The Gas Fast Reactor System

Presented by:

Didier Haas
European Commission, Joint Research Centre

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Content

- *The GFR concept within GIF*
- *Status of the GFR System and Project Arrangements*
- *Main technical challenges*
- *The ALLEGRO consortium and future prospects*

Contributions to the GIF

Japanese Chairmanship since end of 2009 (3 year term): Mr Yutaka Sagayama, from JAEA

GFR – Gas-Cooled Fast Reactor (System Arrangement)
LFR – Lead-Cooled Fast Reactor (MOU)
MSR – Molten Salt Reactor (MOU)
SFR – Sodium-Cooled Fast Reactor (SA)
SCWR – Supercritical Water-Cooled Reactor (SA)
VHTR – Very-High-Temperature Reactor (SA)

										
VHTR	◆	◆	◆	◆	◆	◆	◆	◆	◆	
GFR		◆	◆	◆		◆				
SFR		◆	◆	◆	◆		◆	◆		◆
SCWR	◆	◆		◆						◆
LFR		◆		◆						◆
MSR		◆	◆							

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Motivation for Gas Cooled Fast Reactors

- *Fast reactors are important for the sustainability of nuclear power:*
  - *More efficient use of fuel*
  - *Reduced volumes and radio-toxicity of high level waste*
- *Sodium cooled fast reactors are the shortest route to FR deployment, but:*
  - *The sodium coolant has some undesirable features:*
    - » *Chemical compatibility, void coefficient of reactivity, restricted core outlet temperature to avoid sodium boiling.*
- *Gas cooled fast reactors do not suffer from any of the above:*
  - *Chemically inert, void coefficient is small (but still positive), single phase coolant eliminates boiling.*
  - *Allows high temperature operation without the corrosion and coolant radio-toxicity problems associated with heavy liquid metal reactors (Pb-Bi and pure Pb).*
- *But …*
  - *Gaseous coolants have little thermal inertia – rapid heat-up of the core following loss of forced cooling;*
  - *High density fuels and claddings sustaining extreme temperatures and burnups need to be designed*

Generation IV GFR

- ***Helium coolant***
- ***Fast neutron spectrum***
- ***High outlet temperature***
- ***Back-up for SFR***

+ Transparent coolant

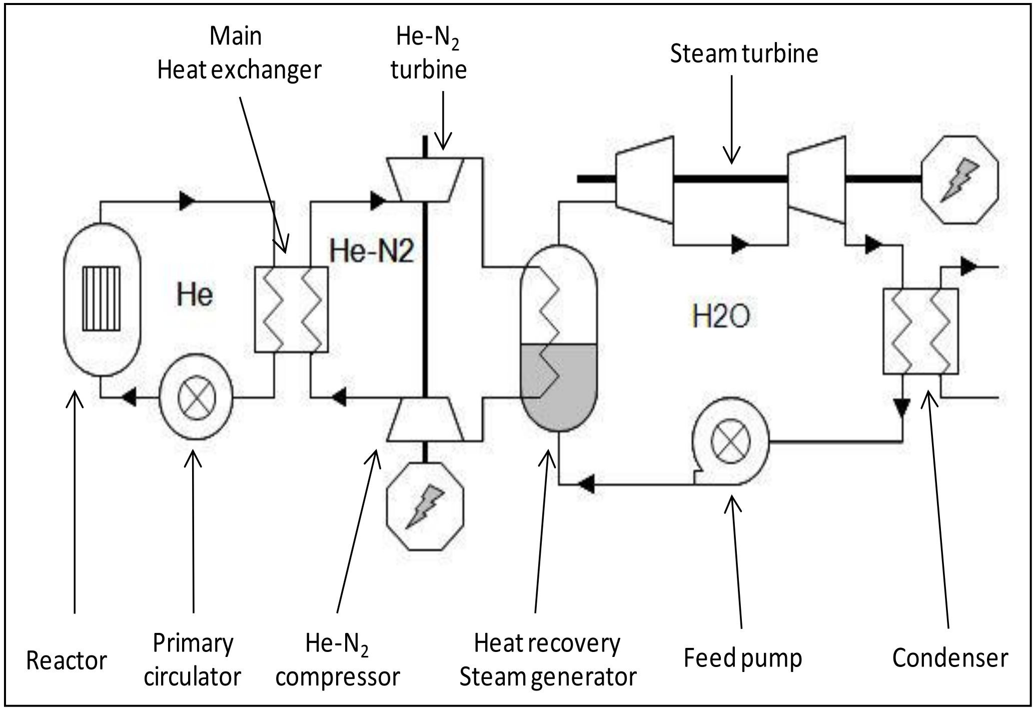
+ High temperature/efficiency

+ Strong Doppler effect

+ Weak void effect

- Decay heat removal (LOCA)

  - ***High power density***
  - ***Low thermal inertia***



Indirect cycle conversion system

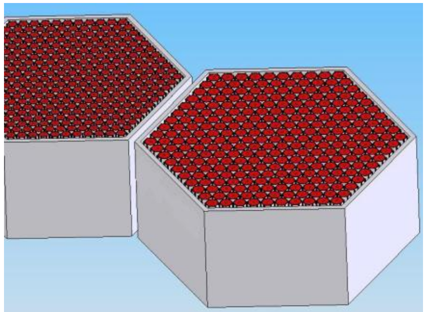
- *Thermal power* *2400 MWth*
- *Coolant in/out* *400°C/850°C*
- *System pressure* *7 Mpa*

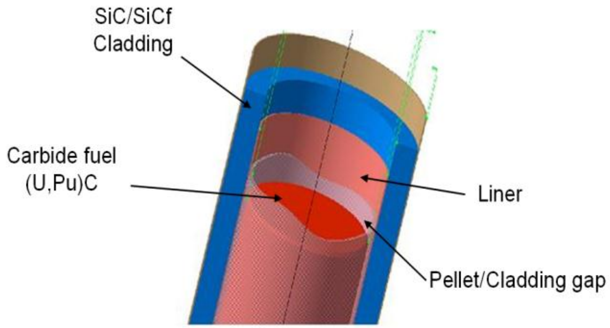
Status of GFR System Cooperation

- *GFR System Arrangement signed by Euratom, France, Switzerland and Japan*
- *Project Arrangement on "Conceptual Design & Safety" signed by Euratom, France and Switzerland*
- *Project on "Fuel & Core Materials" in preparation*

Specific GFR Challenge 1 : Fuel

- *The greatest challenge facing the GFR is the development of robust high temperature refractory fuels and core structural materials,*
  - *Must be capable of withstanding the in-core thermal, mechanical and radiation environment.*
  - *High fissile material volume fraction of the fuel.*
- *Candidate compositions for the fissile compound include carbides, nitrides, as well as oxides.*
- *Favoured cladding material is SiCf/SiC in a pin formats*
- *Practical issues:*
  - *How to encapsulate the fuel in pin – sealing of end plugs*
  - *How to do we combine metallic and ceramic components into a workable fuel sub-assembly ?*





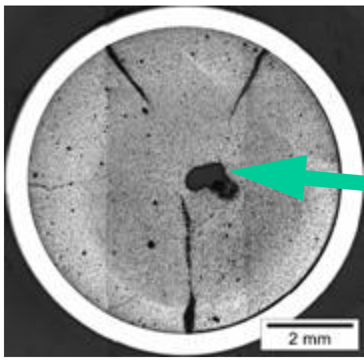
Fissile phase composition: comparison

	Carbide(U,Pu)C	*Nitride(U,Pu)N*	*Oxide(U,Pu)O_2*	*Metallic fuel(U,Pu,Zr)*
Theoritical density (g/cm3)	13.58	14.32	11.5	14
Melting point (°C)	2420	2780	2750	1080
Thermal conductivity (W/m/K)	16.5	14.3	2.9	14
Swelling	1,6% to 2%/at%		0,8%/at%	
Thermal stability	**Stable**	**Stable until 1600-1800°C**	**Very stable**	

- Carbide preferred to nitride for its neutronic properties (N15 enrichment needed)
- Both have relatively high volatility
- Oxide back-up but with lower core performance
- Metallic fuel discarded due to low melting point

NIMPHE Irradiation (CEA – EURATOM)

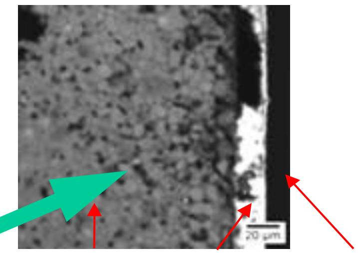
- ***Objective:*** ***Behavior of UPuN and UPuC irradiated in Phénix (but SFR conditions, steel cladding)***
- ***PIE made at CEA and JRC/ITU***



Nimphe 2: **Nitride**

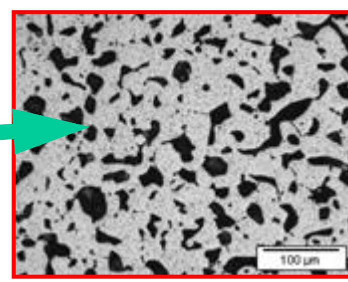
Important fuel de-densification in pellet centre , restructuring.
Central hole

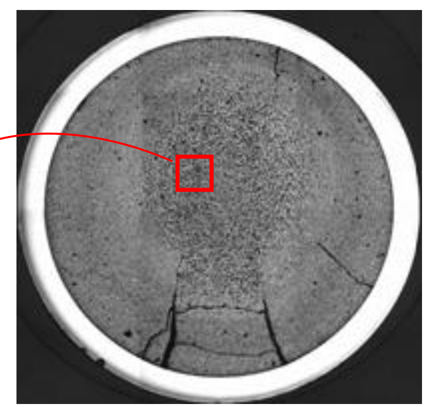
UPuN dissociation, **Pu metal phase on clad**



Nimphe 2: **Carbide**

Gas bubbles at pellet center,
without central hole





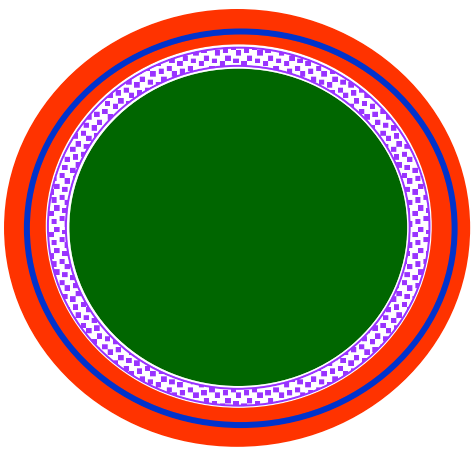
GFR Ceramic pin : a new design

Fuel pellet : UPuC (high density & conductivity)

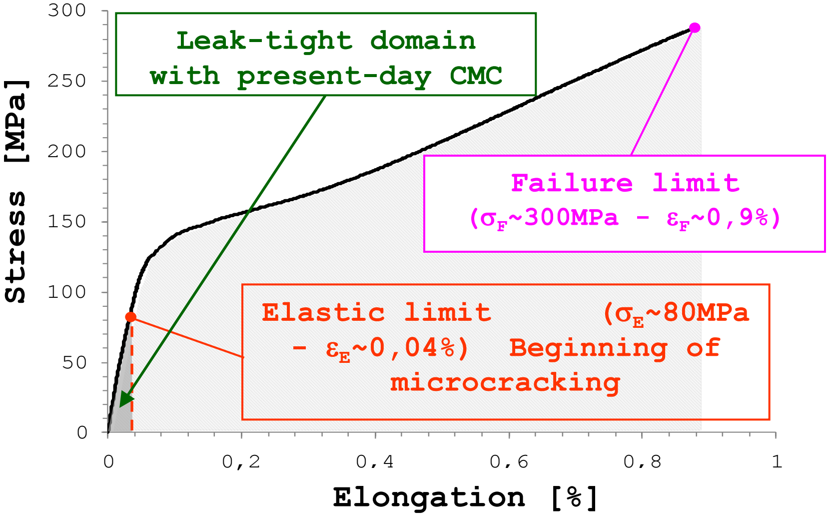
Clad : SiC_f/SiC (refractory & resistant)

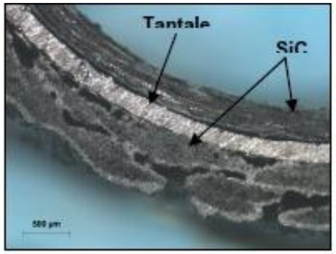
SiC_f/SiC leak-tightness loss beyond elastic limit
⇒ Sandwich → SiC_f/SiC / metal / SiC_f/SiC

Pellet-Clad interaction:
⇒ Improved by buffer (C and/or SiC)



C. Sauder & C. Lorrette (CEA/DMN)

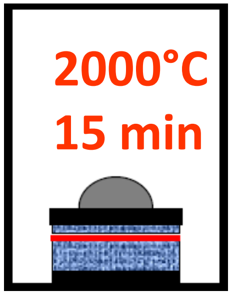




The GFR fuel design : material interactions

Fuel/buffer/liner/cladding interactions

$UC_{1.04}$ / C / SiC / Ta / SiC_f-SiC



Moderate material interaction

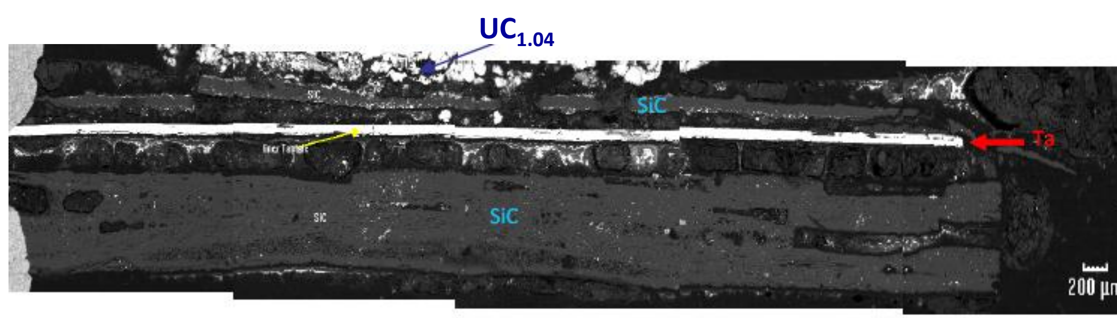
Fuel mostly preserved (buffer effect)

C layer dissolved in fuel

SiC layer mostly preserved

Ta liner mostly preserved (no buffer effect)

Cladding mostly preserved



Courtesy of C. Guéneau (CEA)

Perspectives for GFR fuel

- *Fissile materials:*
  - » *Fabrication experience*
  - » *Stability of irradiated UPuC at high temp.(1600-2000°C)*
  - » *Introduction and effect of minor actinides on UPuC properties*

- *Cladding + diffusion barrier or liner*
  - » *Determination of composite behaviour under irradiation*
  - » *High temp.(1600-2000°C) effects*
  - » *Liner: tightness efficiency, fabrication, effect of damage and stresses*
  - » *Thermo-chemical compatibility*

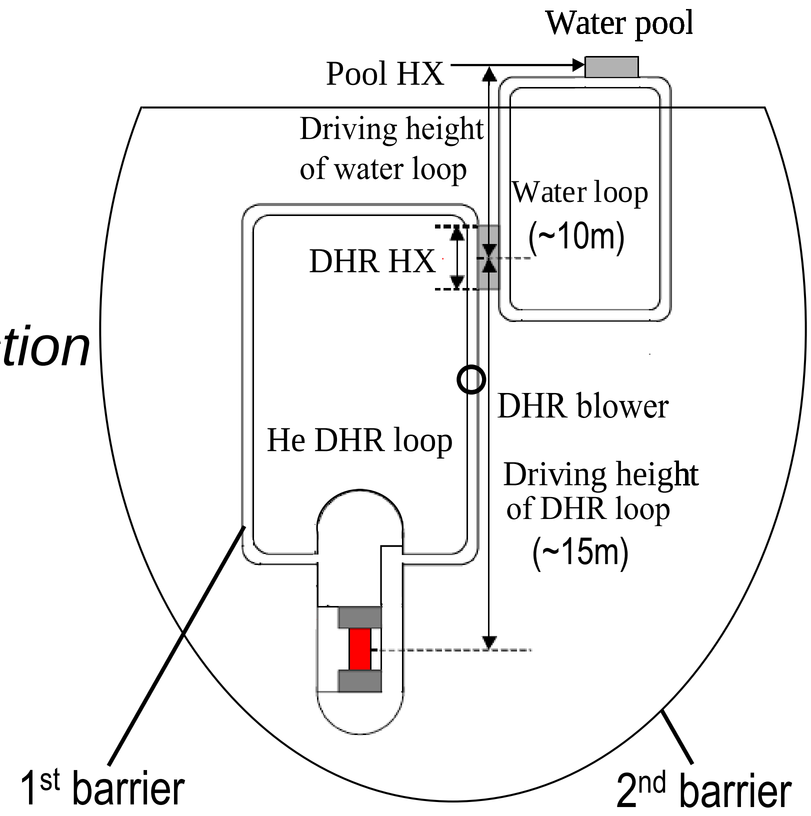
- *Fuel element development*
  - » *Pin optimisation under nominal and accidental conditions*
  - » *Fabrication: prototype pin*
  - » *Irradiation programmes*

Specific GFR challenge 2: Decay Heat Removal (DHR)

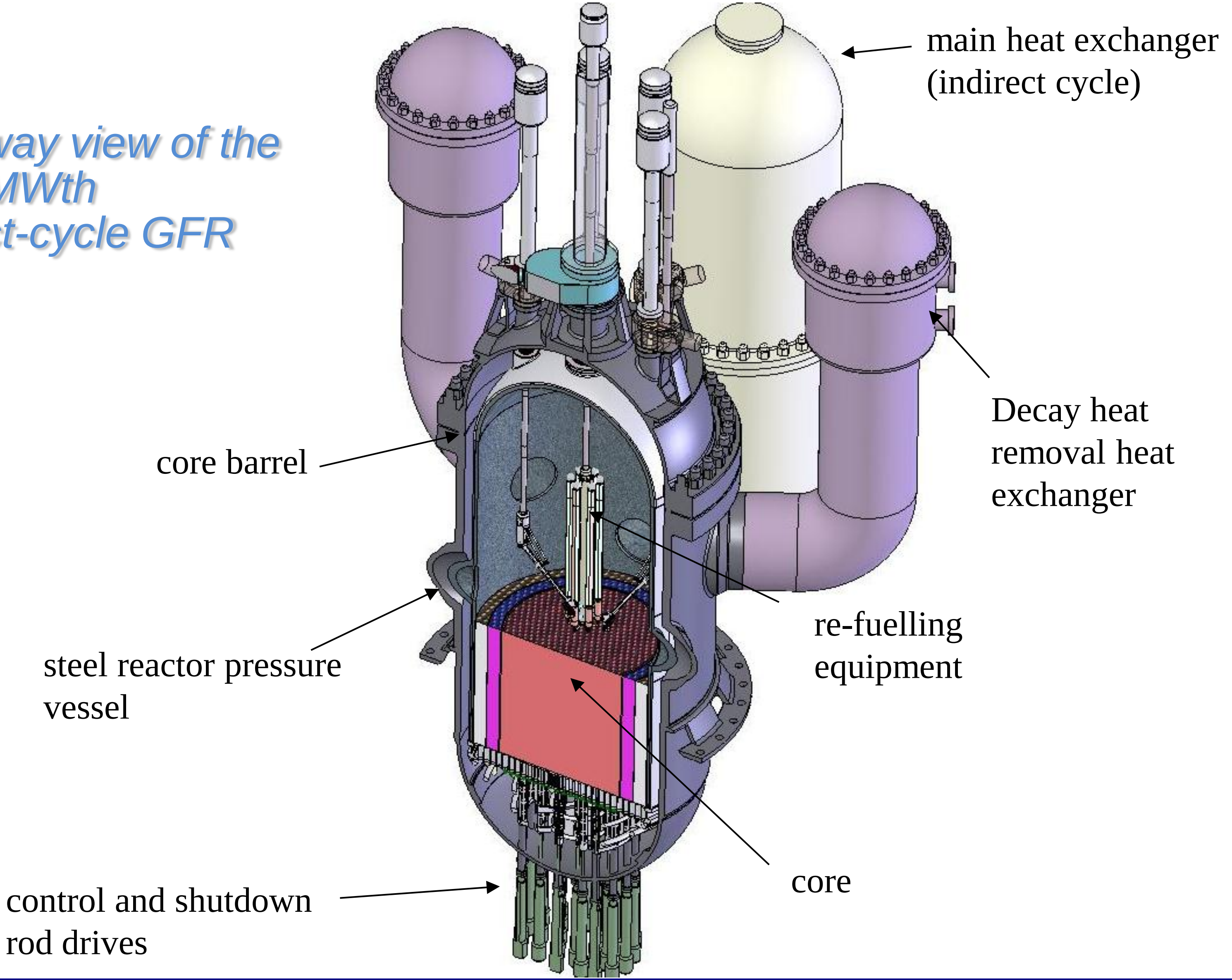
- ***HTR "conduction cool-down" will not work in a GFR***
  - ***High power density, low thermal inertia, poor conduction path and small surface area of the core conspire to prevent conduction cooling.***
- ***A convective flow is required through the core at all times;***
  - ***A natural convection flow is preferred following shutdown***
    - ***This is possible when the circuit is pressurised***
  - ***A forced flow is required immediately after shutdown when depressurised:***
    - ***Gas density is too low to achieve enough natural convection***
      - ***Heavy gas injection helps***
    - ***Power requirements for the blowers are very large at low pressure***
- ***The primary circuit must be reconfigured to allow DHR***
  - ***Main loop(s) must be isolated***
  - ***DHR loop(s) must be connected across the core***

Decay heat removal (DHR): original strategy

- Redundant DHR loops
- Dedicated blowers on helium side
- Secondary water loop at 10 bar
- Water loop working in natural convection
- Final heat sink: water pools
- Two barriers
  - Primary loop
  - Dedicated guard containment

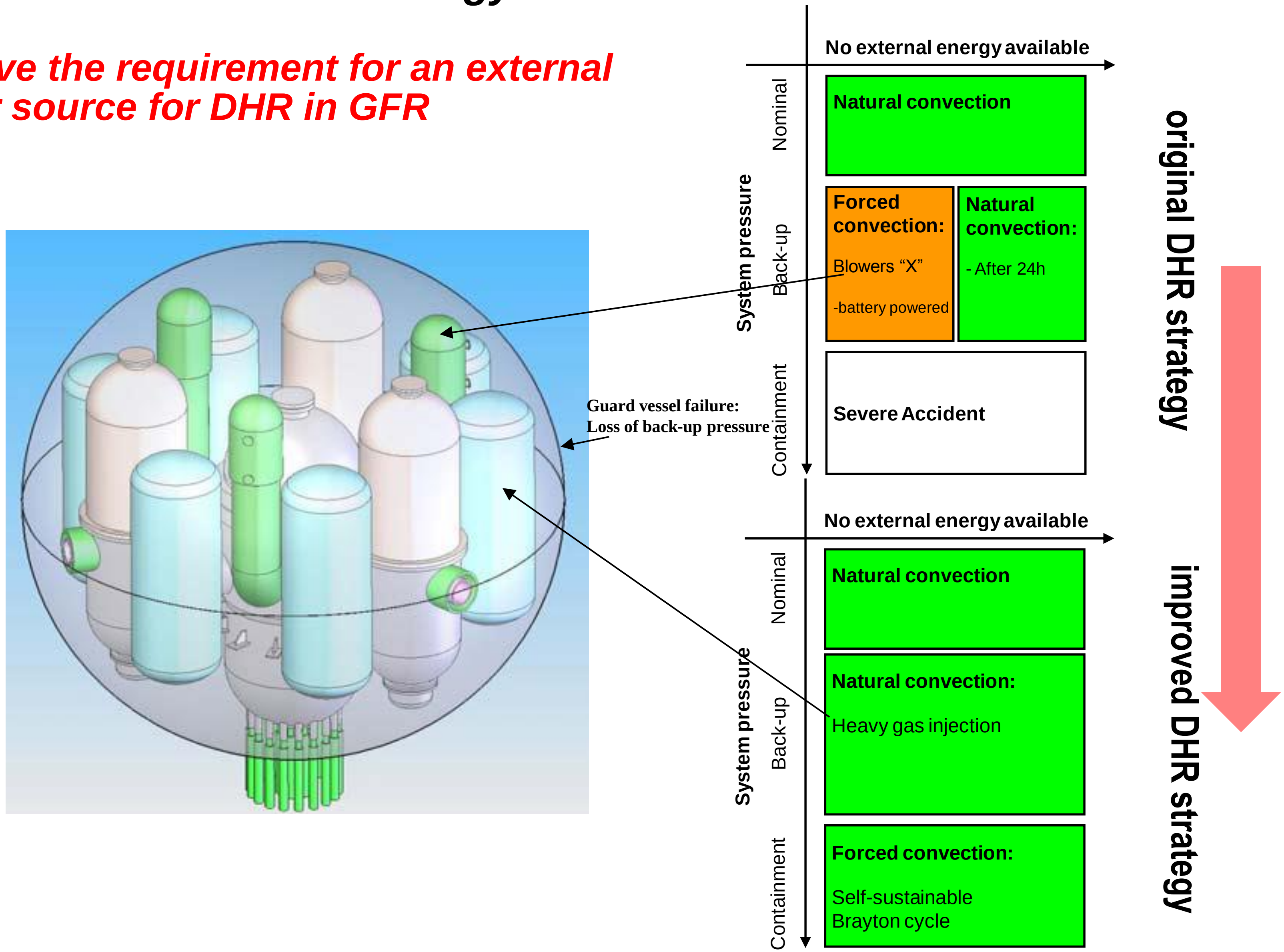


Cut-away view of the 2400 MWth indirect-cycle GFR



Improvements to DHR strategy:

Remove the requirement for an external power source for DHR in GFR



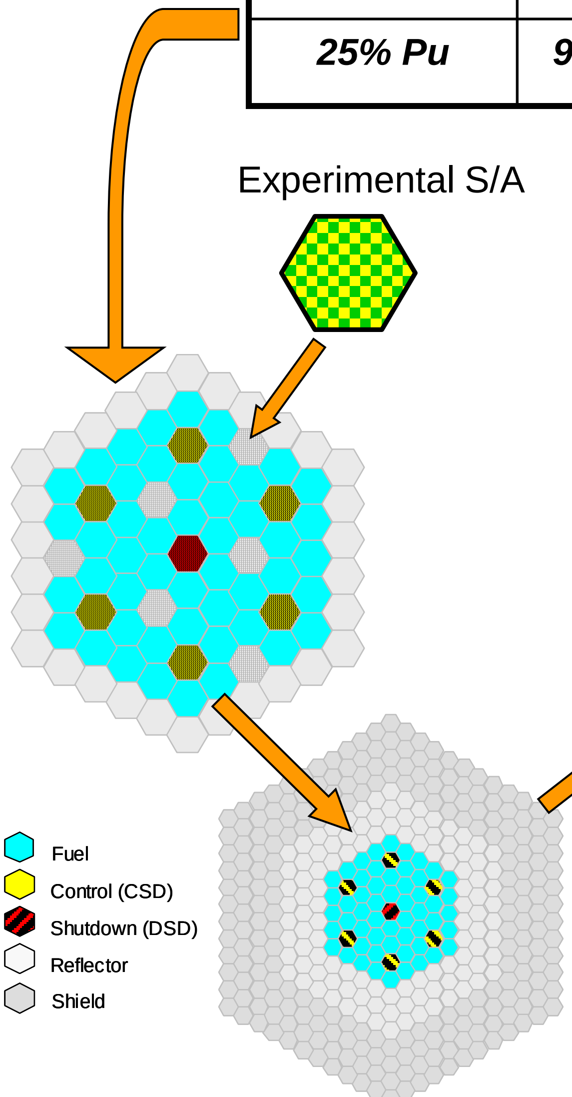
The ALLEGRO consortium

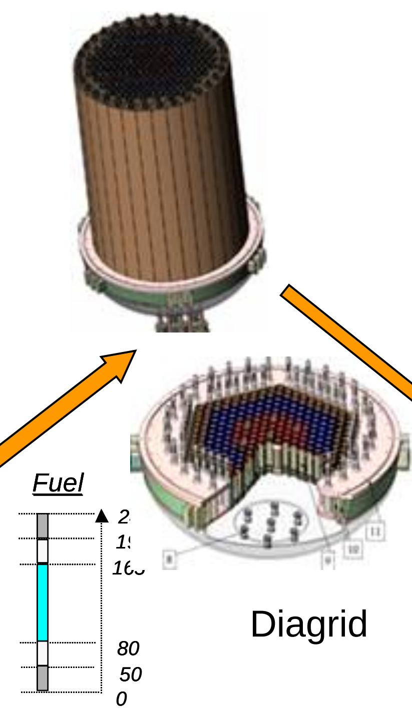
- *Joint preparatory work started in 2010 with support of CEA*
- *Signature of a MoU by AEKI Budapest (HU), UJV Rez (CZ), and VUJE Trnava (SK) in May 2010.*
- *NCBJ (Poland) joined the consortium in June 2012.*
- *Roadmap of construction has been prepared, with the main chapters General design, Safety principles, Licensing, R&D, Governance and IPR issues.*

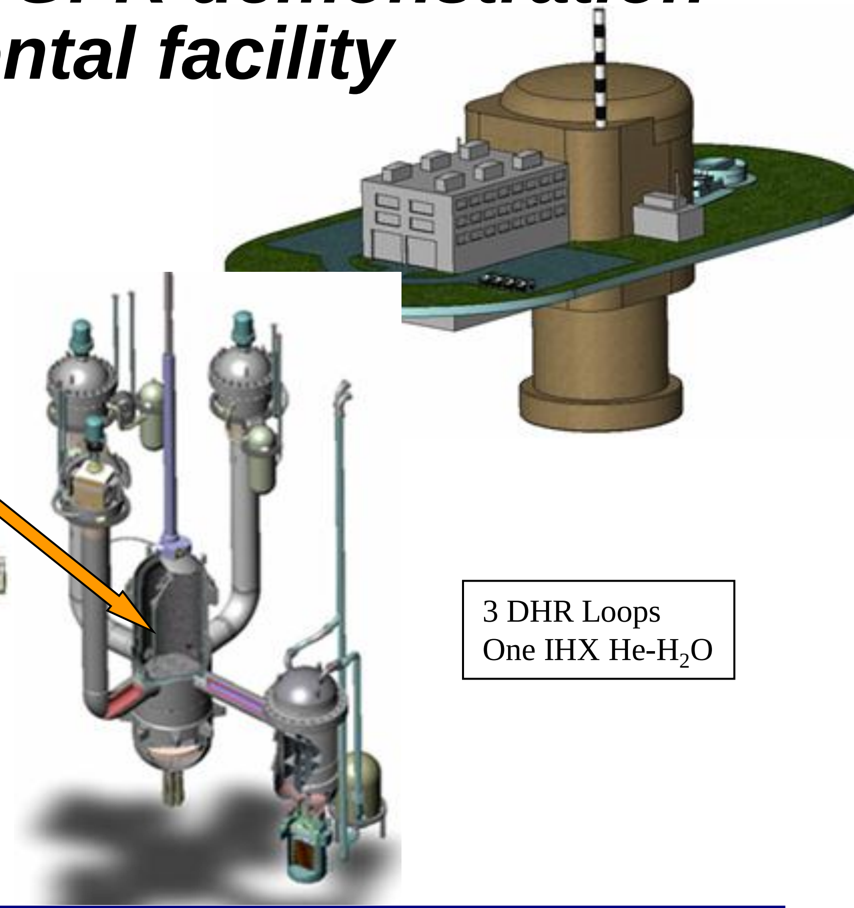
*Note: AEKI is the "MTA Centre for Energy Research" (**MTA-EK**) since January 2012.*

75 MW Core	Fast neutron Φ	Dose	In core vol.	Loading
25% Pu	9 10^{14} n/cm²/s	13 dpa/year	6 x 5 litres	8 days

ALLEGRO: GFR demonstration & experimental facility







Status of ALLEGRO Project

- *The design has been reviewed to take into account new safety criteria.*
- *A preliminary Conceptual Safety Features Review File (CSFRF) will be elaborated by 2012; an operational version is planned for end of 2013.*
- *Discussions with the Safety Authorities are underway.*
- *Several potential sites exist; site selection is planned for mid 2013*
- *Governance structure and financing issues are under discussion.*
- *The preparatory phase can be concluded by the end of 2013.*
- *The licensing & construction phase may start in 2014 if the design qualification and safety analysis have reached a sufficient level (agreement of the Safety Authority of the country of the site).*
- *Start of operation: 2023 - 2025*

Conclusion

- *There has been extensive progress made within the GIF GFR « Conceptual Design and Safety » Project, with a focus on safety aspects*

- *GFR fuel development is critical for this reactor system; results of R&D have been exchanged on a voluntary basis, since there is no Fuel Project signed yet*

- *Although quite substantial, R&D efforts in Europe have been slowed down, priority being given to SFR*

- *In parallel to the R&D shared in GIF, a new initiative (ALLEGRO demonstrator) has been launched recently*

Representatives in the GFR Steering Committee

EURATOM: Richard Stainsby (AMEC), Joseph Somers (JRC)

France: J.-C. Garnier, P. Guédeney (CEA)

Japan: T. Mizuno, N. Uto (JAEA)

Switzerland: W. Hoffelner, K. Mikityuk (PSI)

OECD/NEA: H. Paillère (Secretary)

Thank you for your contribution to the progress of the GFR R&D