Nuclear Engineering and Design 286 (2015) 67–76

Contents lists available at ScienceDirect

Nuclear Engineering and Design

journal homepage: www.elsevier.com/locate/nucengdes

Preliminary study of the decay heat removal strategy for the gas demonstrator allegro

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HIGHLIGHTS

- Improved decay heat removal strategy was adapted for the 75 MW ALLEGRO MOX core.
- New nitrogen injection strategy was proposed for the DEC LOCA transients.
- Preliminary CATHARE study shows that most of the investigated transients fulfill criteria.
- Further improvements and optimizations are needed for nitrogen injection.

ARTICLE INFO

Article history:
Received 27 November 2014
Received in revised form 30 January 2015
Accepted 1 February 2015

ABSTRACT

The helium cooled Gas Fast Reactor (GFR) is one of the six reactor concepts selected in the frame of the Generation IV International Forum. Since no gas cooled fast reactor has ever been built, a medium power demonstrator reactor – named ALLEGRO – is necessary on the road towards the 2400 MWth GFR power reactor. The French Commissariat à l'Energie Atomique (CEA) completed a wide range of studies during the early stage of development of ALLEGRO, and later the ALLEGRO reactor concept was developed in several European Union projects in parallel with the GFR2400. The 75 MW thermal power ALLEGRO is currently developed in the frame of the European ALLIANCE project. As a result of the collaboration between CEA and the Hungarian Academy of Sciences Centre for Energy Research (MTA EK) new improvements were done in the safety approach of ALLEGRO. A complete Decay Heat Removal (DHR) strategy was devised, relying on the primary circuits as a first way to remove decay heat using pony-motors to drive the primary blowers, and on the secondary and tertiary circuits being able to work in forced or natural circulation. Three identical dedicated loops circulating in forced convection are used as a second way to remove decay heat, and these loops can circulate in natural convection for pressurized transients, providing a third way to remove decay heat in case of accidents when the primary circuit is still under pressure. The possibility to use nitrogen to enhance both forced and natural circulation is discussed. This DHR strategy is supported by a wide range of accident transient simulations performed using the CATHARE2 code. This paper presents the DHR strategy selected for ALLEGRO and the CATHARE2 simulations are supporting this strategy.

1. Introduction

The Gas cooled Fast Reactor (GFR) is one of the six concepts selected in the frame of the GEN IV Forum. In the GFR development plan, the European gas fast reactor demonstrator project ALLEGRO ([1–4]) is the first step towards the electricity generating prototype GFR2400, thus it will be the first GFR ever built.

Several objectives are assigned to ALLEGRO. At first, it will demonstrate the viability of the GFR reactor system. Most of the GFR architecture, materials and components are considered at reduced scale in ALLEGRO. With such thermal power (75 MWth)

Abbreviations: CEA, Commissariat à l'Energie Atomique; DEC, Design Extension Condition; DHR, Decay Heat Removal; ETDR, Experimental and Test Demonstration Reactor; EU FP7, European 7th Framework Programme; GFR, Gas Cooled Fast Reactor; LOCA, Loss of Coolant Accident; MHX, Main Heat Exchanger; MOX, Mixed Oxide Fuel; MTA-EK, Hungarian Academy of Sciences Centre for Energy Research; MTR, Material Testing Reactor; PCT, Peak Cladding Temperature.

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http://dx.doi.org/10.1016/j.nucengdes.2015.02.001
0029-5493/

and since it incorporates the main systems arrangement, materials and components foreseen for the GFR (except the energy conversion unit), ALLEGRO will provide at a pilot scale an essential part of the demonstration and qualification of the following specific technologies:

- The core behavior (neutronics, thermal hydraulics and mechanics) and control (innovative control rod devices), as well as the overall reactor dynamic behavior.
- The innovative refractory fuel is using a progressive qualification approach based on two successive core configurations with different fuel technologies and operating conditions. At first, the standard MOX core with metallic clad will be implemented (moderate temperature) in order to irradiate some innovative refractory Sub-Assembly (S/A) at full scale. After this preliminary phase, a full refractory core, representative of the GFR, will be implemented. ALLEGRO will contribute to the fuel qualification between fuel samples irradiation in Material Testing Reactor (MTR) and full scale industrial demonstration in a GFR prototype. The irradiation conditions should be as close as possible to those of the GFR, in terms of fuel and clad temperatures, primary pressure and core design. The GFR fast neutron flux and the ratio dose/burn-up values are targeted within a range of 30%.
- The safety options and components, similar to those of the GFR, are based on a specific close containment enclosing the primary circuit (in order to ensure a primary backup pressure in case of a leak) and relying on moderate power pumping devices or natural convection loops. The key DHR issues to be demonstrated will be the capability of the various systems to overcome the core bypass situations, their ability to operate simultaneously (redundancy effect) or in a complementary manner (forced vs natural convection). As the first gas cooled fast reactor, ALLEGRO will allow to dispose of a first validated safety reference framework.
- Some novel reactor technologies such as core optical measurement devices, fuel handling, transfer and storage devices.
- Some generic gas reactor technologies such as thermal insulation barrier, cross duct pipes, seals for reactor tightness, control and management of the helium quality, blower, heat exchanger, etc.

The study presented in this paper focuses on the safety analysis of the ALLEGRO reactor. Within the EU FP7 ALLIANCE project (2013–2015) [5], the French Commissariat à l'Energie Atomique (CEA) and the Hungarian MTA EK collaborates on the topic of safety problems, in particular for thermal-hydraulic studies using the CATHARE2 code. This paper presents the first achievement of this collaboration, with the CATHARE2 simulation of a wide range of accident transients supporting the concept of the decay heat removal strategy of the reactor. This strategy relies on the use of pony-motors to support the primary blowers as a first way to remove decay heat, and the use of three dedicated loops able to flow in forced convection as a second way to remove decay heat and in natural circulation for pressurized situations as a third way to remove decay heat. The possibility to use nitrogen injection to enhance both forced and natural circulation is discussed.

The paper first presents the current state of the design of the ALLEGRO reactor, then the CATHARE2 code is described focusing on the specific modeling developed for this study, then the DHR strategy proposed for ALLEGRO is presented, and finally the results of the transient simulations are discussed.

2. The Allegro reactor

The current design of the ALLEGRO reactor is presented in Figs. 1 and 2. A more complete description can be found in references [1–4]. The reactor core has 75 MW thermal power and the two main loops (37.5 each) are dedicated to remove the core power (no electricity generation). The primary circuits are cooled with helium and are composed of a motor-driven blower and a gas-to-water heat exchanger (named Main Heat Exchanger, MHX). The secondary circuits are cooled with water and are composed by the secondary side of the MHX, a water pump, a water-to-air heat exchanger (named air-cooler) and a pressurizer. The final heat sink is air (secondary side of the air-cooler). The pony-motor and the primary main blower are connected to the same shaft. In case of successful SCRAM the motor of the main blower is turned off and the pony-motor is started. If the cooling provided by the ponies is sufficient the heat removal path remains the same. The pony motors are driven by independent diesel generators, but in case

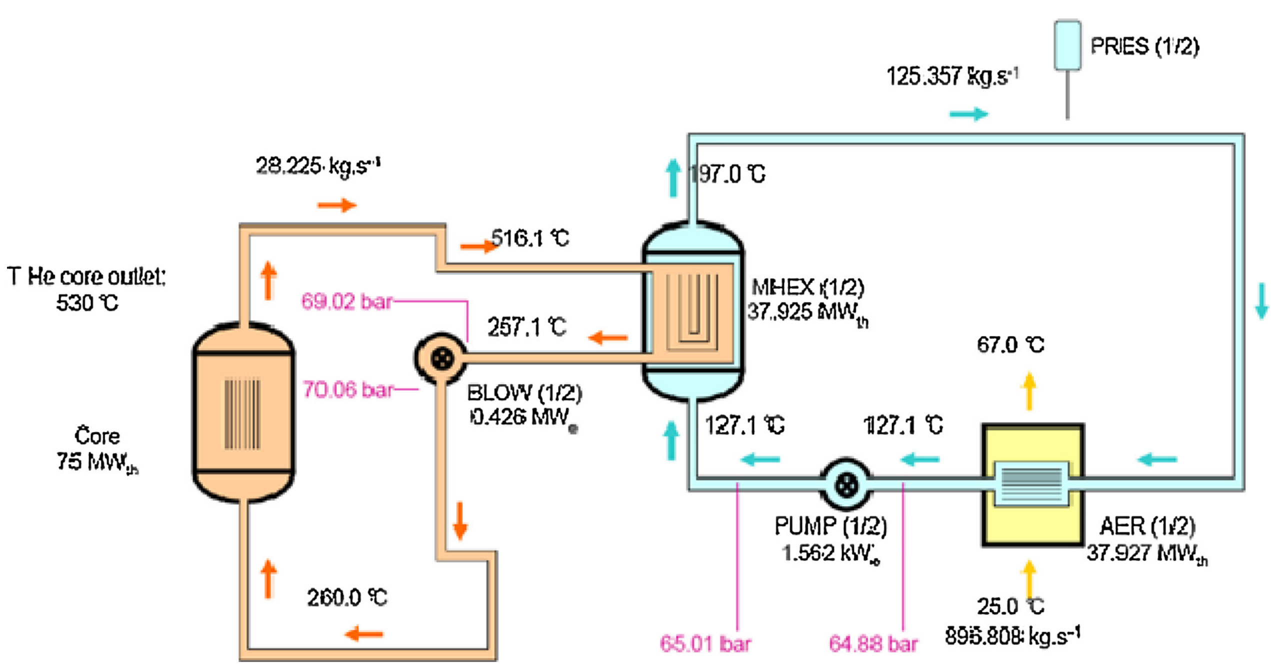

Fig. 1. Schematic of ALLEGRO thermal-hydraulic cycle: BLOW = blower, MHEX = Main Heat Exchanger, AER = Air-cooler.