ever GFR demonstrator

- To establish **confidence** in the GFR technology with the following objectives:

A) To **demonstrate the viability** in pilot scale & **qualify specific GFR technologies** such as:

- Core behavior & control including fuel
- Safety systems (decay heat removal, ...)
- Gas reactor technologies (He purification, refueling machine …)
- Integration of the individual features into a representative system

B) **To contribute** (by Fast flux irradiation) **to the development of future fuels** (innovative or heavily loaded in Minor Actinides)

C) To provide test capacity for high-temp components or heat processes

D) To dispose of a first validated Safety reference Framework

- **Power conversion system is currently not required in ALLEGRO.**

Philosophy by CEA for the ALLEGRO core design

- Three distinct phases of operation ⇒ three different core configurations:

- STARTING MOX (or UOX) CORE
  - Oxide fuel in SS (MOX ~25% Pu) – Phenix-based hex. Fuel Assemblies
  - Core outlet temperature limited to ~530 °C

Oxide / SS fuel has small safety margin

- INTERMEDIATE CORE (containing 1 to 6 refractory FAs)
  - Exp. refractory FAs: (U,Pu) carbide pellets in SiCf-SiC pins (29-35% Pu) inside thermally insulated metallic hex. wrapper tube.
  - Outlet temperature: Test assembly ~800-850 °C (reduced flow rate at FA inlet)
    Average core ~530 °C

- FINAL REFRACTORY CORE
  - Average core outlet temperature increased to ~800-850 °C

Refractory fuel needs R&D

- Remark: ALLEGRO must be designed for the high-temperature option (incl. low-to-high T upgrade procedure of certain technologies)

ALLEGRO CEA concepts to be continued in Central Europe

~2002

- **ETDR CEA 2008** (**E**xp. **T**echnology **D**emonstration **R**eactor)
  50 MWt, 1 loop, He/water (FP6 GCFR STREP)
- **ALLEGRO CEA 2009** (ALLEGRO is not an acronym)
  75 MWt, 2 loops, He/water (FP7 GoFastR)
- **ALLEGRO CEA 2010**
  75 MWt, 2 loops, He/gas (He), Patented option (turbomachinery)

~100 MWt / m^3

CEA + EURATOM

2010

- **ALLEGRO V4G4 2019**
  ≤ 75 MWt, 2-3 loops, He / (N_2-He)
  based on ALLEGRO CEA 2009

50-100 MWt / m^3

May 2010
Memorandum of Understanding
MTAEK – UJV – VUJE

August 2013
V4G4 Centre of Excellence
MTAEK–NCBJ–UJV–VUJE (+CEA & CVR)

CZ
HU
SK
PL
F

ALLEGRO V4G4: Background

- 2002-2010: CEA - Development of GFR2400 & ALLEGRO 50-75 MWt
- 2010-2025: CZ-HU-SK- PL- Preparatory phase of ALLEGRO:
  - 05/2010: MoU: Prepare documents (pre-conceptual design) for decision makers (ALLEGRO Yes/No)
  - 08/2013: „V4G4 Centre of Excellence“ - Association (legal entity) founded in SK
    - VUJE Trnava (SK): Responsible for Design & Safety (with ÚJV)
    - ÚJV Řež (CZ): Helium technology, R&D and Experimental support
    - MTAEK Budapest (HU): Fuel & Core
    - NCBJ Swierk (PL): Materials (?)
    - Associated members: CEA (FR) 2017, CV Rez (CZ) 2018

Industry

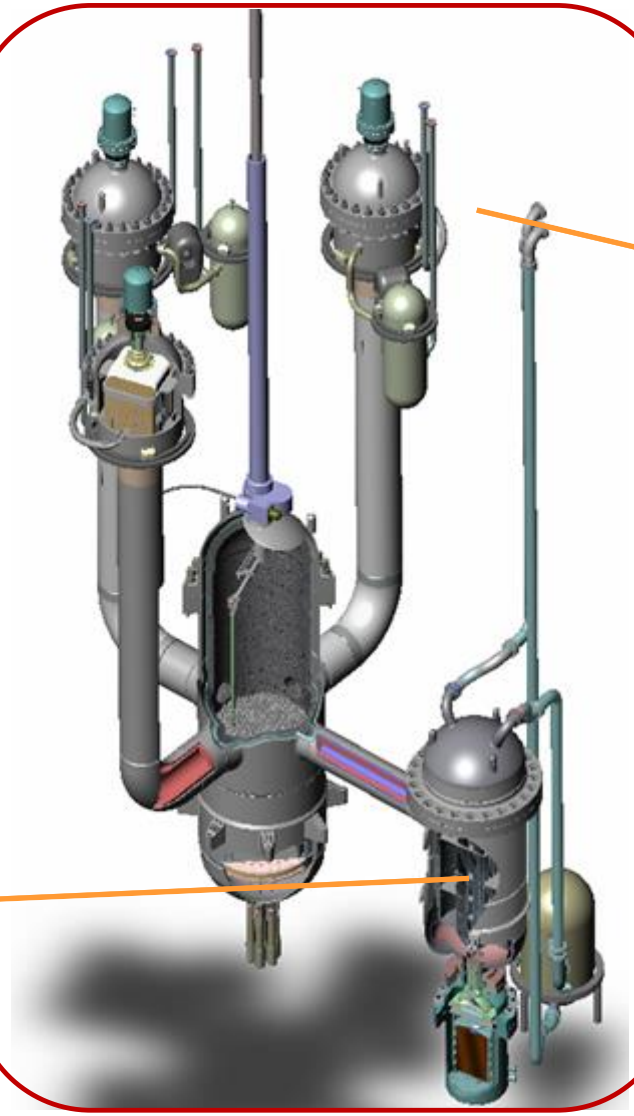
Research

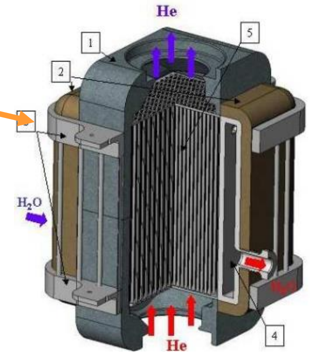
- ALLEGRO Preparatory phase by V4G4 CoE:
  - Pre-conceptual Design: Revision of ALLEGRO CEA 2009 → New ALLEGRO V4G4 concept (2020-25)
  - Safety: Core coolability (passive mode)
  - R&D and Exp. support: Under formulation (helium technologies underway)

ETDR CEA 2008 (50 MWt) – Design of I. circuit

Main parameters	Value
Core outlet T	**260 / 560 °C** (driver core), **480 / 828 °C** (refract. core)
Primary coolant	**Helium 7 MPa**
Secondary circuit	**Water 6.5 MPa**

Note:
I. circuit is enclosed in a close containment (guard vessel) not shown here

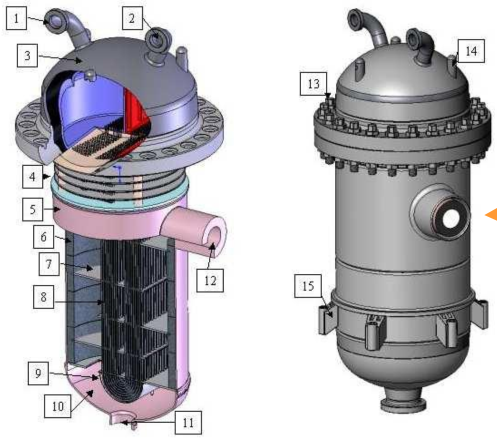




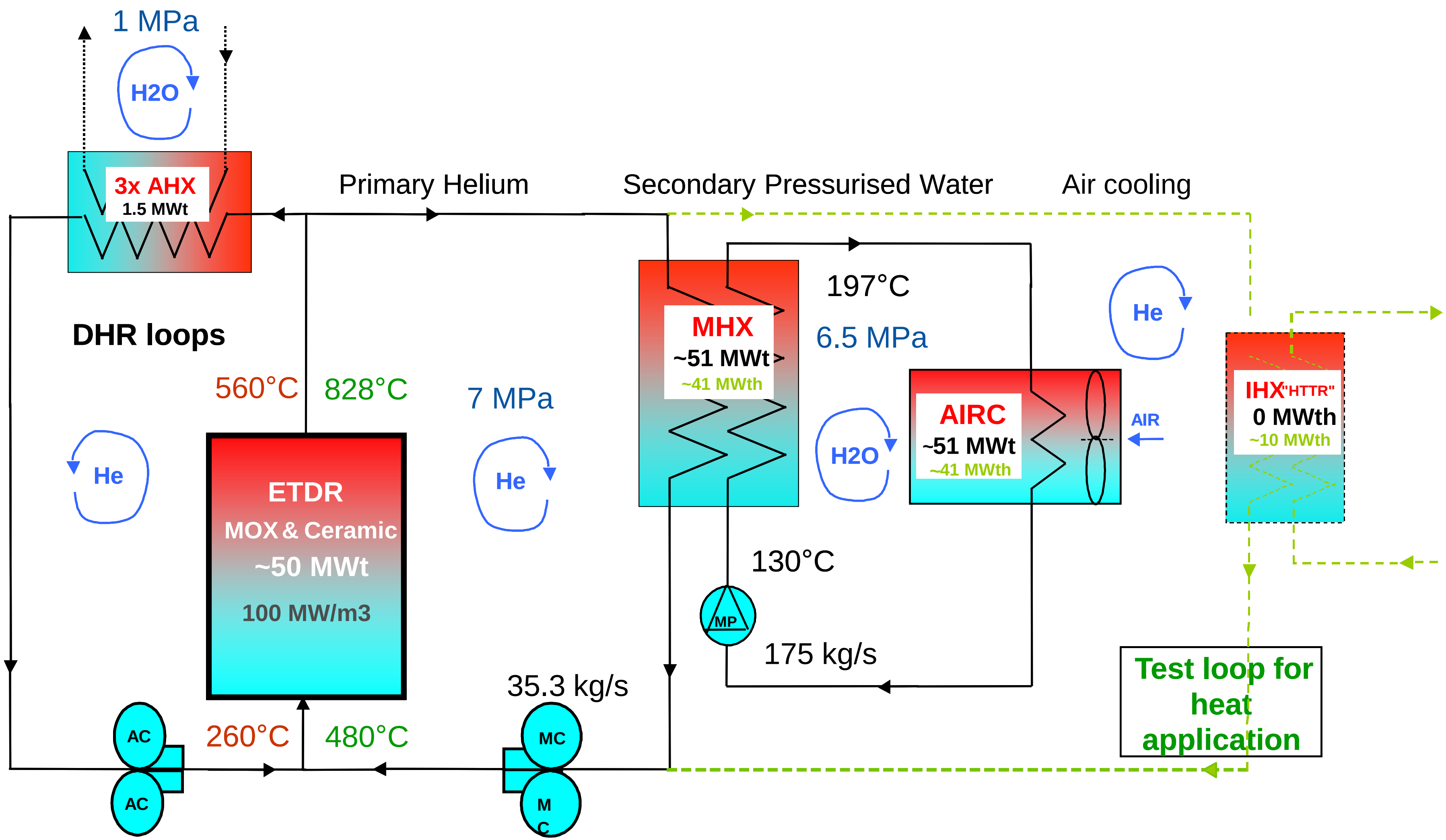
Decay Heat Removal
(DHR)
Heat Exchanger

Note: This DHR HX does not promote natural convection

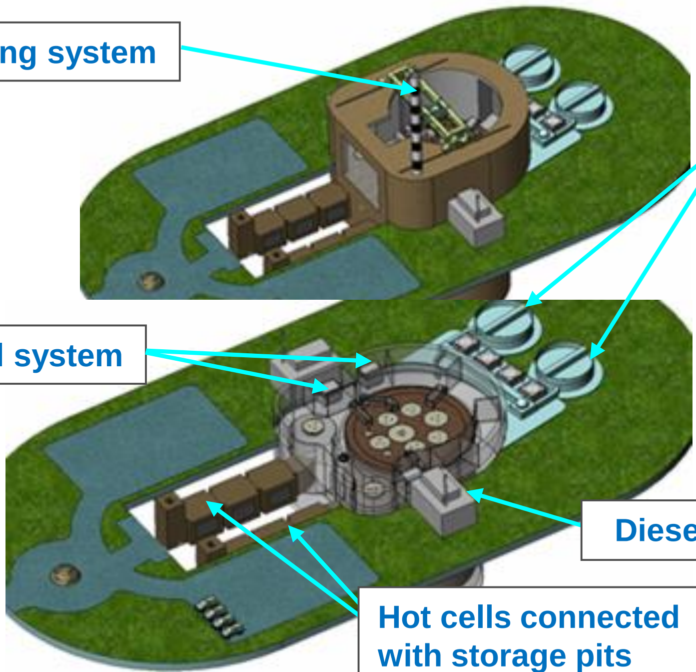
Main HX (gas/water)
(similar to IHX
in JAEA HTTR)

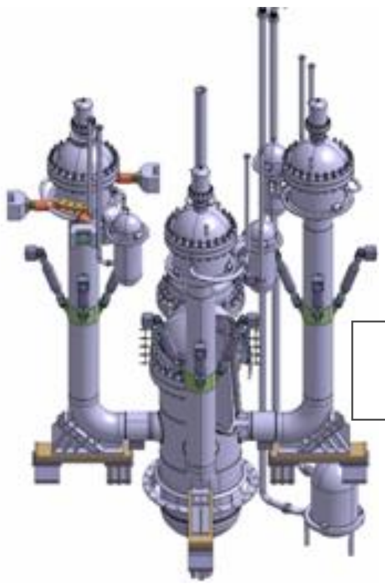


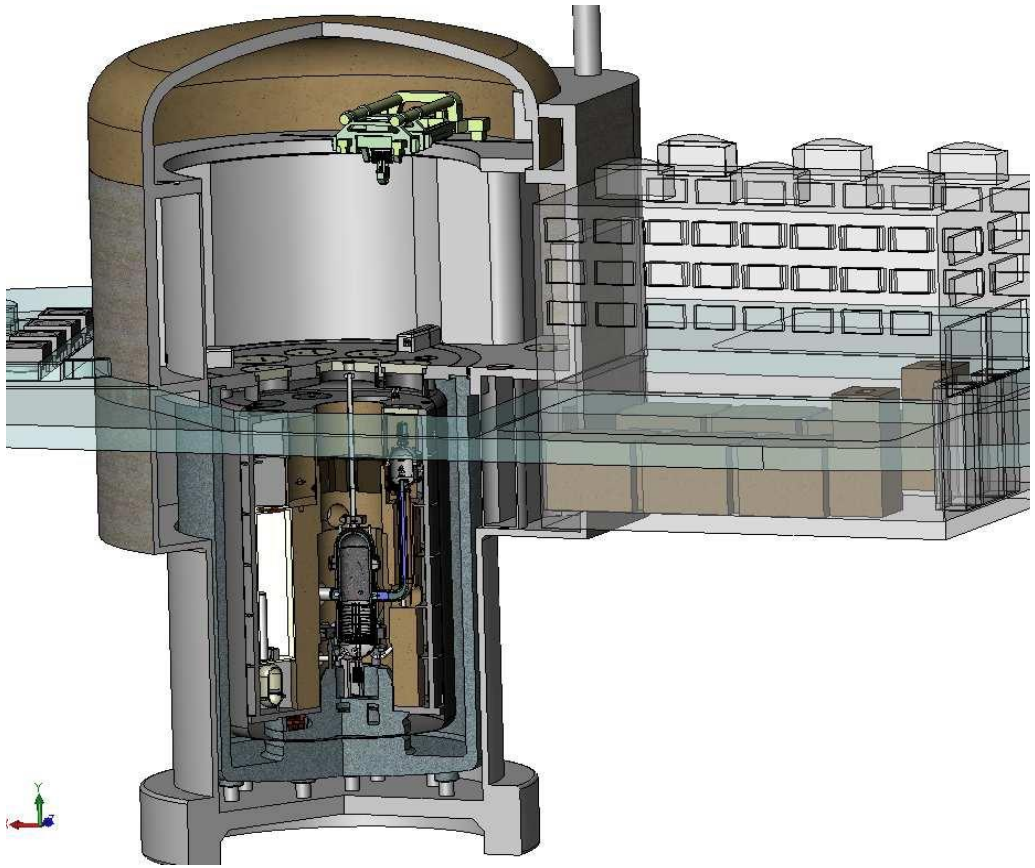
ETDR CEA 2008 (50 MWt) – Thermal scheme



ETDR CEA 2008 (50 MWt) – Global view

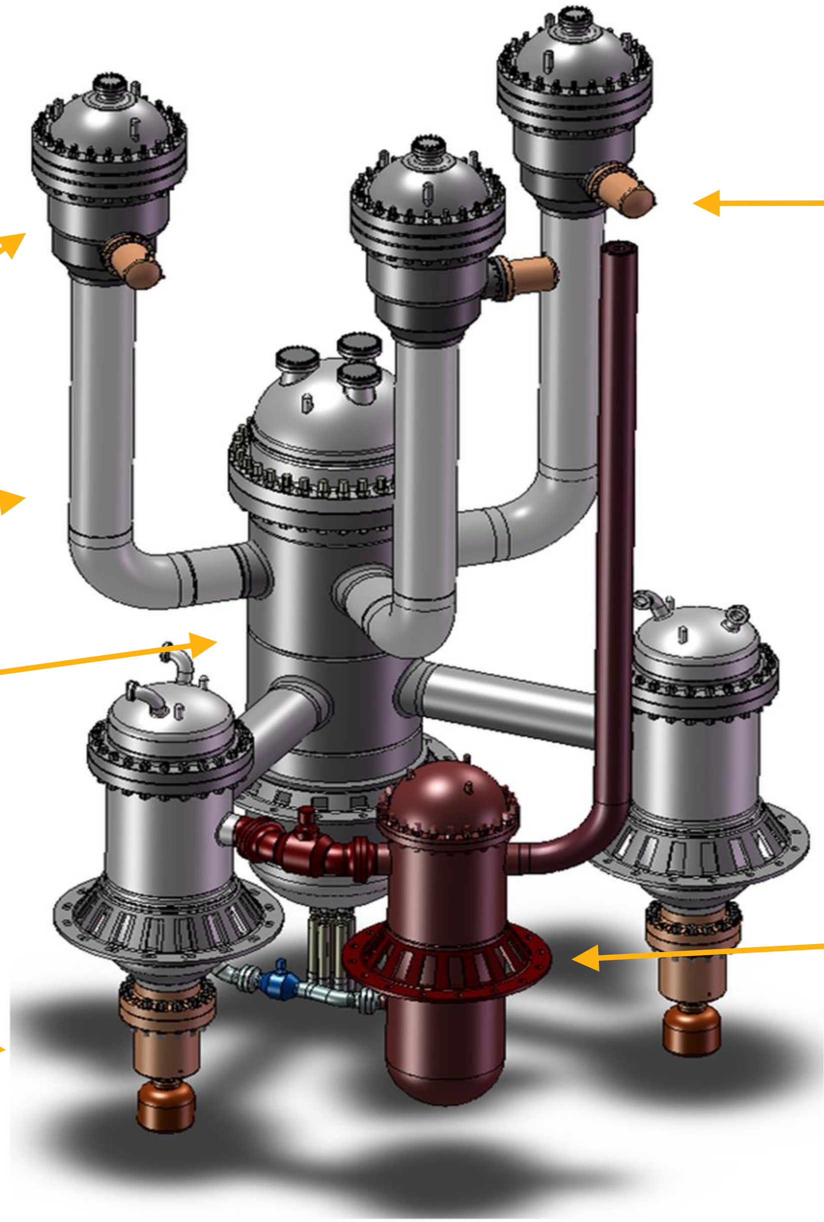






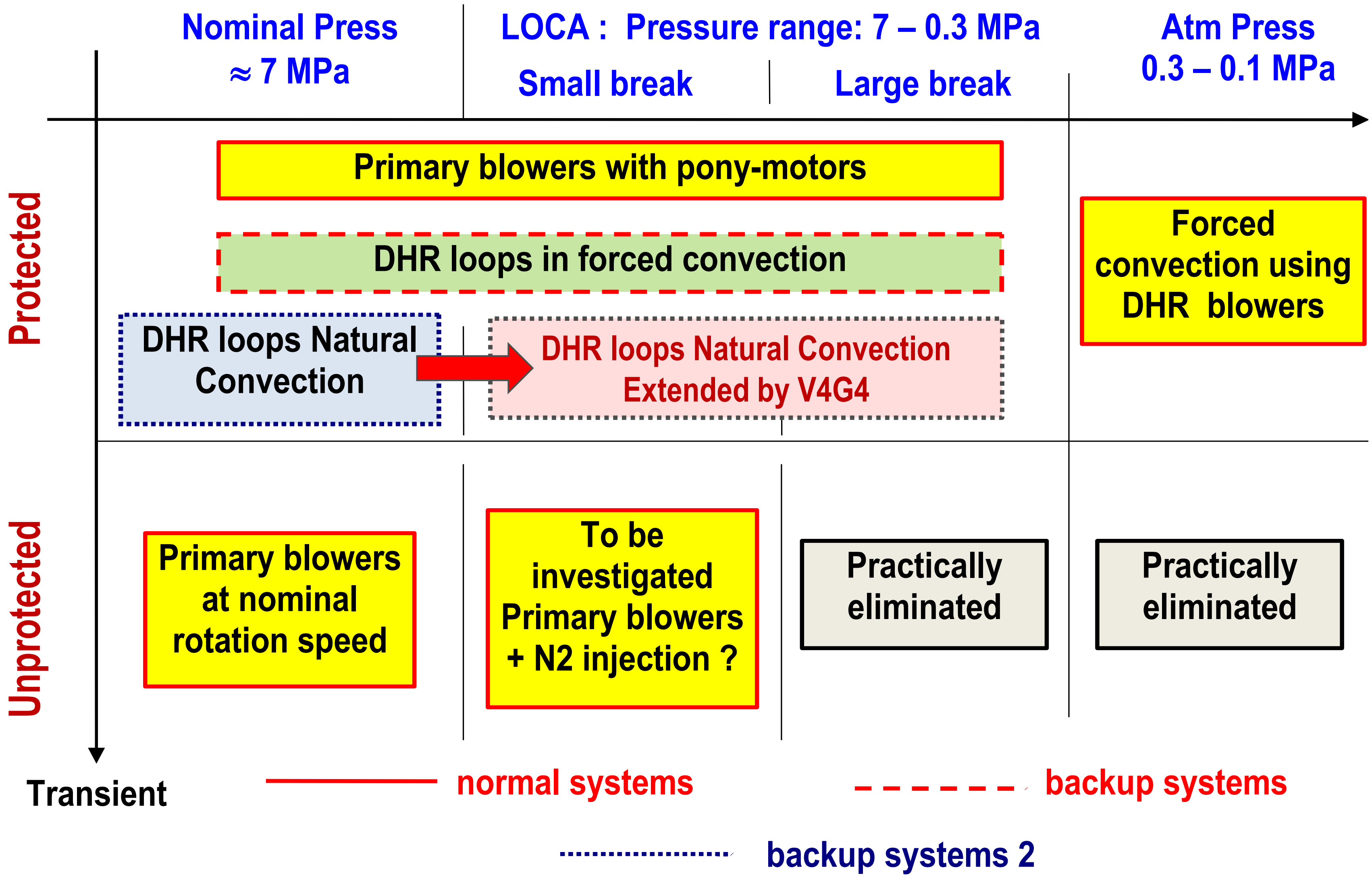
ALLEGRO CEA 2009 (75 MWt) – Design of I. circuit

Main parameters	Value
Core outlet T	**260 / 530 °C** (driver core), **400 / 850 °C** (refract. core)
Primary coolant	**Helium 7 MPa**
Secondary circuit	**Water 6.5 MPa**

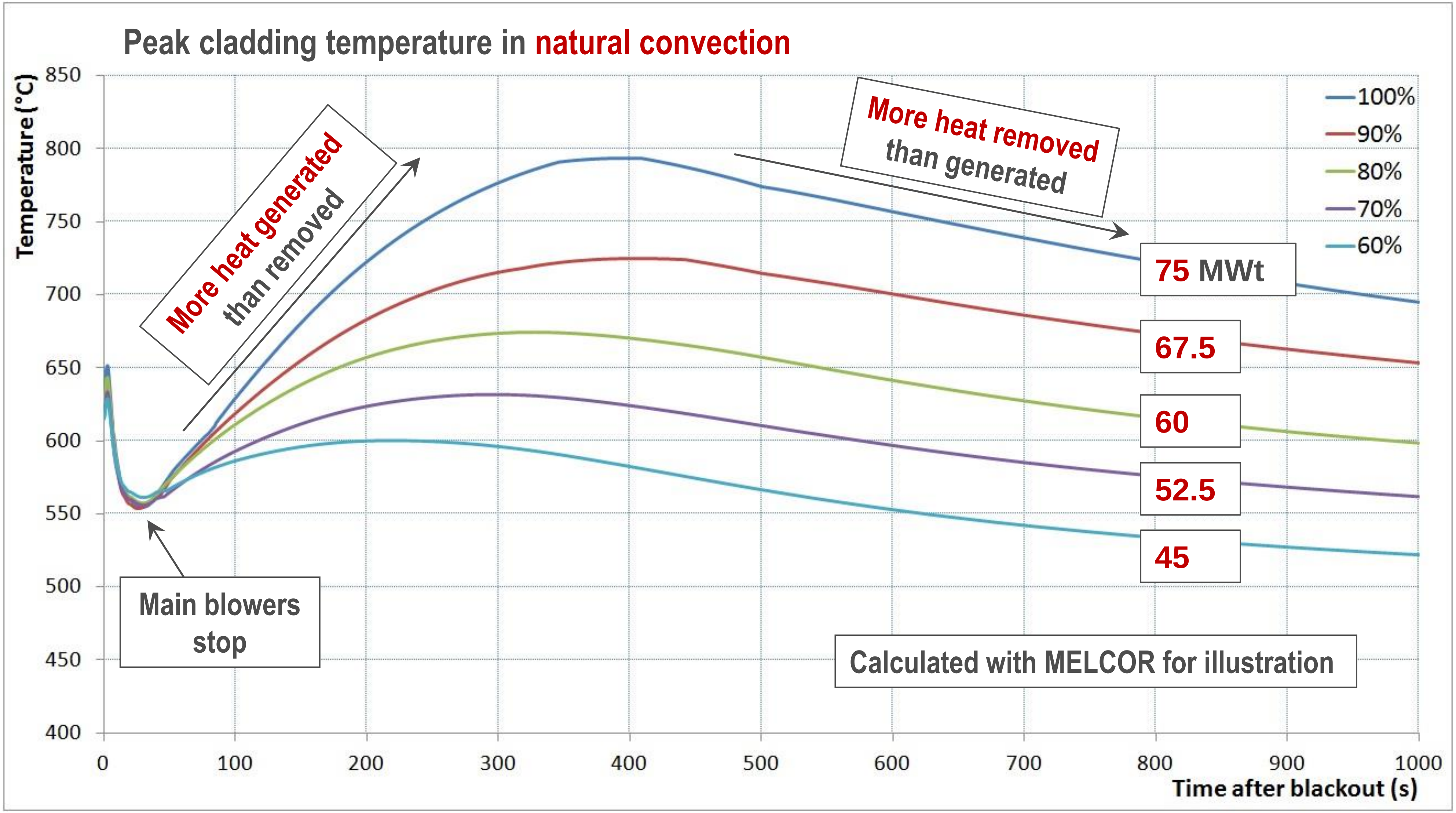


Coolable in LOCA only when active systems available

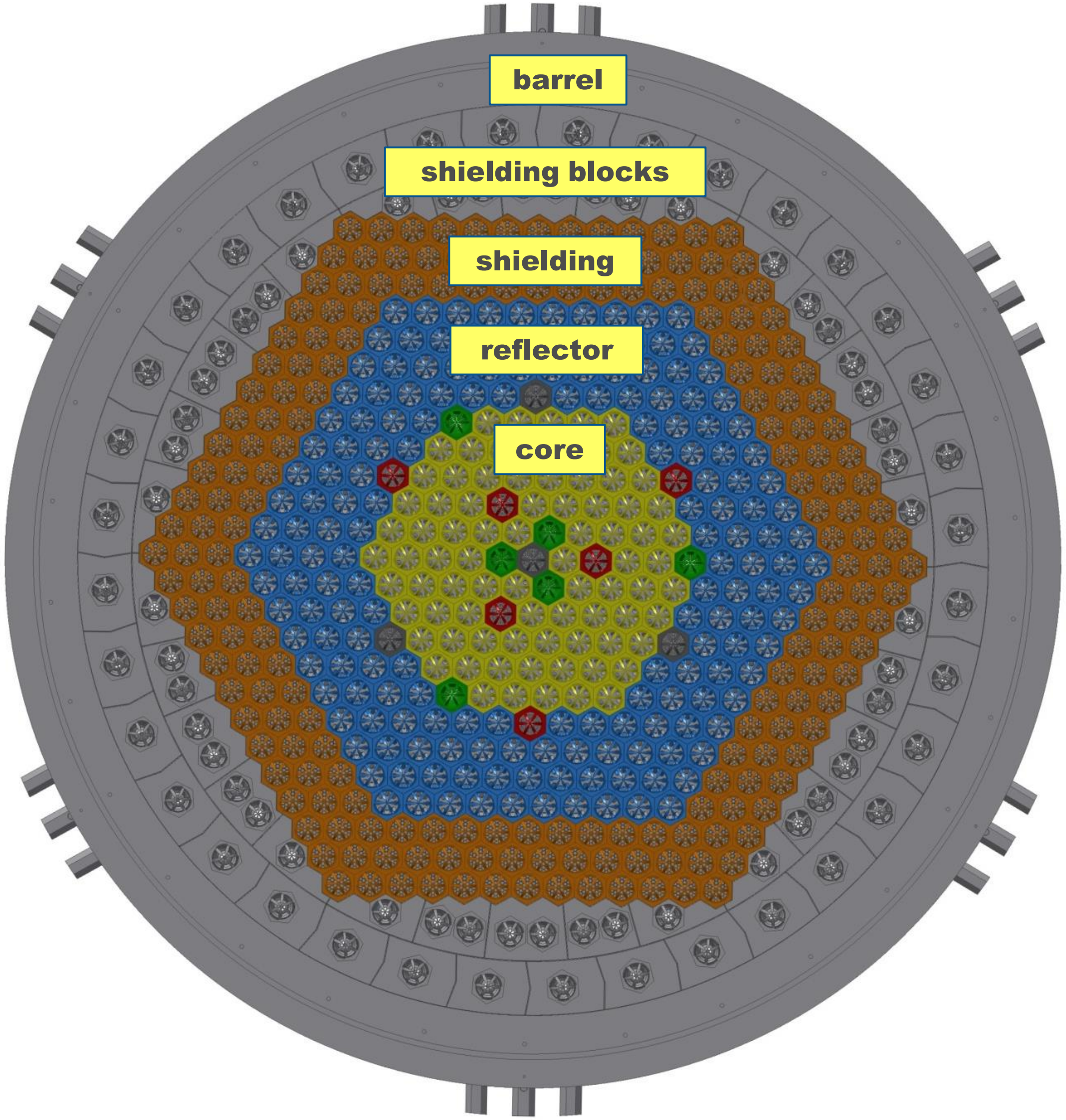
ALLEGRO CEA 2009 – Safety: DHR Strategy



ALLEGRO CEA 2009 – Safety: Example of a station blackout

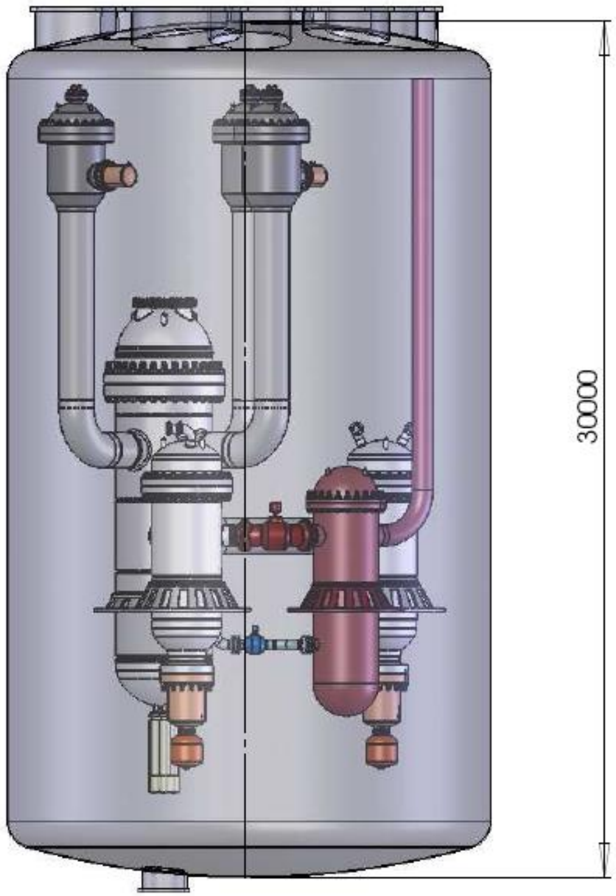


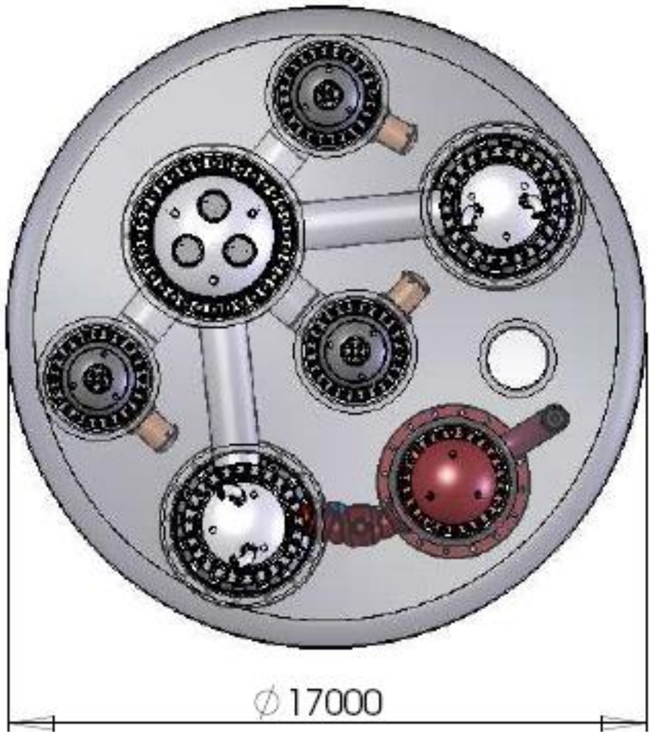
ALLEGRO CEA 2009 – RPV internals



- A) Driver core
  - Fuel: MOX in 15-15Ti steel
  - Reflector: 15-15Ti steel
  - Shielding: B_4C in stainless steel
- B) Refractory core
  - Fuel: (U,Pu)C in SiC_f / SiC
  - Reflector: ZrC
  - Shielding: B_4C in stainless steel
- Common structures
  - Shielding blocks: Steel
  - Barrel: Steel

ALLEGRO CEA 2009 – Design of Guard Vessel (GV)





Purpose of GV:

- Improve core coolability in LOCA
- Provide gas backpressure >1 bar
- Forced convection: Reduce pumping work
- Natural convection: Improve gas circulation

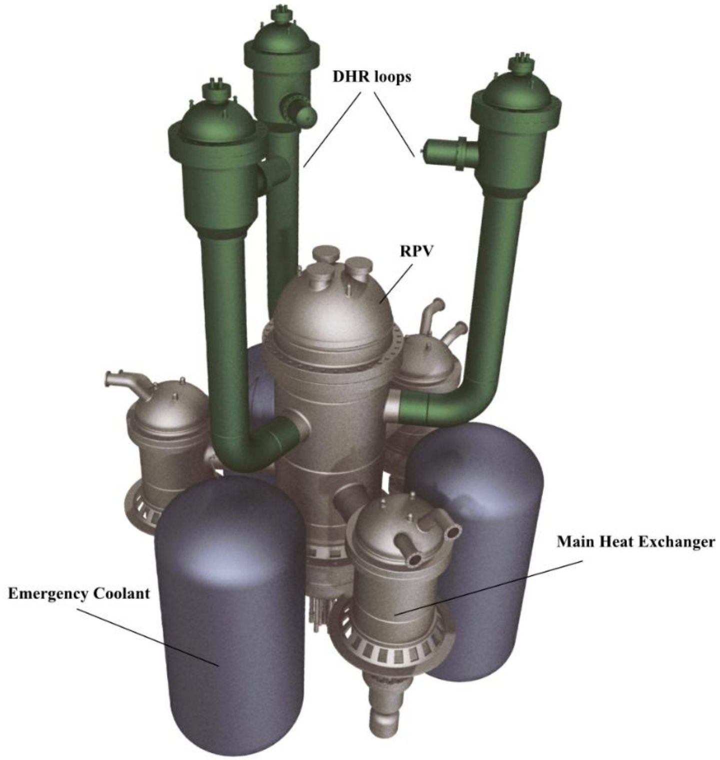
Note:
Internal concrete support structures are not shown

- **Normal operation**: Nitrogen+He (leakages), ~1 bar
- **Accident (LOCA)**: Nitrogen+He, backpressure: ~3-4 bar
  + N_2 injection: 10 bar or more

ALLEGRO V4G4: Restart of development in 2013-2015

- ALLEGRO CEA 2009: Status
  - Design: Mainly fuel & I. circuit (Neutronics & fuel in detail)
  - Fuel: MOX (small compact core)
  - Safety: Core coolability by using active systems mainly
  - Auxiliary systems addressed marginally

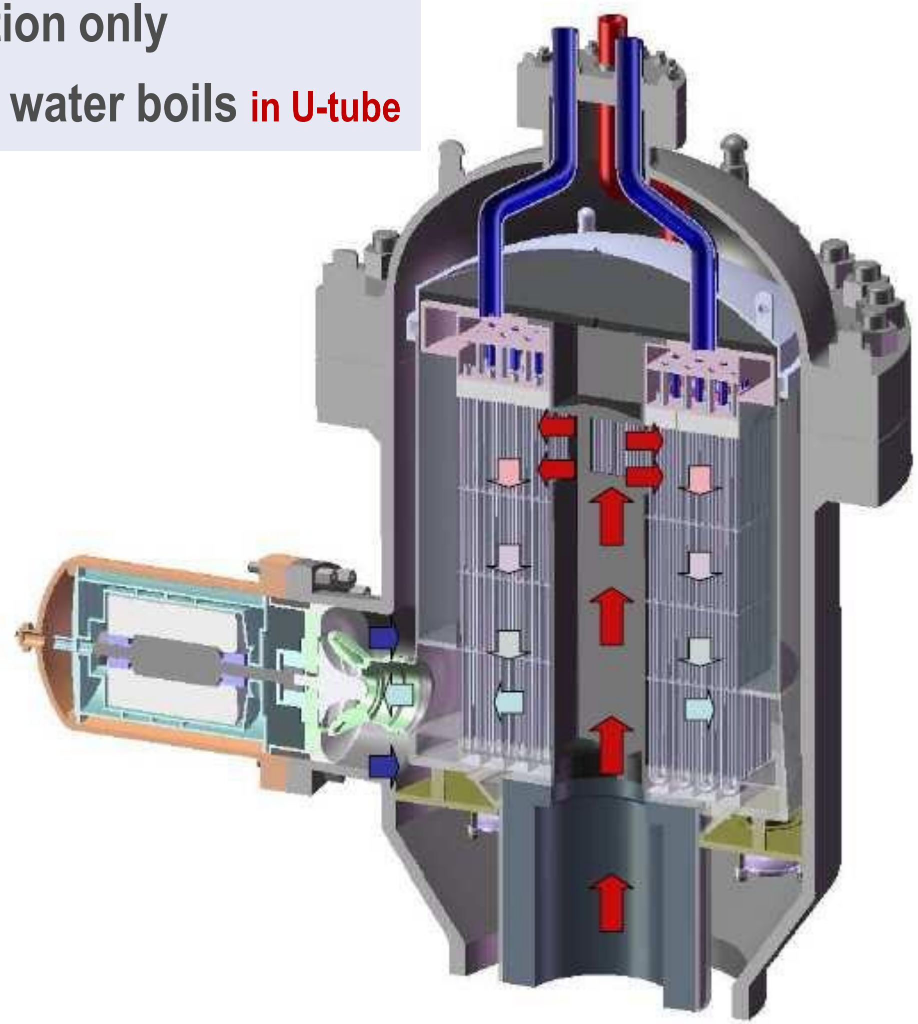
- ALLEGRO V4G4 Goal: Make it feasible & safe
  - Design: To be closer to GFR 2400
    - Gas in the II. circuit (possibly including turbomachinery)
  - Safety: Core to be coolable using (semi)passive systems
  - Fuel: UOX fuel (<20% U235) instead of MOX (feasible ?)
    - Option for easier operation and diversification of suppliers
  - Technology also in focus (He-related technology, …)



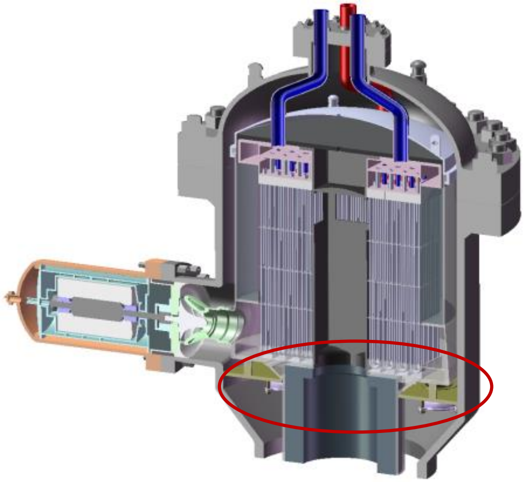
ALLEGRO CEA 2009 – Design of DHR HX

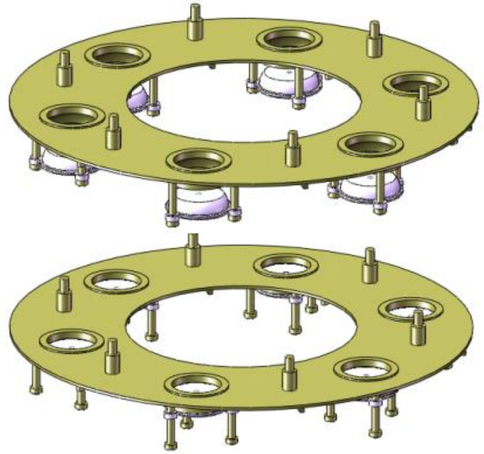
- Designed to remove ~2.5 MWt (~3% of 75 MWt)
- Optimized for **forced** convection only
- Susceptible to instabilities, if water boils **in U-tube**

U-tubes
(water inside)



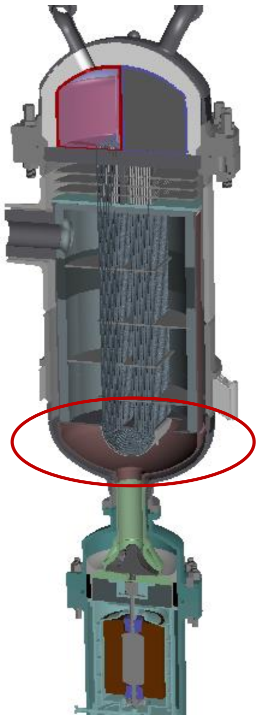
ALLEGRO CEA 2009 – DHR check valves & Main isolation valves

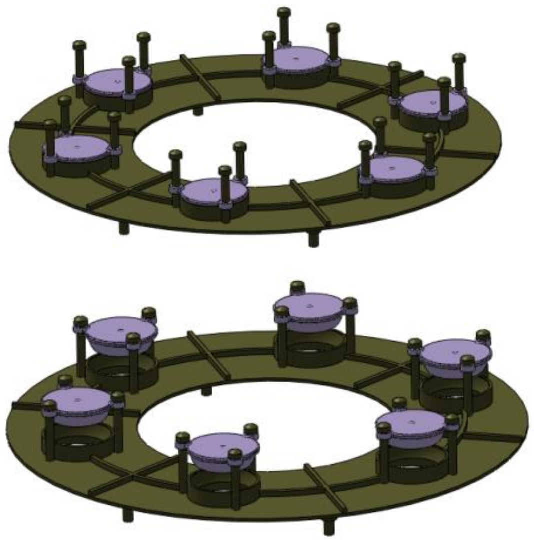




OPEN
Main blowers OFF

CLOSED
Main blowers ON

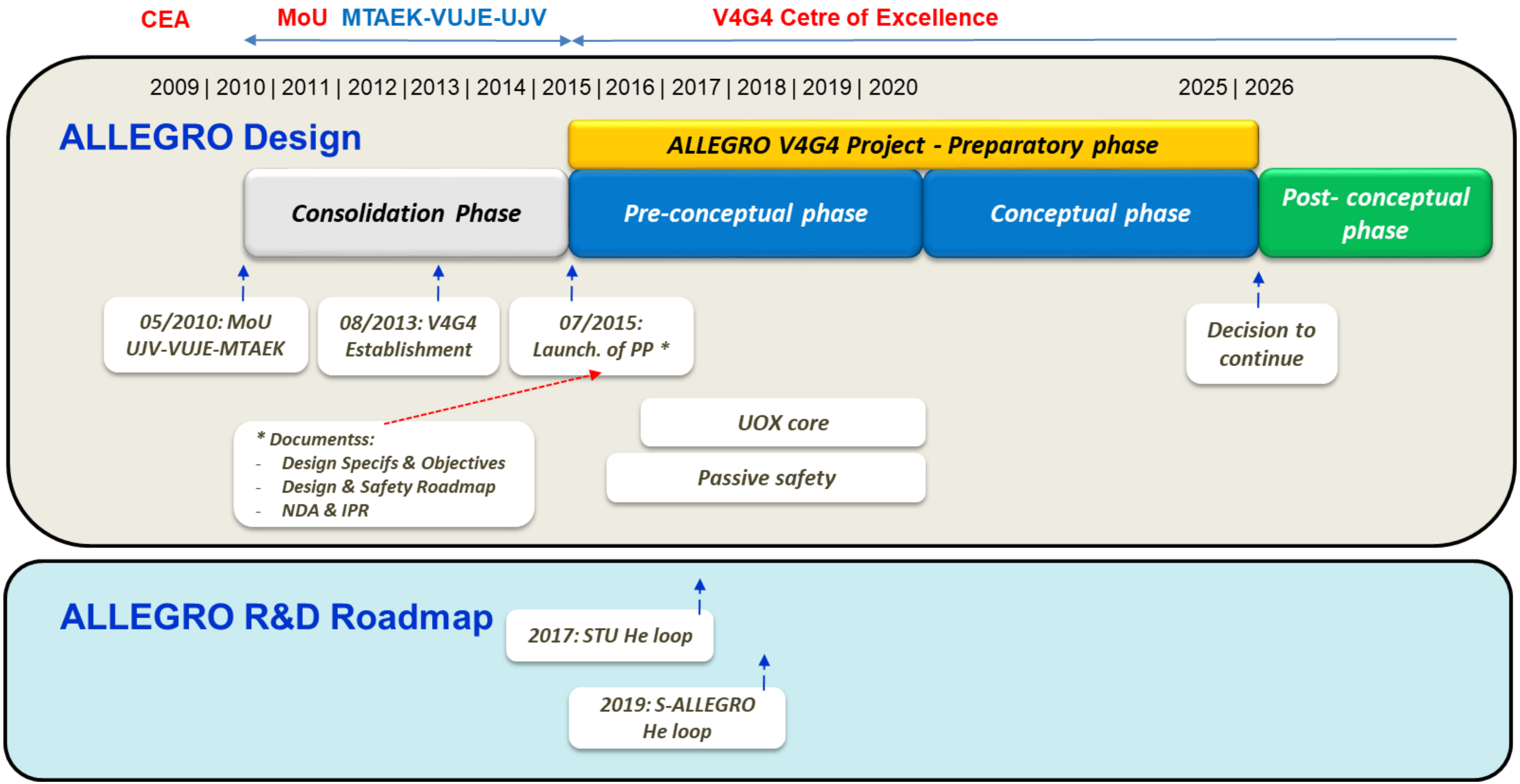




CLOSED
Main blowers OFF

OPEN
Main blowers ON

ALLEGRO V4G4 Time Schedule



ALLEGRO V4G4: Pre-conceptual design proces (1)

Input:
- ALLEGRO Design Specifications

Input:
- ALLEGRO Safety Requirements

- ALLEGRO Design & Safety Roadmap

- ALLEGRO Business plan

PRELIMINARY DESIGN

Core & Fuel Neutronics
- Justification of fuel type & material (pin, plate, …, MOX, UOX, ...)
- Preliminary design/geometry of core, fuel, reflector, shielding (parametric studies on Keff, dpa, cycle length, ...)
  - Output: cca 1 to 3 core configurations

Primary circuit
- Justification of type of the pressure boundary (Metallic RPV, PCRV)
- Schematic/preliminary design (mainly RPV)
- Thermal calculation: Parametric studies to justify:
  - Coolant p & T (core inlet & outlet)
  - Coolant mass flow rate

Safety & Decay heat removal (DHR) system
- Strategy & assumptions (e.g. GV with elevated P)
- Preliminary design :
  - Type & Number & Size of DHR loops (high, low P)
  - DHR HXs & other DHR-related components

Guard vessel (P >1 MPa)
- Schematic design, Preliminary design & Feasibility study

Preliminary CAD
Optionally other components in schematic design

SAFETY

Safety assessment
- Definition of transients, acceptance criteria & IEs excluded by design
- Core coolability calculations in protected accidents (all transients, all core configurations):
  - LOFA & SBO, Internal break & SBO
  - LOCA & SBO: Parametric GV backpressure levels
  - WI
- Core coolability calculations in unprotected accidents:
  - ATWS, …

ALLEGRO R&D
- Roadmap

Output:
- Coolable & Safe Design
- ALLEGRO XXXX Concept Database

Note to levels of design:
- Schematic (no dimensions)
- Preliminary (dimensions "by hand & CAD")
- Pre-conceptual (= more detailed "preliminary"

ALLEGRO V4G4: Pre-conceptual design proces (2)

Input:
- ALLEGRO Design Specifications

Input:
- ALLEGRO Safety Requirements

- ALLEGRO Design & Safety Roadmap

- ALLEGRO Business plan

Primary circuit
- Th calcul, # of loops, DHRS strategy, …
- Strategy for Support & Dilat. Elements
- Isolation valves

Core design
- Refinement of Keff, dpa, cycle length, ...
- Design of Fuel, CSD, DSD, Refl., Shield., …
- Reactor protection system

RPV
- Internals
- CRDM, …

DHR system
- Strategy
- Design

Coax. Piping
- Design
- Th. Shield.

Main HX
- HX, Vessel,
- Shielding, …

Main blower
- Design
- Motor

Secondary circuit
- Coolant type, Thermal calcul. (p, T, m)
- HX type, Design, …

Secondary DHR circ.
- Coolant type, Thermal calcul. (p, T, m)
- Design, HX type, …

Core catcher
- Strategy,
- Design

I.C. Isolat. valves
- Design

Fuel handling s.
- Strategy,
- Design

III. Circuits
- Main
- DHR

Support & Dilatations
- Design

Bushings
- Design

CRDM
- Design

GV design & internals
- Design of metal lic & concrete vessel
- Concrete support structures
- Gas (He, N, …) storage
- I. Coolant make-up system
- I. Coolant management system
- I. Circuit insulation
- GV Heat removal system
- GV atm. management system
- GV He recovery system
- GV bushings

Containment design & Internals
- Design of containment & internls
- II. Coolant management system
- HVAC
- Fuel storage

Pre-conceptual CAD

Analyses & Procedures
- Dilatations, Vibrations
- Activity transport & deposition I. C.
- Filters and waste management
- Reactor start-up & shutdown

25

Instrumentation
- Strategy
- List
- Design

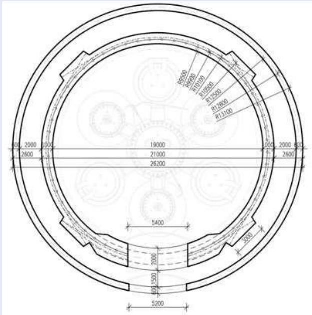
Safety assessment
- Protected transients
- Unprotected transients
- PSA

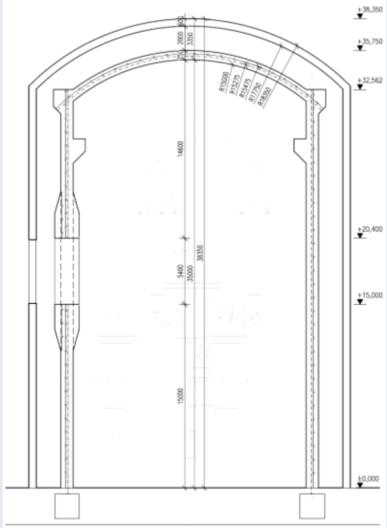
ALLEGRO R&D
- Roadmap

Output:
- ALLEGRO XXXX Concept Database

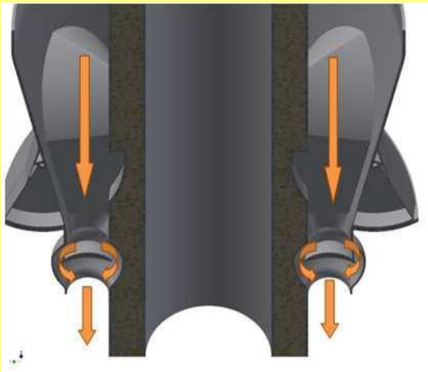
ALLEGRO V4G4: Design work underway focused on safety (1)

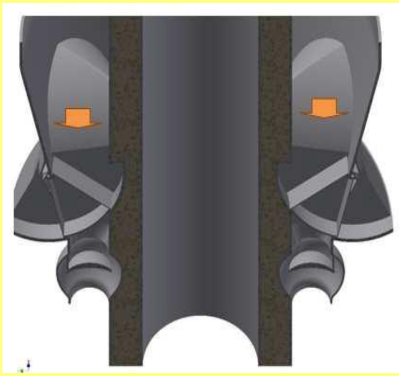
- **Guard vessel** (feasibility study)
  - **Goal**: Design pressure ~**1.5** MPa
    (**driving force for natural convection**)
  - Study: Pre-stressed concrete with steel liner
  - Complication: Openings to access the interior

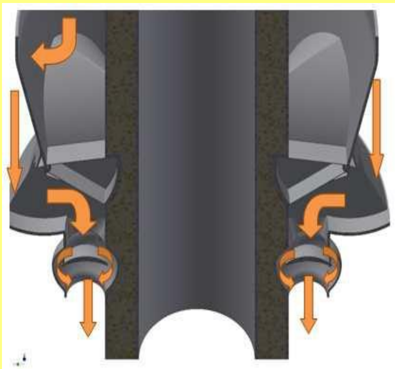




- **Decay heat removal (DHR) system** (optimization of design)
  - **Goal: Minimize He flow resistance, when DHR blower is stopped** (in natural convection mode)

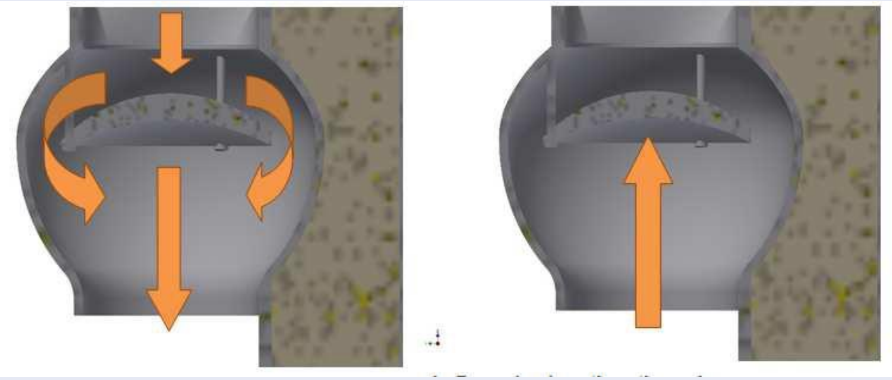






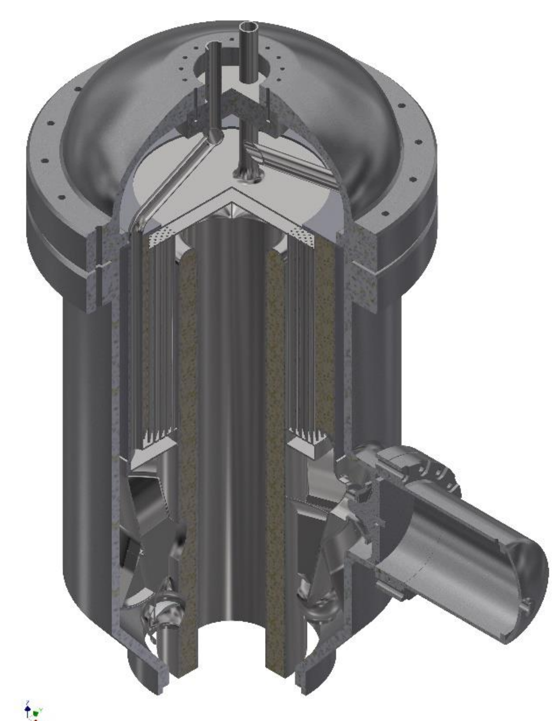
ALLEGRO V4G4: Design work underway focused on safety (2)

- **Passive disc check valve** (inside DHR loop, optimization work)
  - Goal: - Verify experimentally its functionality
    - Optimize its design
  - Closed during reactor operation
  - Opens passively during shut down / accident



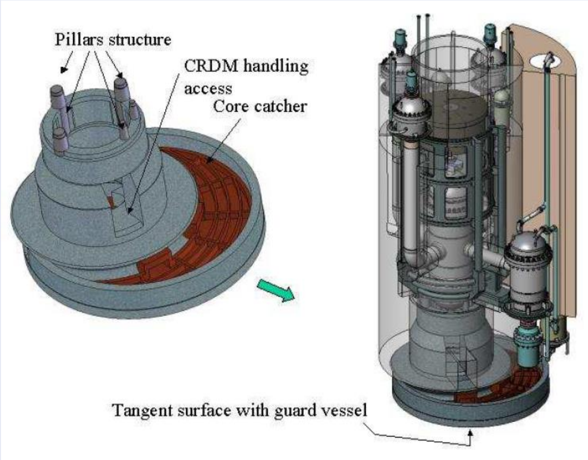
- **DHR heat exchanger** (new design)
  - Goal: - Minimize flow instabilities on water side in passive mode **(straight tubes instead U-tubes)** (-> water upwards, He downwards)
    - Minimize He flow resistance in passive mode

Note: Passive mode = natural convection



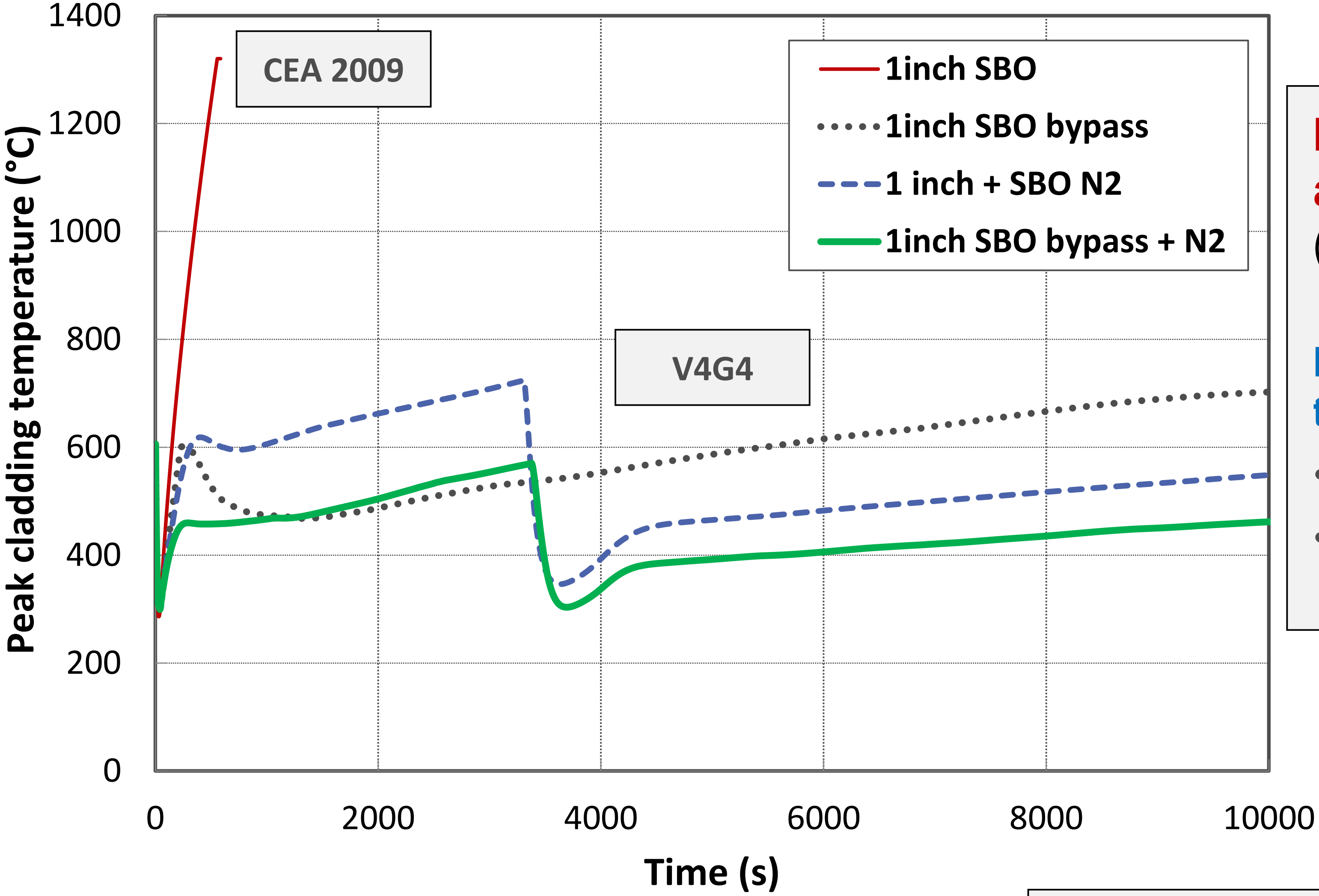
ALLEGRO V4G4: Design work underway focused on safety (3)

- Core catcher (→ new pre-conceptual design)
  - Goal: Mitigate severe accident consequences
  - CEA 2009: Approximate idea only
  - V4G4: To develop a new design



- Exp. Helium loop S-ALLEGRO: Coaxial cross valve for DHR loop (optimization)
  - Goal: - Reliably switch the He flow inside the DHR coaxial piping

ALLEGRO V4G4 (MOX core 75 MWt): Core coolability solved (?)
Small break loss-of coolant accident in passive mode



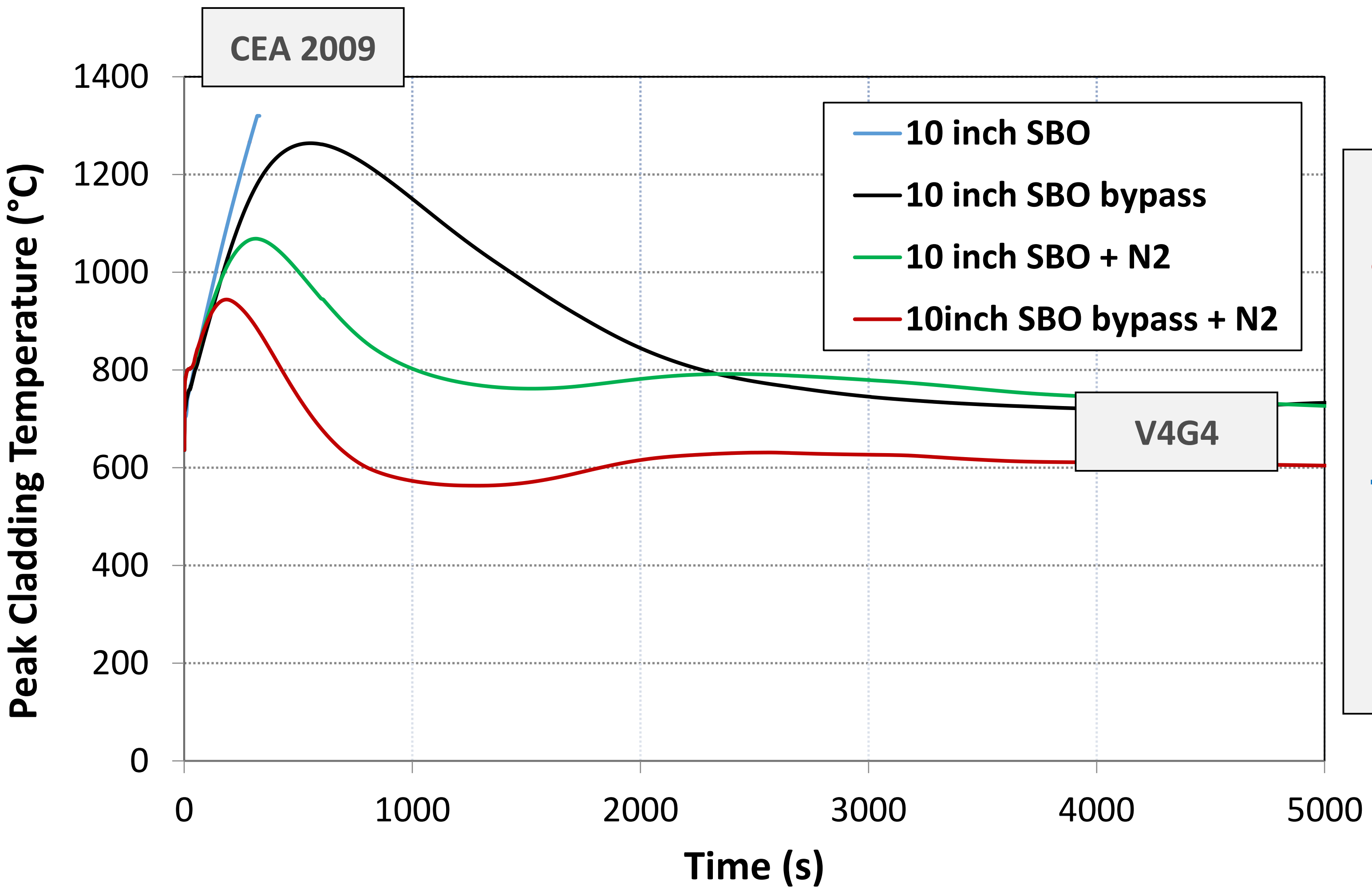
Protected SB-LOCA (1“) aggravated with SBO (passive mode)

Better core coolability thanks to design improvements:

- DHR blower bypass
- GV pressurization using N2 (>10 bar)

SB-LOCA – Small Break Loss of Coolant Accident
SBO – Station Blackout

ALLEGRO V4G4 (MOX core 75 MWt): Core coolability solved (?)
Large break loss-of coolant accident in passive mode



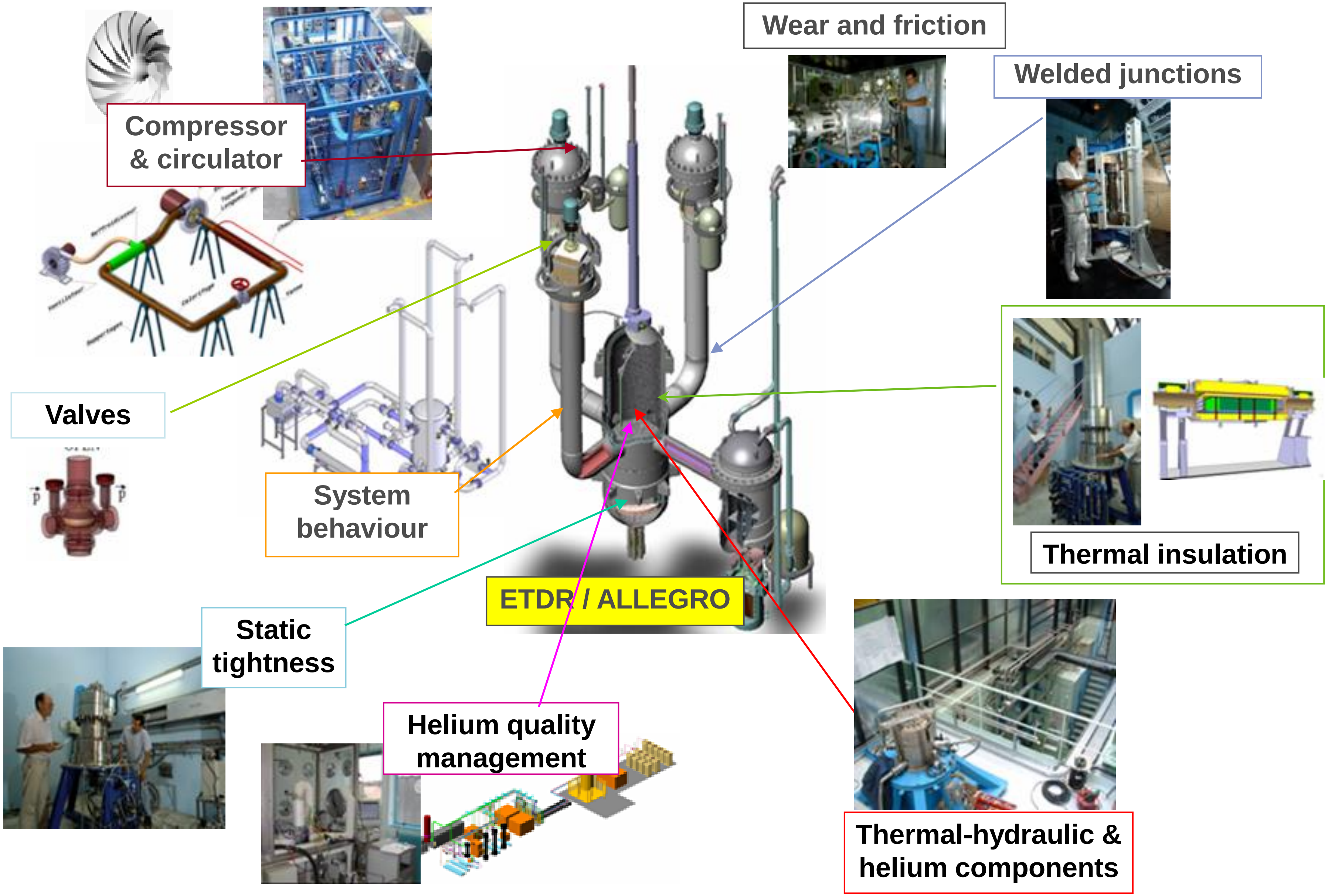
Protected LB-LOCA (10") aggravated with SBO (passive mode)

Better core coolability thanks to design improvements:

- DHR blower bypass
- GV pressurization using N2 (>10 bar)

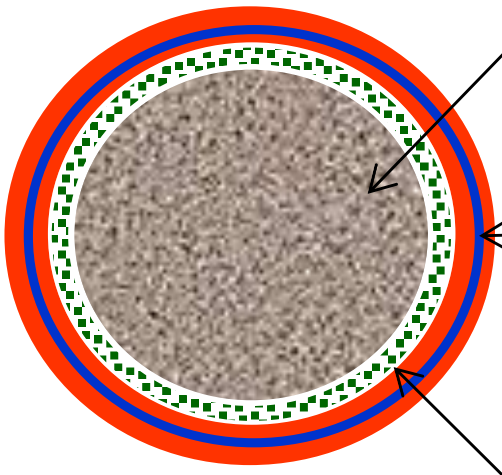
LB-LOCA – Large Break Loss of Coolant Accident
SBO – Station Blackout

R & D for ALLEGRO at CEA (2002-2009)



R & D on pin carbide fuel with SiC_f-SiC clad: Reserved to CEA

- GFR fuel R&D remains long-term perspective
  - (U,Pu)C swelling
  - Metallic liner for leak tightness
  - End plugs (hermetic sealing)
  - Buffer bond (thermochemical compatibility)

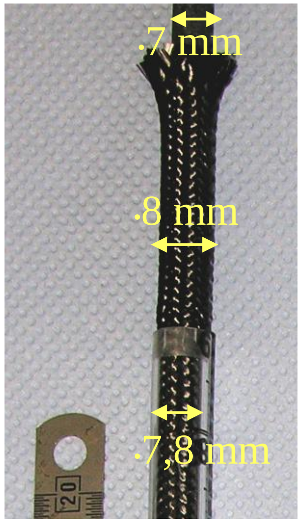


UPuC fuel pellet

<u>« Sandwich » cladding</u>
Inner SiC/SiC layer
Middle metallic liner
Outer SiC/SiC layer

<u>« Buffer » bond</u>
High porosity C-based braid

- CEA: Development of the refractory fuel is in waiting mode for this moment.



P. David & G. Rochais (CEA/DMAT)

R & D needs in support to ALLEGRO

- **Safety of oxide cores** (MOX or UO2)
  - **System thermohydraulics (core coolability), Guard Vessel** (& core catcher) **issues**
- **Helium technology**
  - **He quality management, recovery, tightness, components (valves, HXs)**
  - **Subassembly TH, Insulation, fuel handling, instrumentation, …**
- **Computer codes:**
  - **Benchmark activities: ERANOS, MCNP, SERPENT, KIKO,** HELIOS, SCALE, **CATHARE2, RELAP5, MELCOR 2.1**
- **Materials qualification**
  - **Composite Matrix Ceramic clad, Metallic clad for oxide core**
  - **Control rods & elements, S/A structural materials**
  - **Thermal barriers, Other structures (core catcher, structural materials)**
- **Fuel qualification**
  - **Oxide fuel, Carbide fuel**

R & D for ALLEGRO: Main priorities after 2015 (1)

- **Exp. validation of the DHR approach**
  - Natural circulation He loop STU, Trnava (SK) – Commissioned in 2016
  - He-loop S-ALLEGRO (I. phase), CV Rez (CZ) – Commissioned 2017, in use ~2019
- **Guard vessel resistant to elevated pressure (> 1 MPa)**
  - Key structure to promote natural circulation in accident conditions
  - Feasibility of such a large structure (metal, concrete)
- **Heat transfer from wire-wrapped rods bundle into prototypic He (7 MPa, up to 850 °C)**
  - Validation: System & CFD codes.
  - Facilities: - ESTHEL stand (proposed at CEA) has not been built
    - ESTHAIR stand using air & low T only (CEA Grenoble)
  - Exp. data: - Best-estimate Nu number & friction factor correlations for bundles
    - Assessment of temp. non-uniformities (hot spots)
  - Design: Feasibility of cladding surface roughening for wire-wrapped claddings

R & D for ALLEGRO: Main priorities after 2015 (2)

- Feasibility of safe N_2 injection into RPV
    - Risk to heavily undercool RPV internals due to N_2 expansion (risk of embrittlement)
- Feasibility of turbomachinery in II. circuit connected electrically with primary blower
    - Modification of the CEA Innovative option (shaft replaced with el. motor & el. wires)
- Core catcher (pre-conceptual design)
    - Size, shape, materials, cooling, …
- DHR heat exchanger
    - Resistant to high T (1250 °C for 30 min.) & to water boiling at II. side
    - Low flow resistance required
- Valves for I. circuit
    - Disc check valves (DHR HX vessel), Main isolation disc valves (Main HX vessel)
    - Possibly isolation valve for coaxial piping (?)

R & D platforms in the V4G4 Centre of Excellence

- **Helium loops: Thermohydraulic phenomena**
  Natural circulation studies, code validation, core coolability, …)
  - **STU He loop** (STU Trnava, SK)
  - **S-ALLEGRO** (CV Rez, Pilsen, CZ)

- **Helium loops: Material research in controlled He atmosphere**
  - **HTHL1** (CV Rez, CZ): Out-of-pile
  - **HTHL2** (CV Rez, CZ – SUSEN): In-pile (LVR-15)

- **Helium purification** (Univ. Chemistry & Technology, Praha, CV Rez, CZ)
  - **Individual stands: Mastering of the GFR & VHTR related technology**

- **Helium recovery from N2+He mixture (CV Rez, CZ)**
  - **Membrane stand: Testing of He separation using membranes technology**
  - **Small-scale demonstration facility: In construction (2020)**

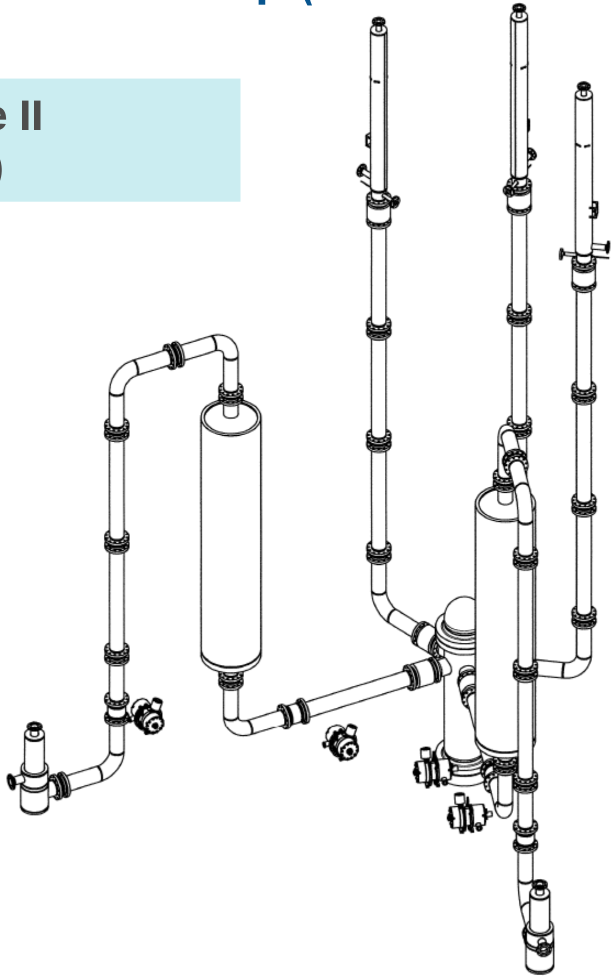
- **Corium interactions (CV Rez, CZ)**
  - **Cold crucible** (CV Rez, CZ – SUSEN): Core catcher related material issues

R & D for ALLEGRO on DHR system: He Loop S-ALLEGRO (CZ)

- **Goal: To study DHR phenomena** (Commissioned in 2019, CV Rez, Plzen, CZ)
- **Mock-up of ALLEGRO: 1 MW el., 7 MPa, 260/530 ºC, 400/850 ºC**
- **Phase I / II: RPV, 1x / 2x I. loop (main HX He/He), 1x / 3x DHR loop (DHR HX He/water)**

Phase I
(2019)

Phase II
(>2025)



R & D for ALLEGRO on DHR system: STU He Loop Trnava (SK)

- Goal: To study decay heat removal phenomenology in natural circulation.
- Design: One loop (heating zone & HX)
- Commissioned in 2016,
- Owned by Slovak Technology University (STU) Bratislava, located in Trnava (SK)
- Parameters:
  - I. circuit: He 3-7 MPa, 220 kW, ~200 - 520 ºC
  - II. circuit: water
  - Vertical distance Core to DHR HX: 10 m

He recovery from GV atm.: Experimental stand (CV Rez, CZ)

- **Goal**:
  To test **membrane** separation of He from N_2+He mixture

- First tests with Polymer PRISM® membrane (for max. 40 ºC) in a dedicated stand.
  - Sufficient selectivity for He has been confirmed.

- To be tested: Ceramic membranes

- **Underway**:
  Development of a demonstration small-scale facility for testing & verification of **He recovery from GFR GV atmosphere** (N2+He) using a membrane separation.

Cold crucible: Material research (CV Rez, CZ)

- Project planned for ALLEGRO-related **core catcher** research
- To test UO_2/SS corium interaction with **innovative sacrificial material**

Parameters

Power supply

Transistor generator:	Output power 300 kW
	Frequency 100 – 800 kHz
Tube generator:	Output power 160 kW
	Frequency 1.5 – 2.0 MHz

Crucible

Volume of the melt up to 20 dm^3

Up to 50 kg melt with temperature 3000 °C

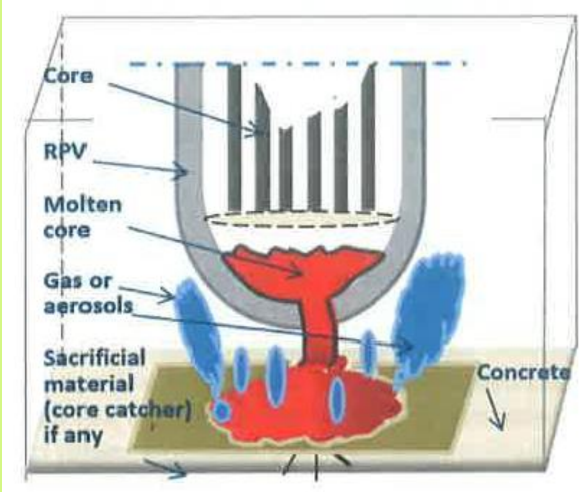
Pulling system

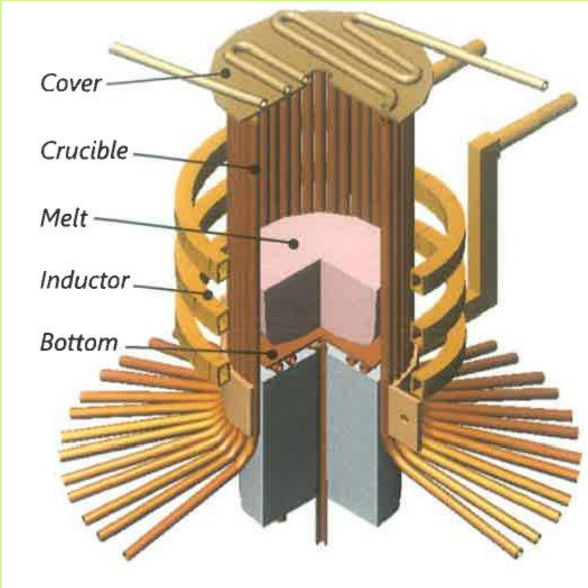
Pulling rate: 0.1–1.5 mm/min

Vacuum chamber

Melting in any atmosphere

Melting of radioactive materials

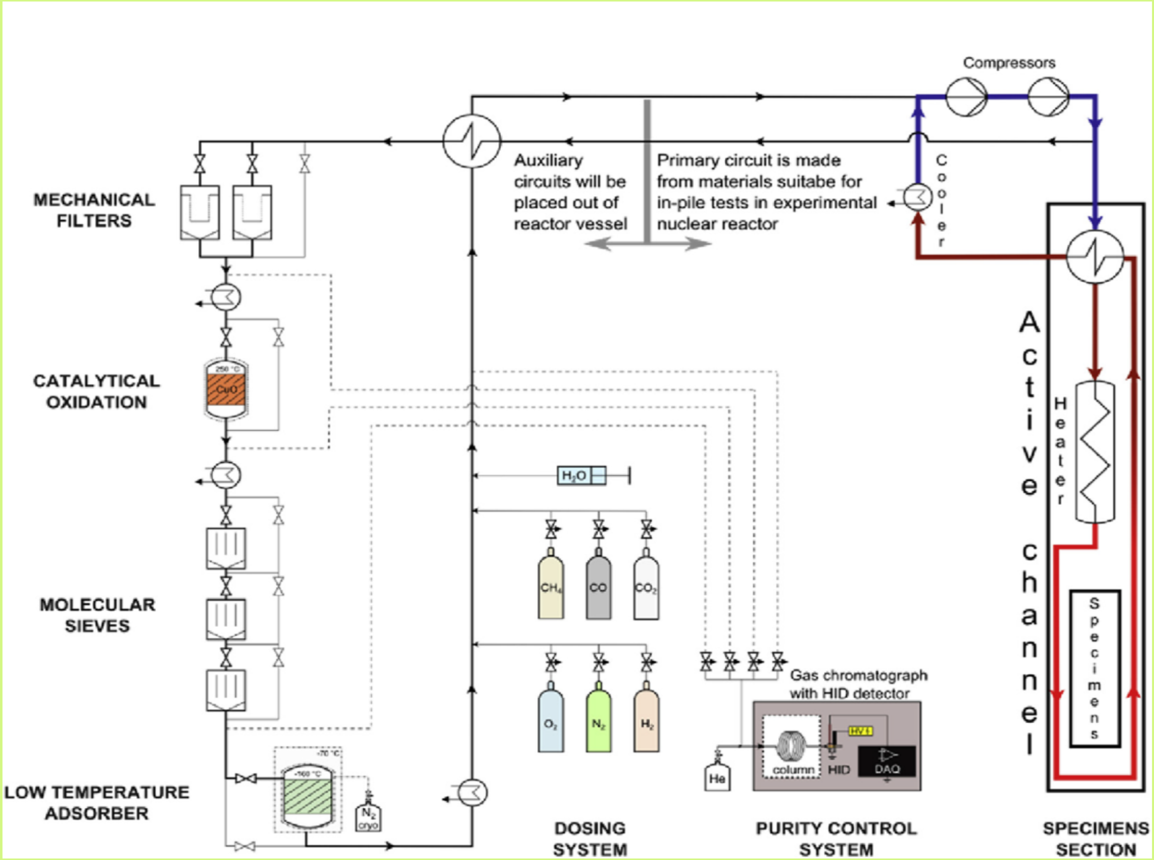




Detail of induction system

Helium loops HTHL1, HTHL2 (CV Rez, CZ) for material research

- **Both loops are nearly identical (HTHL1: Out-of-pile HTHL2: In-pile)**
  - Max. ~850 C, 7 MPa He, 38 kg He/h, coupons or tubular specimens
  - HTHL2: To be inserted into the atrium fuel of LVR-15 (CV Rez):



- Thermal: $1.5 \cdot 10^{14}$ n/cm^2/s
- Fast: $2.5 \cdot 10^{14}$ n/cm^2/s
- Electrically heated test section for samples:
  D=<**60** mm, H=~**500** mm

Perspectives of ALLEGRO & Conclusions (1)

- **ALLEGRO** (compared to LMFBR) **In the phase of proving feasibility & passive safety**

- **ALLEGRO CEA 2009 is a good technical base for further development by V4G4 CoE**
  - Its safety characteristics need substantial improvement
  - … while respecting 1) Technical feasibility and 2) Target mission of the demonstrator.

- **V4G4 CoE (2013) is a good legal base for restarting the development work**

- **Short-term priorities in the development:**
  - Achieve reasonable level of safety using passive systems (where possible)
  - Design UOX-based driver core

  … while maintaining sufficient power density & irradiation characteristics (SiC dpa)

Perspectives of ALLEGRO & Conclusions (2)

- **Short-term priorities in the R&D** (driven by the design requirements)
  - Coolability in protected transients using natural convection
  - Feasibility of Guard vessel for elevated pressure
  - Optimization of DHR system (valves, HX, pressure drop, …)
  - Turbomachinery in II. circuit
  - Potentially alternative cladding material for the driver core

- **Simulation tools need additional validation**
  - Neutronic & thermohydraulic codes
  - Fuel performance codes