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ADVANCEMENTS IN EXPERIMENTAL INFRASTRUCTURE FOR LEAD FAST REACTOR RESEARCH: THE VLF AND PHRF FACILITIES

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1. ABSTRACT

This paper presents the development and operation of experimental infrastructure at Ansaldo Nuclear, dedicated to advancing research in lead fast reactor (LFR) technology. The infrastructure comprises two key facilities: the Versatile Lead Loop Facility (VLF) and the Passive Heat Removal Facility (PHRF). This paper discusses the conceptualization, design, and operational aspects of these facilities, highlighting their significance in advancing the understanding and development of advanced reactor technologies, particularly LFRs.

2. INTRODUCTION

In the field of R&D of innovative nuclear technologies belonging to the so-called "Generation IV", the most advanced is currently the Lead Fast Reactor (LFR) [1]. Lead as a coolant has excellent nuclear properties being transparent to neutrons allowing to have a hard neutron spectrum in the core and good radioisotope retention capacity [2], as well as excellent heat transfer properties [3]. On the other hand, it introduces challenges e.g., high freezing temperature (i.e., 327 °C) that would be burdensome in cases of accidental scenarios that could lead to the freezing of lead and therefore to potential damage to the plant, opacity that significantly complicates refuelling operations of the reactor and corrosion that leads to mechanical degradation of structural materials. Despite the significant challenges, the use of lead as a coolant remains attractive as there are currently many LFRs in the world under development between concept, design and construction. Among these, there is the Westinghouse LFR (WEC-LFR), a medium-size and passively safe reactor with a power output of 950 MWth (approximately 450 MWe). To address knowledge gaps in liquid lead technology, dedicated experimental campaigns are necessary. In particular, for the WEC-LFR reactor, an innovative safety system has been designed able to remove the decay

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heat and at the same time keeping the primary coolant above freezing point during an accidental scenario. The working principle of this safety system is based on the transition of heat transfer regime from water pool boiling to natural air convection. Therefore, the experimental plant that aims to test the operation and performance of this safety system is the PHRF. Moreover, a thermal-hydraulic characterization of key components which will be part of the WEC-LFR is needed. This will be possible thanks to the VLF.

3. OVERVIEW OF THE EXPERIMENTAL FACILITIES

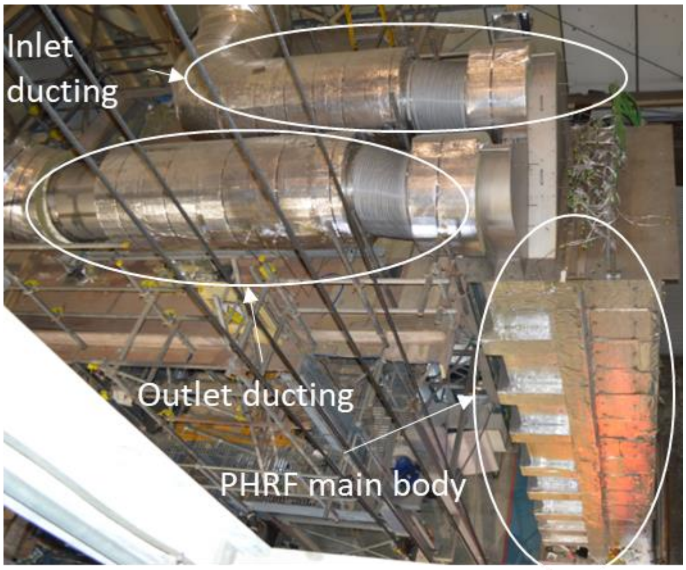

Fig. 1 General arrangement of the PHRF

The PHRF represents at relevant scale the passive heat removal system of the Westinghouse LFR, transferring decay heat from the reactor block to a pool of water using various heat transfer mechanisms, including conduction, convection, and radiation. Its design enables indefinite heat removal by allowing outside air to replace water following complete boiling. Its operation is based on the transition of the heat transfer regime from pool boiling (higher heat transfer efficiency in the short-term phase) to natural convection air cooling (lower heat transfer efficiency in the long-term phase). Moreover, since the main mechanism of heat exchange is radiation which has a proportionality with the temperature to the fourth power, as the temperature of the lead decreases the heat transmitted is significantly reduced, delaying the possible freezing of the coolant over time. Table 1 below shows the main parameters of the PHRF.

Table 1 Parameters of the PHRF

Coolant	Water and air
Power	500 kW
Operating pressure / temperature	Ambient pressure / up to 700 °C
Flow range	Air flow range between 0 – 3 kg/s

On the other hand, the VLF is an experimental rig aimed at the thermal-hydraulic characterization of key components of the Westinghouse LFR (i.e., the primary heat exchanger liquid lead/supercritical water and the Fuel Bundle). The experimental data will be used to understand the hydraulic characteristics of the components to assess their heat transfer performance, informing designs for optimization strategies and validating computational codes for the analysis of in-lead components having complex geometries. The experimental facility essentially consists of three systems: the primary loop, the secondary loop, and the lead preparation, conditioning, and pressure control system. The VLF features a lead loop capable of operating at temperatures up to 650°C, housing a 500-kW electric fuel bundle simulator resembling the Westinghouse LFR bundle. Additionally, it incorporates a hybrid microchannel-type diffusion-bonded heat exchanger, simulating the primary heat exchanger of the Westinghouse LFR design. Heat removal is performed by a supercritical water-cooling loop with a design pressure of 300 bar and maximum operating temperatures reaching 620°C.

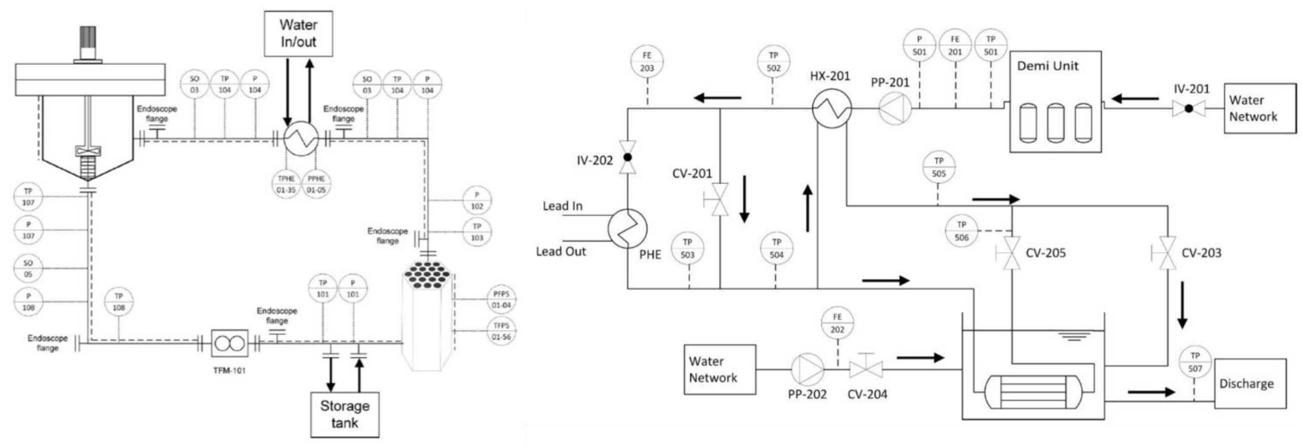

Fig. 2 Primary and secondary loop scheme of the VLF

Table 2 below shows the main parameters of the VLF.

Table 2 Parameters of the VLF

Coolant	Lead and supercritical water
Power	500 kW
Operating pressure / temperature	Lead side 1 bar / 390 °C – 650 °C Water side 300 bar / 20 °C – 620 °C
Flow range	Lead flow range between 0 – 40 kg/s Water flow range between 0 – 0.5 kg/s

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