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Pre-test analysis of accidental transients for ALFRED SGBT mock-up characterization

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ABSTRACT

In the framework of the Horizon 2020 SESAME project (thermal hydraulics Simulations and Experiments for the Safety Assessment of MEtal cooled reactors), the CIRCE pool facility has been refurbished by ENEA to host HERO test section (Heavy liquid mEtal pRessurized water cOoled tubes) with the aim to test an innovative concept of the steam generator bayonet tubes proposed for ALFRED (Advanced Lead Fast Reactor European Demonstrator) and to provide experimental data for code validation. HERO consists of a bundle of seven bayonet tubes characterized by an active length of six meters (1:1 with the ALFRED steam generator tube length). The main purposes of the research were to investigate the thermal hydraulic behavior of the innovative concept and provide a set of experimental data aiming at validating STH (System Thermal-Hydraulic) code. The calculations were carried out adopting RELAP5-3D©, updating the nodalization scheme validated with the experimental data of CIRCE-ICE campaign. The experiment consists of a transition from forced to natural circulation in a loss of flow accidental scenario; in order to identify the initial conditions of the experiment, several full power conditions were simulated. Starting from the reference steady state conditions, five transient tests were simulated to evaluate the effect of the reduction of the secondary mass flow rate (reduced from the nominal value to simulate the activation of the DHR system) and the effect of the heat losses compensation. According with the calculation, HERO test section offers excellent thermal-hydraulic behavior ensuring a sufficient natural circulation conditions to remove the decay heat in the short term.

1. Introduction

The construction of a demonstrator reactor is a fundamental step for the LFR (Lead-cooled fast reactor) development. At this purpose, in the frame of LEADER project (Lead-cooled European Advanced DEmonstration Reactor), ALFRED (Advanced Lead Fast Reactor European Demonstrator) was presented as the scaled-demonstrator reactor for the LFR technology (Frogheri et al., 2013). The growing interest in the lead-cooled fast reactors, required to identify sources of financing. In this framework, FALCON (Fostering ALfred CONsortium) Consortium Agreement was signed on December 2013 and it was the first step for the construction of ALFRED. The purpose of FALCON is to obtain resources, at first, to complete the technology development and design face and then, to support the reactor construction phase (Frignani et al., 2017).

The configuration of the steam generator bayonet tubes (SGBTs) for ALFRED is an innovative concept based on super-heated steam double wall bayonet tube steam generator which allows the increase of the safety margin of the nuclear power plant, strongly reducing the probability of the interaction between primary and secondary coolant and detecting any leakages from the liquid metal or the steam, by monitoring the pressure of the helium inside the gap volume.

Sapienza University of Rome supports the Experimental Engineering Division by the ENEA Brasimone Research Center in the heavy liquid metal (HLM) technology development, in particular in the framework of STH code validation and safety analysis. In this frame, the CIRCE (CIRColazione Eutettico) pool facility has been refurbished to host the new test section, called HERO (Heavy liquid mEtal pRessurized water cOoled tubes), aimed to investigate a bundle of seven bayonet tubes characterized by the active length of 6 m, in scale 1:1 with the tubes which will compose the ALFRED SGBT concept.

The pre-tests analysis aims to investigate the transition between forced and natural circulation in a loss of primary flow scenario and to select the initial and boundary conditions for the SESAME validation

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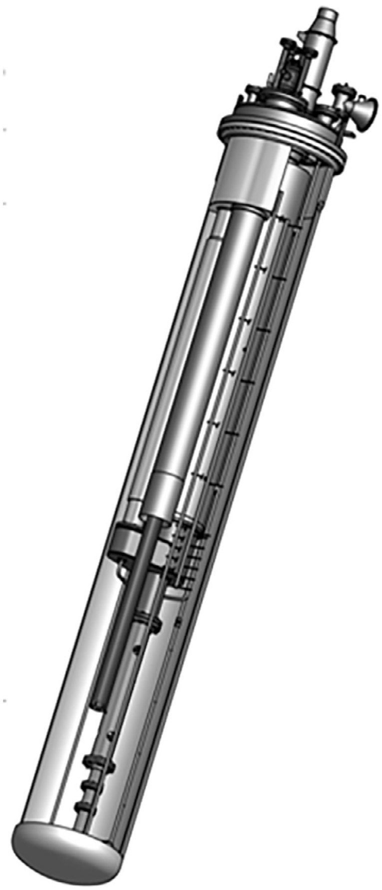

Fig. 1. CIRCE-HERO test facility.

benchmark (Tarantino et al., 2016).

In this paper, the main results of the pre-test calculations, carried out using the system code RELAP5-3D©, are exposed and discussed.

2. The experimental facility

CIRCE is a multipurpose pool type facility aimed to study innovative HLM systems; it consists of the main vessel, filled with about 70 tons of lead-bismuth eutectic (LBE) and designed to host different test sections welded to the bolted heads, and two auxiliary tanks, intended to store the liquid metal during the upkeep phases and to maintain the LBE during the transfer phases (Narcisi et al., 2017a) (Turroni et al., 2001).

The test section, hung from the head of the main vessel, is the same used during the ICE (Integral Circulation Experiment) experimental campaign (Martelli et al., 2016) except for the heat exchanger (HX) which is substituted with the new steam generator. The test facility aims to reproduce the primary system of an innovative LFR, highlighting the thermal-hydraulic behavior of the steam generator bayonet tube (Frogheri et al., 2013). Fig. 1 shows a graphical rendering of the test facility and it highlights the positioning of HERO, which is inserted in a dedicated flange of the vessel heads and partially located inside the cylindrical shroud of the previous HX. The liquid metal flow path in the test section is described with arrows in Fig. 2; after descending the downcomer of the facility, the LBE enters the test section passing through the feeding conduit, which represents the inlet section of the primary system. The feeding conduit is equipped with a Venturi-nozzle flow meter, to measure the LBE mass flow rate passing through the fuel pin simulator (FPS), which consists of a bundle of 37 electrically heated pins; the main features of the heat source (HS) are summarized in Table 1. The relative position between the pins and the wrapper is fixed by three spacer grids which identify three zones in the FPS (see Fig. 3): the bottom mixing zone, located upstream of the lower spacer grid, the active length between the lower and the upper spacer grid, and the top mixing zone downstream of the upper spacer grid. Moreover, the pins are kept in the correct positions with a lower grid, which guarantees the

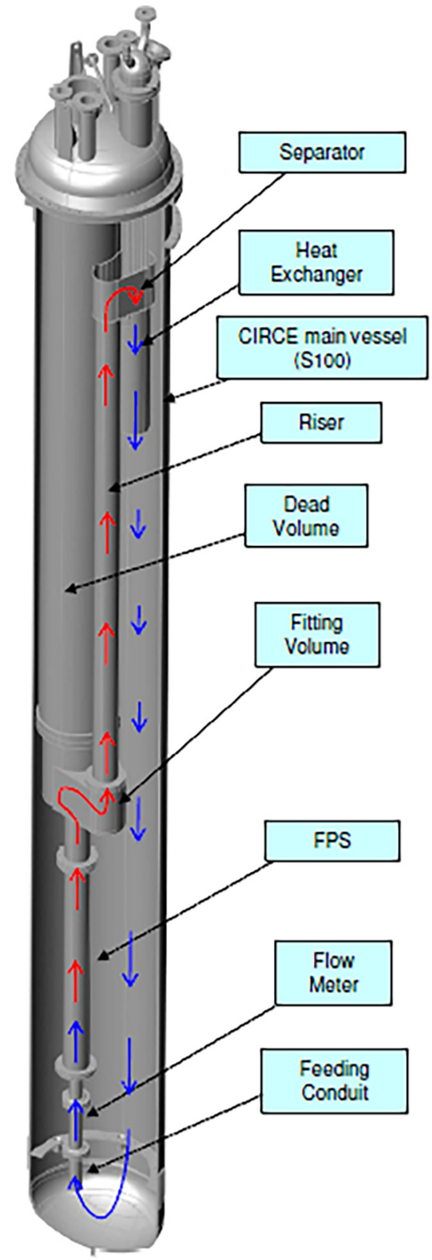

Fig. 2. Primary main flow path.

Table 1
FPS main parameters.

Parameter	Value
Active length	1000 mm
Pin diameter	8.2 mm
Pitch to diameter ratio	1.8
Nominal thermal power	800 kW
Thermal power per pin	25 kW
Heat flux at the pin wall	1 MW/m^2