

ANTARES

The AREVA HTR-VHTR Design

The world leader in nuclear power plant design and construction powers the development of a new generation of nuclear plant

»» A long history of HTR technology development

Within the AREVA group, new plant design is managed by FRAMATOME ANP, an AREVA and Siemens company. Through SIEMENS (and INTERATOM), the development of the HTR technology in Germany is now part of FRAMATOME ANP's rich advanced reactor portfolio:

- Construction and operation feedback of the AVR Joint Research Reactor (which has been operated for 21 years) and of the Thorium High Temperature Reactor (THTR)
- Development of the MODUL reactor by INTERATOM
- Design, testing and manufacturing of components for HTR technology
- Helium purification processing and handling experience
- Licensing experience

The MODUL reactor is the basis for the PBMR now being under development in South Africa. The design of the MODUL is realized in a 10 MW scale well known as HTR 10 in China, now in operation.

In France, FRAMATOME ANP worked with General Atomics for close to 20 years.

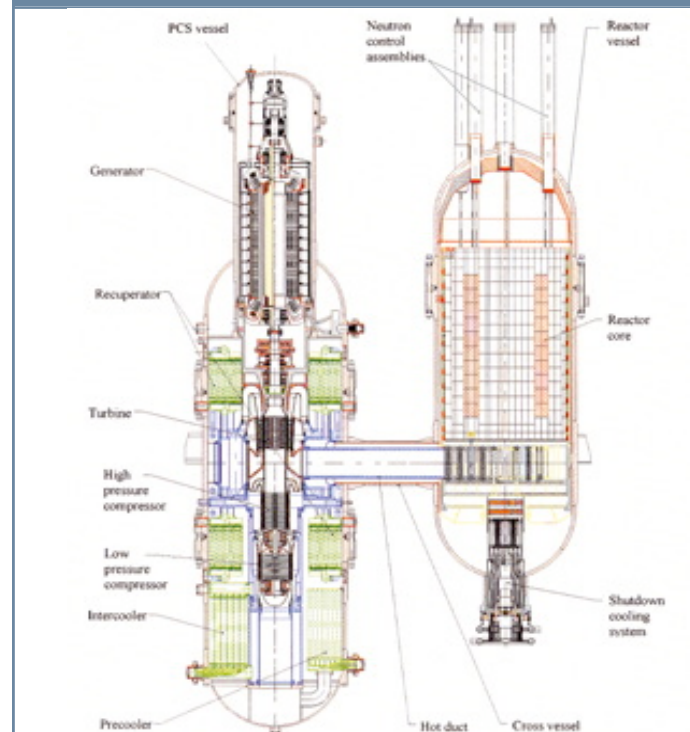
- In a first phase, FRAMATOME ANP participated in the development and cost studies of the pressure vessel and steam generator for the Modular High Temperature Gas Reactor (MHTGR).
- Later, FRAMATOME ANP was associated with Russian institutes and General Atomics to develop the conceptual design of a more advanced technology: the Gas Turbine Modular Helium Reactor (GT-MHR).

FRAMATOME ANP has been deeply involved in HTR fuel programs with the French Atomic Energy Commissariat (CEA) and the European Union.

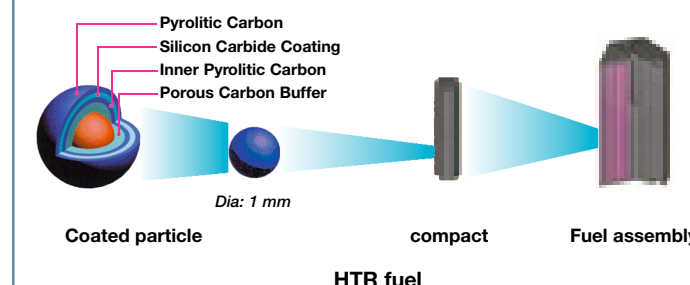
- Fuel manufacturing developments for particles and compacts have been conducted on CEA and CERCA laboratory-scale lines for fuel particles and fuel compacts, respectively.
- CERCA, a FRAMATOME ANP subsidiary, also has manufactured HTR fuel compacts for the U.S. program.

Modular concepts support the elimination of many safety systems, simplifying the design and leading to capital cost reduction.

Modern HTRs: reactor and fuel design

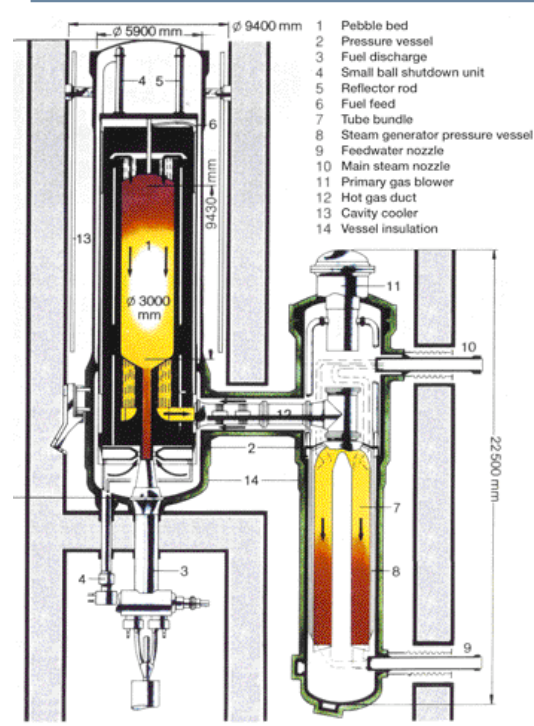


GT-MHR module arrangement



HTR fuel

Arrangement of HTR MODUL 200



German Test facility for HTR Materials and Components

10 MWth

Thermal power

950 °C

Helium temperature

47 bar

Operating pressure

Total operating history

> 900 °C → ~7,000 hours

> 700 °C → ~12,000 hours

FRAMATOME ANP has demonstrated capabilities and experience in HTR modular plant and component design, both for pebble and block fuel concepts.

➤ Modern HTRs: a promising and flexible concept

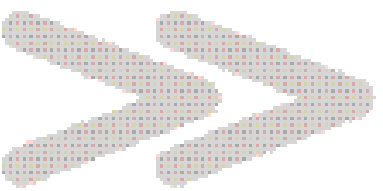
FRAMATOME ANP's evaluations indicated that identified modern modular HTRs are a promising concept to meet the requirements of enhanced safety, higher efficiency, competitiveness and waste management. Evaluations performed by the Generation IV International Forum (GIF) identified a similar conclusion.

Process heat applications are also a distinctive feature of modern HTRs. Hydrogen production is seen as a promising solution to meet the ever growing needs for clean energy.

Modern, medium-sized power modular HTR units will allow more flexibility to match planned small expansions in some electricity markets.

The HTR technology also provides potential for future improvements:

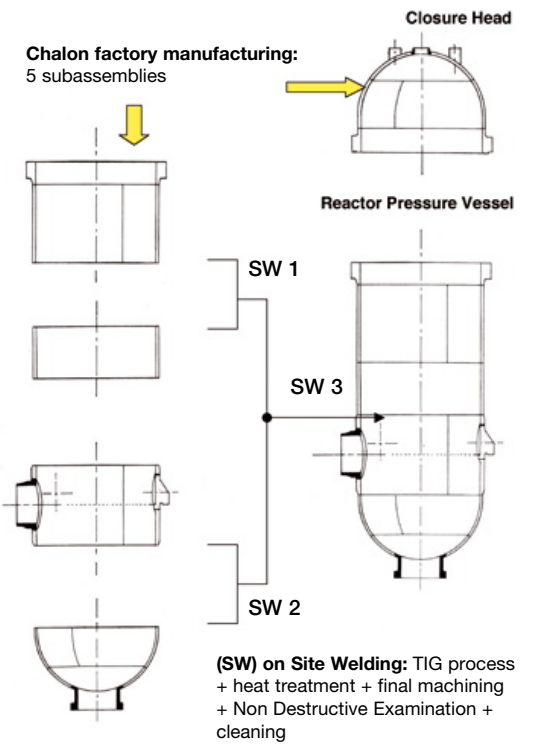
- increased operating temperature, to enhance thermodynamic efficiency and produce hydrogen by splitting water
- new fuel management (U, Pu, Th cycles; very high burnups; Pu inventory control; minor actinides consumption)
- optimized economics



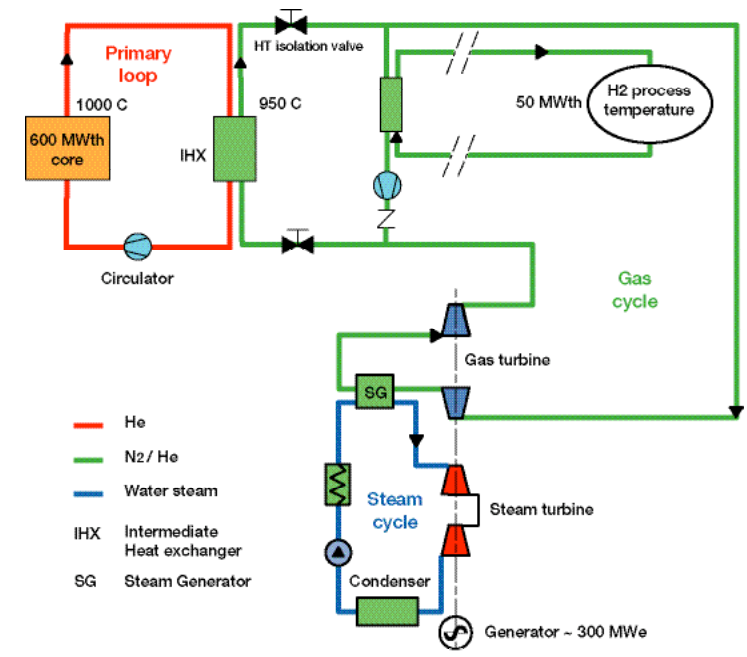
AREVA is investing in HTR development to add this technology to its long-term nuclear power plant design portfolio.

➤ A new design: building on proven technology to optimize performance and minimize development risk

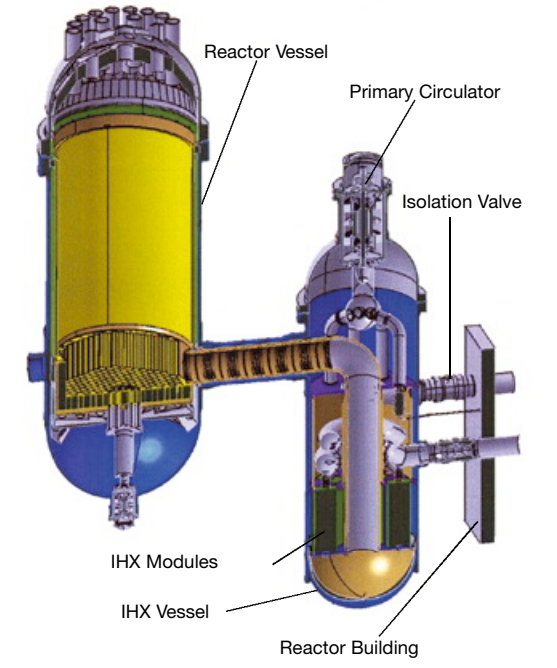
Modular Reactor Vessel Fabrication at FRAMATOME ANP's Chalon Manufacturing Plant and on site



Possible arrangement with electricity and hydrogen cogeneration



The Indirect-Cycle High Temperature Reactor



Unmatched experience in large component design and manufacture, along with sound risk assessment, led FRAMATOME ANP to select an original indirect cycle architecture, facilitating both power and hydrogen generation.

The nuclear reactor is coupled to the applications through an Intermediate Heat exchanger (IHX) and establishes the basis for a common heat source design, minimizing the development challenges associated with the reactor and primary heat transport system.

This new approach optimizes electricity generation by:

- Using a conventional air turbine for the high temperature range (gas cycle)
- Using a conventional steam cycle for the lower temperature range (steam cycle).

Conceptual design is in progress. Large component manufacturing feasibility has been established.

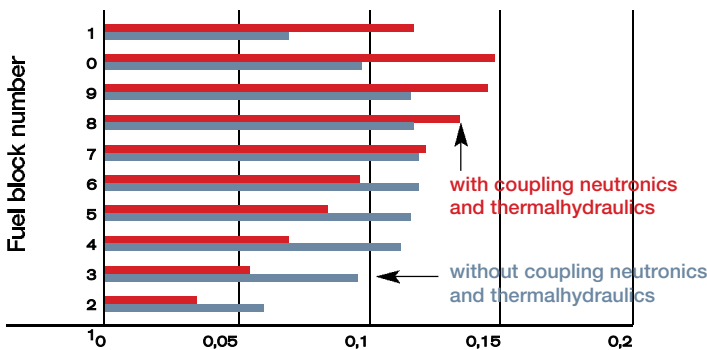
>> Focused R&D: programs for key issues

FRAMATOME ANP, together with EDF, CEA and other industry and research partners, is leading the ongoing HTR European development. It also performs an independant large R&D program:

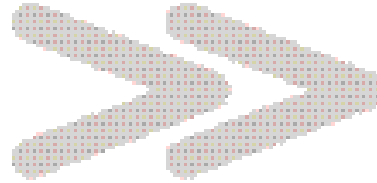
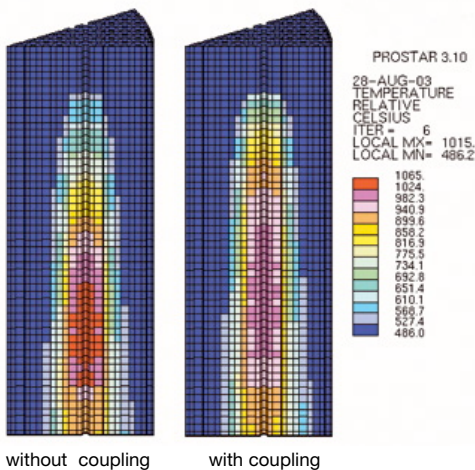
- Development and qualification of HTR specific calculation tools
- Research on high temperature materials and helium technologies
- Development of key components (compact high performance heat exchangers, reactor vessel fabrication, etc.)
- Development of a high performance fuel fabrication process

Example of computer code coupling development resolving core power distribution CRONOS (neutronics) and STAR-CD (thermohydraulics)

CRONOS 2 results: axial power distribution (with and without coupling)



STAR-CD results : temperature fields



FRAMATOME ANP: the partner for your VHTR project

Temperature effects are important due to large temperature range between inlet and outlet core temperature



The goal of the ANTARES* Development Program is to create a commercially competitive Advanced High Temperature Reactor to meet future industrial demands for electricity generation and process heat supply. The critical success factors for realizing the ANTARES vision are synergistic with FRAMATOME ANP's core business and resource capabilities. These include:

- mastering HTR fuel technology,
- anticipating and pursuing the R&D necessary to achieve ANTARES objectives and innovative concepts,
- for the longer term, applying our experience and resources to develop improved HTR concepts.

* AREVA New Technology based on Advanced gas cooled Reactor for Energy Supply



The ANTARES Development Program includes considerations for improvements in power output and outlet temperature.

FEATURES/PARAMETERS	ELECTRICITY PRODUCTION PLANT DESIGN	VHTR DESIGN
Plant Configuration	Cogeneration applications	Multi-purpose demonstration with H ₂ production and power generation in parallel
Nuclear Heat Source Module Configuration	Indirect cycle Helium-cooled reactor Single primary loop	
Reactor Power	600 MWth	
Reactor Outlet Temperature	up to 850 °C	up to 900 to 1000 °C
Primary Coolant Pressure	7 MPa	6 MPa
Reactor Vessel Material	SA 508 or 9 Cr – 1 Mo	9 Cr – 1 Mo
Core Configuration	Prismatic core	
Fuel Particle Type	SiC coating UCO or UO ₂ kernel	SiC or ZrC coating
Operating Max Fuel Temp. (Guideline)	1300 °C	
Accident Peak Fuel Temp. (Guideline)	1600 °C	
IHX Design	Compact	
IHX Nominal Heat Load	600 MWth	
IHX Primary Inlet Temperature	Up to 850 °C	900 to 1000 °C
Secondary Fluid	Nitrogen/Helium mixture	tbd
IHX Secondary Outlet Temperature	Up to 800 °C	850 to 950 °C
Secondary Coolant Pressure	7 MPa	6 MPa
Process Heat Supply Temp. to Heat Process Unit	Any temperature up to 800°C	800 to 900 °C
Hydrogen Production Unit	Conventional or advanced medium temperature process or electrolysis	H ₂ chemical or high temperature steam electrolysis processes
Power Generation System	Combined cycle gas turbine (closed circuit)	