GAS-COOLED FAST REACTOR - ALLEGRO DECAY HEAT REMOVAL STUDIES

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Received 10 May 2017; accepted 25 May 2017

Abstract

One of the key issues in the design of the Gen IV GFR ALLEGRO (Gas-cooled experimental Fast Reactor) is the core cooling in accident conditions, mainly due to the low thermal inertia of the helium coolant.
The decay heat removal system (DHR loops), and their main components must be studied under such conditions to check and improve their efficiency in the most penalising accident regimes.
This paper is divided into two parts. First part presents a brief description of the reactor main parameters. Second part is dedicated to the analysis of representative scenario related to decay heat removal – Total Blackout with one DHR loop in natural circulation.
The studies on the Decay Heat Removal of ALLEGRO presented in this paper was carried out by the V4G4 consortium of partners: VUJE (Slovakia), UJV (Czech Republic), MTA EK (Hungary), NCBJ (Poland) and associated with CEA (France).

Key Words: ALLEGRO, Gas-cooled Fast Reactor, Decay Heat Removal, natural circulation.

1. Introduction

The GFR system, a high-temperature helium-cooled fast-spectrum reactor with a closed fuel cycle is one of the six Gen IV systems. It combines the advantages of fast-spectrum systems for long-term sustainability of uranium resources and waste minimization (through fuel multiple reprocessing and fission of long-lived actinides), with those of high-temperature systems (high thermal cycle efficiency and industrial use of the generated heat, similar to Very High Temperature Reactors).
The advantages of the gas coolant are that it is chemically inert (allowing high temperature operation without corrosion and coolant radio-toxicity) and single phase (eliminating boiling), and it has low neutron moderation (the void coefficient of reactivity is small).

However, there are some technological challenges related to the use of gas coolant. It is low thermal inertia leading to rapid heat-up of the core following a loss of forced cooling. Also, the gas-coolant density is too low to achieve effective natural convection to cool the core at low pressures. The power requirements for the blower are also important.

2. Brief description of ALLEGRO reactor

The design of the ALLEGRO consists of two helium primary circuits, three decay heat removal (DHR) loops integrated in a pressurized cylindrical guard vessel. The two secondary water circuits are connected to water-air heat exchangers.
The ALLEGRO reactor would operate not only as a demonstration reactor of GFR technology, but also as a test pad of using the high temperature coolant of the reactor. Thanks to the high outlet temperature, ALLEGRO reactor is possible to use for generating process heat for industrial applications and a research facility. The fast neutron spectrum makes it attractive for fuel and material development, testing of some special devices or other research works.
The 75 MW_{th} ALLEGRO reactor shall be operated with two different cores. The starting core with UOX (Uranium Oxide) or MOX (Mix Oxide) fuel in stainless steel claddings will serve as a driving core for six experimental fuel assemblies containing the advanced carbide (ceramic) fuel. The second core will consist solely of the ceramic fuel and will enable to operate ALLEGRO at the higher target temperature.

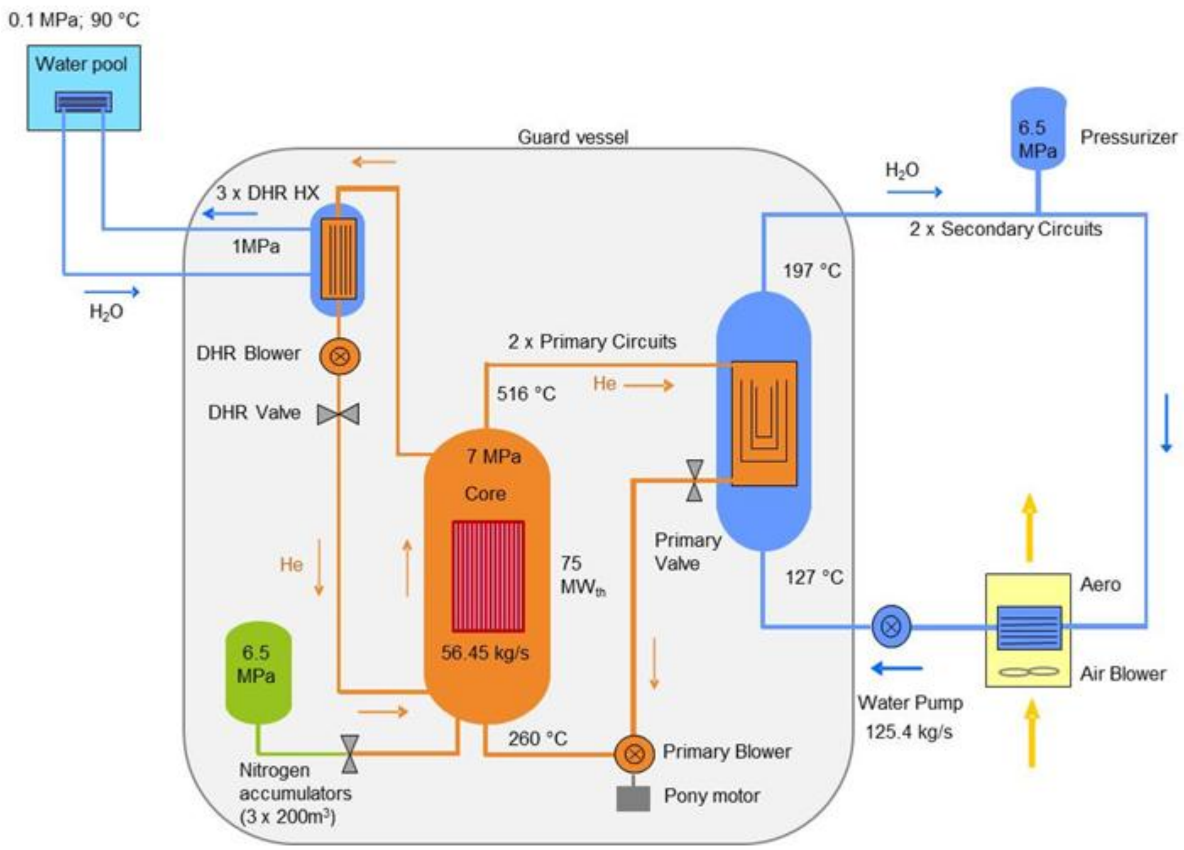

Fig.1: *Description of main ALLEGRO circuits and components*

Basic nominal parameters and general features of the ALLEGRO demonstrator are listed in the next table and depicted on the figure above.

Tab.1: *Main design characteristic of ALLEGRO*

Parameter	Nominal parameter / value	Comment
Nominal Power (thermal)	75 MW	Reduced power is being considered in the range 30 – 75 MW.
Nominal Power (electrical)	0 MW	
Power density	100 MW/m^3	Reduced power density is being considered in the range 50 – 75 MW/m^3.
Fuel	MOX/ SS cladding	Start-up core. Feasibility of LEU UOX for the start-up core is being investigated.
	UPuC/ SiCSifC cladding	Long term core.
Type of fuel assembly	Hexagonal wrapper and wired fuel rods	
Number of fuel rods per assembly	169	
Number of fuel assemblies	81	
Number of experimental fuel assemblies	6	
Number of control and shutdown rods	10	
Primary circuit coolant	Helium	
Secondary circuit coolant	Water	Gas is being investigated
Tertiary circuit coolant	Air	Atmosphere
Primary pressure	70 bar	
Core inlet/outlet temperatures	260/516 °C	Should be upgraded for full core refractory fuel.
Number of primary loops	2	
Number of secondary loops	2	
Number of DHR loops	3	Directly connected to the primary vessel
DHR circuits coolant	Helium	
DHR intermediate circuits coolant	Water	
DHR heat sink	Water pool	
DHR exchangers nominal capacity per loop	2.4 MW	
Number of accumulators	3	Filled with Nitrogen

3. Safety issues, Decay Heat Removal

The investigation of safety issues is linked to the very low density of the pressurized helium coolant, which results in a very low thermal inertia on the coolant side. Despite the good heat capacity of the helium, there is low heat removal efficiency under natural circulation.
So, in the process of ALLEGRO feasibility studies a Total Blackout transient is postulated.

4. DHR studies (calculation) – Total Blackout with one DHR loop in natural circulation

The initiating event „Total Blackout" is characterised by total loss of electric power supply of all powered systems of a unit during operation at nominal power.

Specification of analysed case:

- Initiating event: Total Blackout
- Relevant acceptance criteria: $T_{cladMAX} < 1300$ °C
- Heat removal from the core: 1 DHR loop in natural circulation
- Failure of other systems: The pony motors of main blowers and DHR blowers start-up failure.

The aim of this calculation is to demonstrate the capability and the reliability of the passive way of the decay heat removal from the ALLEGRO using natural circulation in order to accomplish the decay heat removal safety function.
The acceptance criterion evaluated for this initiating event is that cladding temperature shall not exceed 1300°C.

Evaluation of analysed case:
The Total Blackout leads to immediate trip of main blowers, secondary system pumps and air coolers in tertiary system. The backup electricity (batteries/diesel) is provided only for SCRAM and ESFAS system and also for primary loops and DHR loops isolation valves. The isolation valves on second and third DHR system are failed to open. The residual heat from the core is removed by one DHR loop in natural circulation mode.
Decreasing of primary system flow rate after closing main isolation valves in both loops decreases heat removal rate from the core and it leads to increasing the core outlet gas temperature. Maximum cladding temperature reaches the value 998 °C in 820 s.

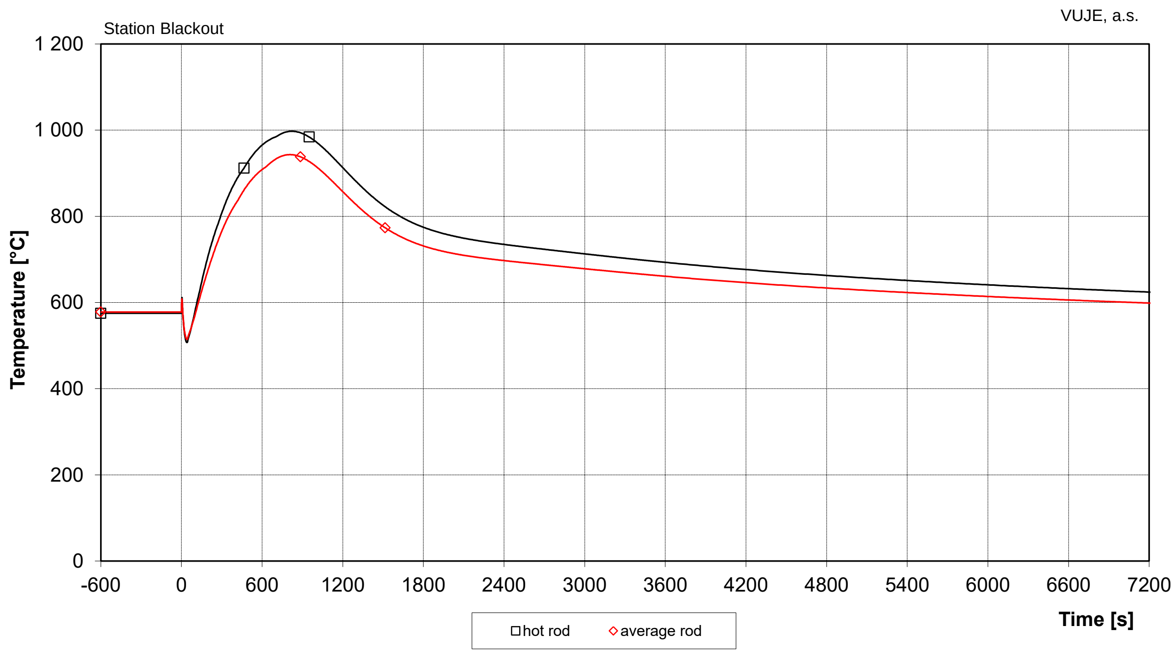

Fig.2: *Maximum cladding temperature*

The previous figure shows the behaviour of maximum cladding temperature in hot rod and in average rod during postulated accident. Maximum cladding temperature was reached in the hot rod. The reason is the hypothetical hot channel which contains hot rod assumes the higher initial power, the higher fuel pin power and higher linear power compared to average channel with average rods.
In the time when both main loop isolation valves are fully closed (at 45 s), the core power is equal to 3 MW and heat removal is not established yet, so the temperature starts to rapidly increase. The equalization of the power transferred to DHR system and the power generated in the core occurred at 540 s and the available DHR system started to be effective, but with the delay due to low thermal inertia of helium coolant.
Nevertheless, the analysis shows that decay heat removal by using 1 DHR system in natural circulation mode is possible, and the generated residual heat is removed from the core by secondary and DHR system. Evaluated acceptance criterion is fulfilled, but the fuel cladding temperature is near the temperature at which the local cladding defects can occur with possible leaks of fission products to the coolant.

5. Conclusion

The experimental GFR ALLEGRO project is being developed by the V4G4 consortium. One of the key issues related to safety of using gases as coolant in a fast reactor is related to the decay heat removal capabilities in accidental conditions due to the lack of thermal inertia of the system and the poor capabilities of gases to remove heat by natural convection.
This issue is being investigated in support to the design of ALLEGRO through the improvement of the core design and the safety related systems and components (lower power density, guard vessel, safety injection accumulators, passive feed of main blowers etc.)

Acknowledgement
This work has been partially carried out in the frame the European project VINCO (Contract Number 662136).

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