The European programme for the development of advanced technologies for High and Very High Temperature Reactors

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The HTR/VHTR development in Europe

There has been a European programme for development of HTR technology since 1998

- 1998-1999: in FP4, INNOHTR, 150 k€, 10 partners, state-of-the-art assessment, identification of R&D needs
- In 2000, creation of the European HTR Technology Network in order to have a stabilised partnership for defining and implementing a coherent HTR technology development programme in Europe
- 2000-2005: in FP5, 10 contracts, ~16,5 M€, ~ 20 partners,
  - Re-mastering and developing base technologies
  - Addressing key feasibility issues of modular HTRs

HTR-TN
High Temperature Reactor Technology Network

The HTR/VHTR development in Europe

- 2005-2009: in FP6
  - 1 integrated project, RAPHAEL for the development of HTR/VHTR technologies
  - Large participation of HTR-TN partners in a project for developing advanced materials for extreme operating conditions, ExTreMat
  - Links with other related FP6 projects, GCFR and HYTEC
  - Additional activities on HTR waste issues in a STREP expected from the 3rd call
  - Development of international cooperation
    - Generation IV International Forum
    - Possibilities of bilateral relations presently examined (INET, PBMR, USDoE)

Objectives of the European programme of development of HTR technology

- To provide technologies for the industrial deployment of modern modular HTRs in Europe

  ⇒ ***Strong links with existing industrial projects*** in which industrial partners are involved (ANTARES, PBMR, NGNP (?))

  ⇒ ***Need of a demonstrator as soon as possible*** (by the end on the next decade)

  ⇒ ***Need of long term continuity and dynamics in the programme***

- To have the programme strongly oriented towards extending the scope of applications of HTR, for efficiently addressing the global warming issue

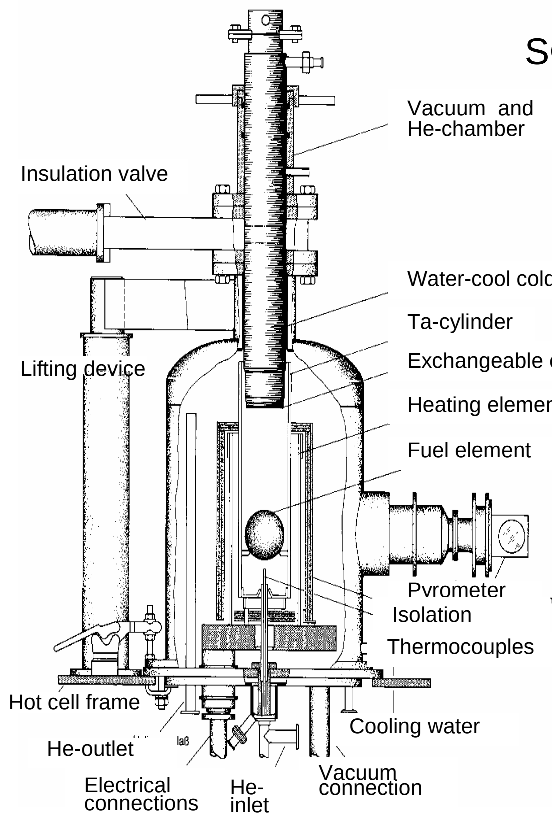
Electricity ⟶ ***Industrial process heat applications***

Achievements in FP5 (1)

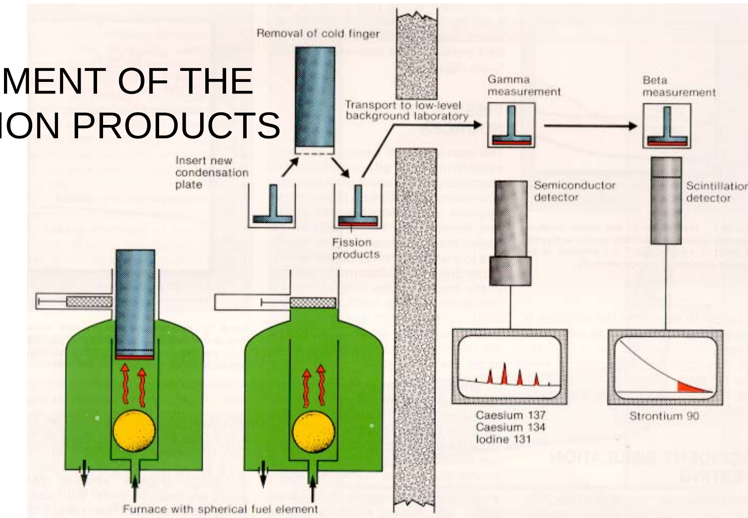
- Computer code development and qualification
  - Reactor physics: qualification of reactivity calculation
  - Fuel: thermo-mechanical models for the coated particle
- Fuel technology
  - Mastering the basis of fuel kernel and coating fabrication technologies
  - Irradiations of « state-of-the-art » German fuel in order to explore the performance of this fuel in extreme operating conditions (HFR, Petten, Netherlands)
    - Irradiation at 1000°C, 160 GWd/tHM completed
    - Preparation of the irradiation at 850°C, 200 GWd/tHM, with on line fission gas monitoring finalised, irradiation starting in the next HFR cycle
  - Heat-up facility for accident simulation on irradiated fuel commissioned in ITU (Karlsruhe)

Simulation of accident transients in the KÜFA facility

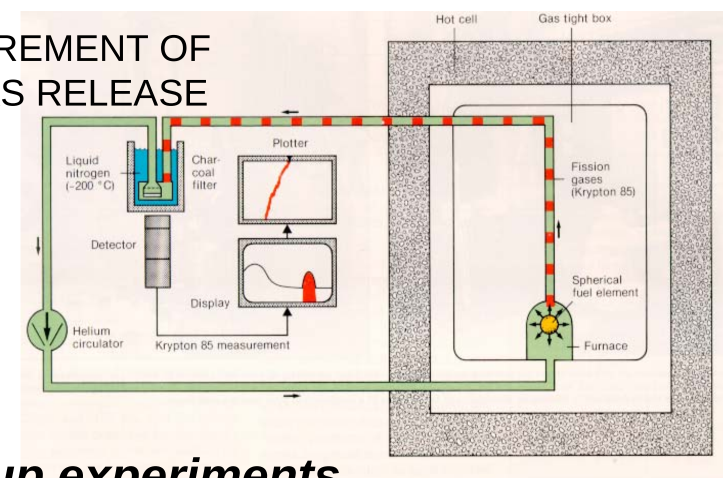
COLD-FINGER APPARATUS



MEASUREMENT OF THE SOLID FISSION PRODUCTS



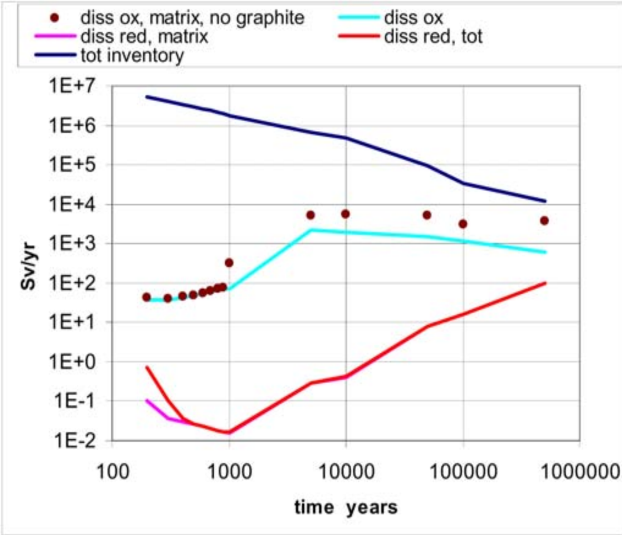
MEASUREMENT OF THE GAS RELEASE



KÜFA facility for post-irradiation heat-up experiments (JRC – ITU, Karlsruhe)

Achievements in FP5 (2)

- Fuel back-end and waste management
  - « Analytical » long term tests: behaviour of the different fuel materials in representative geochemical conditons
  - ⇒ First prediction of a coated particle lifetime in deep disposal conditions: > 10 000 years
  - Irradiated graphite decontamination process laboratory scale development



- Materials
  - Irradiation of the material selected for the « hot vessel » option (allowing higher operating temperature than with PWR steel, ~ 400°C), Modified 9Cr 1Mo
    - ⇒ No significant impact of irradiation on mechanical properties
  - First screening irradiation of 5 different grades proposed by different worldwide graphite manufacturers, at 750°C
- Safety approach
  - Development of an approach based on universally accepted safety standards, but taking into account the unique safety features of modular HTRs
    - « inherent » safety
    - Containment Issue

RAPHAEL, the new HTR/VHTR project of FP6 (1)

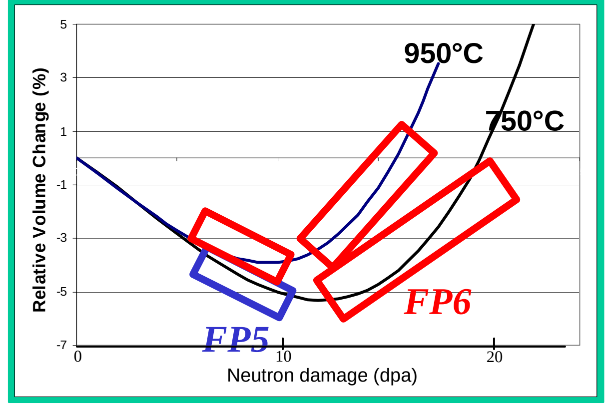
RAPHAEL = ReActor for Process heat, Hydrogen And Electricity production

- Integrated Project
- ~ 20 M€, 33 partners from 10 countries
- Objectives:
  - Consolidating base generic HTR/VHTR technologies
  - Exploring advanced solutions for improving HTR performances
    - higher temperature,
    - higher fuel burn-up
    - improved competitiveness
    - extending the domains of application (electricity ⟶ co-generation of heat and electricity)

RAPHAEL, the new HTR/VHTR project of FP6 (2)

- 8 sub-projects
  - Core Physics
  - Fuel technology
  - Back-end of fuel cycle
  - Materials
  - Components
  - Safety
  - System integration
  - Coordination
- 2 advisory groups
  - Industrial User Advisory Group (executives of nuclear industry, utilities, industrial engineering companies, process heat end users)
  - Safety Advisory Group (safety authorities, IAEA)

RAPHAEL: continuity with FP5



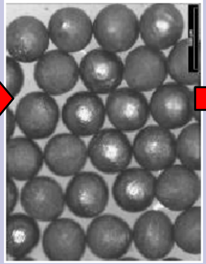
- Graphite:
  - Restarting of the irradiation at 750°C
  - New irradiation launched at 950°C
- Heat-up tests of the the fuel irradiated during FP5
- Fuel modelling: statistical methods for modelling the behaviour of a large number of particles
  Particle → fuel element → whole core
- Reactor physics: continuation of the assessment of the neutronic code HTR modelling capability
  - Coupling with thermo-fluid dynamic calculation
  - Transient calculation
  - Validation of burn-up calculation up to very high burn-up

Data from reactor operation (AVR, HTR-10…) (applies to the first two items)

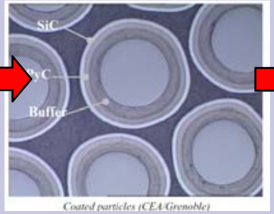
Isotopic analysis of a very high burn-up irradiated pebble (applies to the third item)

RAPHAEL: integration with industrial projects

UO_2 kernel fabrication



Dummy kernel coating



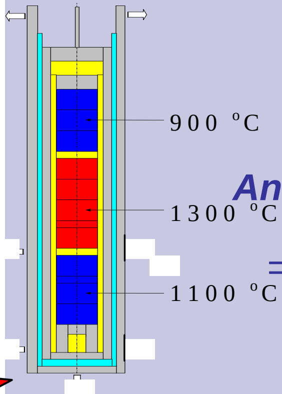
FP5

UO_2 kernel fabrication

ANTARES programme: CAPRI laboratory scale HTR fuel fabrication line

UO_2 kernel coating

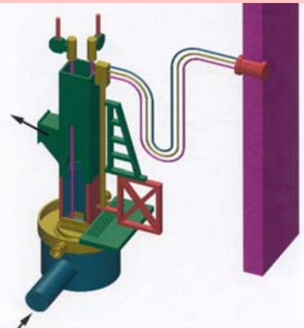
Compacting



FP6 RAPHAEL: Analytic irradiation in HFR ⇒ representative fuel material properties

	Irradiation #1	Irradiation #2
Irradiation position	HFR-G3	HFR-G3
Temperature (°C)	900, 1100, 1300	900, 1100, 1300
Irradiation time (Full Power days)	100	350
HFR cycles (~25 F.P. days/cycle)	4	14
Irradiation time (Calendar days)	120	425
Thermal fluence (n/m²)	0.7-1.2*10²⁵	2.7-4.2*10²⁵
Fast fluence (E>0.1 MeV) (n/m²)	1.0-1.7*10²⁵	3.3-6.0*10²⁵

ANTARES programme: CAPRI fuel performance testing



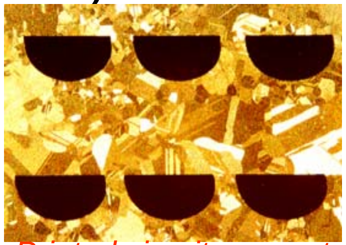
Irradiation Device

OSIRIS irradiation device

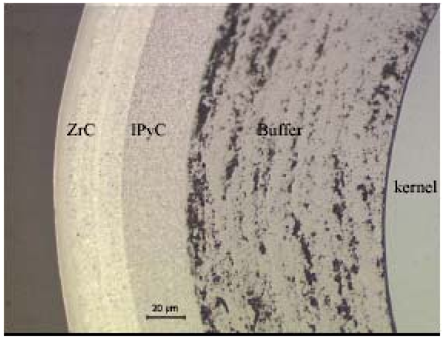
(+ Accident behaviour in KÜFA)

RAPHAEL: innovation

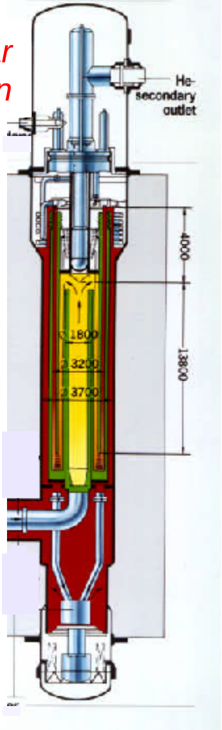
- Development of components for heat applications
  - Intermediate heat exchanger (IHX)
  - Circulator
- Fuel: fabrication of advanced coated particles
  - UCO kernel
  - ZrC coating
- Materials for very high temperature
  - Nickel base alloys
  - C-C composites
  - \+ Inputs from ExtreMat



Printed circuit concept



Tubular design



RAPHAEL: integration

- Technical integration
  - Providing R&D needs from real industrial projects
  - Providing boundary conditions for R&D from such projects
  - Assessing the consequences on the reactor of the coupling with heat applications (in particular thermochemical hydrogen production process)
  - Assessing the consequences of R&D results on design
- Transverse actions
  - Communication plan
  - Education and training
  - Quality management

Summary: what will be achieved after FP5 and FP6 and what is next to be done? (1)

- FP5 and FP6 results:
  - Validation of HTR modelling capability of computer tools (core physics, fuel performance, system transient analysis)
  - Fabrication processes and performance assessment of the state-of-the-art fuel
  - Selection of the key materials (vessel, IHX)
  - Feasibility of key components
  - Elaboration of a safety approach adapted to specific safety features of modular HTRs
  - Preliminary studies on HTR specific waste management
  - + Exploratory studies on advanced technologies

Summary: what will be achieved after FP5 and FP6 and what is next to be done? (2)

- What is next?
  - Objective:
    - First step towards an industrial demonstrator

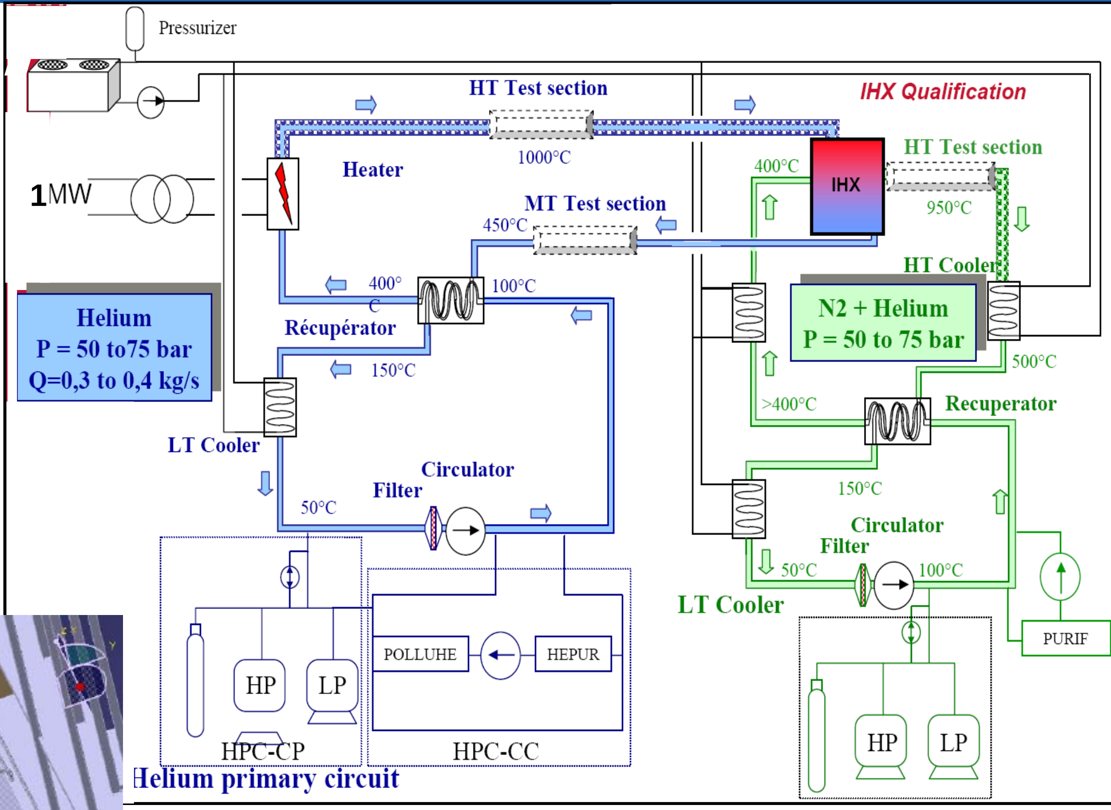
    ⇒To go beyond base R&D towards the demonstration

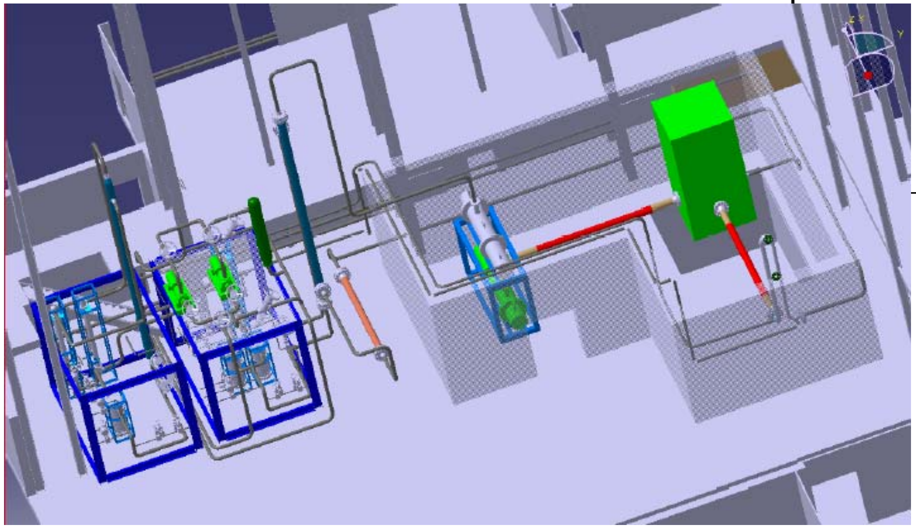
    ⇒To organise a strong interaction between R&D and design
  - Programme outline (1)
    - Qualification for licensing and industrial operation
      - *Computer tools*
      - *Fuel (representativeness of industrial fabrication, statistics)*
      - *Materials*
      - *Components*

    ⇒Need of large test facilities
      - *Helium loops*
      - *Large irradiation facilities*
      - *Critical mock-up*
      - *Large flow loops*

Summary: what will be achieved after FP5 and FP6 and what is next to be done? (2)

HELITE loop
1 MW





Summary: what will be achieved after FP5 and FP6 and what is next to be done? (3)

- What is next?
  - Programme outline (2)
    - Developing the technologies for the next step (advanced materials and fuel, innovative components, etc)
    - Filling the remaining gaps of the present programme
      - *HTR specific waste management*
      - *Radio-contaminant transport (?)*
      - *…*

⇒ In order to keep in the future its usefulness for industrial application, the European HTR programme should follow the dynamics of industrial projects and the effort dedicated to this programme should be expanded in order for it to stay alive.