KEY MILESTONES OF NEWCLEO'S THERMAL-HYDRAULIC EXPERIMENTAL PROGRAMME
OTHELLO, CIRCE-NEXTRA and PRECURSOR Projects

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INTRODUCTION:

*new*cleo [1] is carrying out, in close cooperation with ENEA, a broad-scope R&D programme to support LFR design and safety demonstration, covering thermal-hydraulic experimentation, equipment qualification, materials development, testing and qualification, chemistry, instrumentation development and qualification, etc.

As far as thermal-hydraulics is concerned, experimental campaigns have been planned to meet a variety of needs, such as: basic investigation, component performance characterization, support to code validation, demonstration of reactor operation (via integral testing), and investigation on specific accidental scenarios. Such experimental activities are being conducted on several basic, separate effect, and integral test facilities allowing testing with either molten lead or LBE. These include some of the existing ENEA test facilities in operation at the Brasimone Research Centre (like CIRCE [2], NACIE [3], HELENA), as well as brand new facilities that are being designed and built by *new*cleo and that are going, with a few exceptions, to be installed and operated at ENEA Brasimone site.

The following experimental projects are focused on in the following: OTHELLO, a huge loop-type molten lead separate effect test facility meant for component testing; CIRCE-NEXTRA, an adaption of the existing CIRCE pool-type LBE test facility, intended for investigation on Steam Generator Tube Rupture scenarios; Precursor, a pool-type molten lead integral test facility representing (at a reduced scale) a LFR-AS-30 reactor system and allowing extensive testing/demonstration in relevant LFR normal operation conditions as well as in certain off-normal conditions.

1. OTHELLO

The Oxygen-controlled Thermal-Hydraulic Experimental Lead Loop (OTHELLO) is a separate effect test facility designed to allow thermal-hydraulic investigations relevant to design and safety of *new*cleo's Lead-cooled Fast Reactors (LFR). This facility includes various test sections that replicate key components at representative scale and operating conditions.

The loop includes an integrated oxygen control system to maintain the chemical environment within operational ranges expected in the reactor. A dedicated branch of the primary loop is equipped with a cold trap and a filtering section, to allow evaluating their performance during online operation.

The main objectives of the test sections in the OTHELLO facility are the following:

- Characterization of the convective heat transfer in the LFR Fuel Assembly (FA), under both normal and off-normal conditions. To such aim, OTHELLO is equipped with a 2 MW electrically heated Fuel Pin Bundle Simulator (FPBS), with a representative geometry and a reduced number of pins (FIG. 1).
- Investigation on flow-induced vibrations in the FA, considering the effects of the support structure and pin spacers. To such aim, OTHELLO is equipped with two unheated FPBS, with different degrees of representativity.

— Characterization of the heat transfer performance of *new*cleo's innovative Steam Generators (SGs), which feature a horizontal spiral-tube bundle design. For such purpose, OTHELLO is equipped with a Steam Generator Test Section (SGTS) that replicates, on both the primary and the secondary side, the reference reactor TH operating conditions (pressure, temperature, flow rate). The test section (FIG. 2) also includes representative support structures and subcomponents.

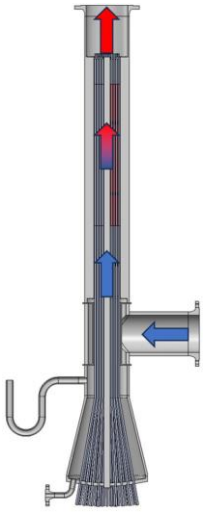

FIG. 1. Notional sketch of OTHELLO heated FPBS.

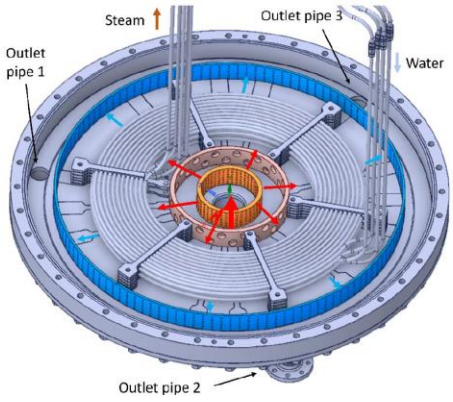

FIG. 2. Notional sketch of OTHELLO SGTS.

To cover the entire operational range of the reactor for each test section, the loop is designed to be operated for a wide range of lead mass flow rates (~ 0 ÷ 300 kg/s). This flexibility introduced significant challenges in the design of key components and systems, as well as in the selection of instrumentation.

The OTHELLO facility is expected to bridge the gaps in the understanding of phenomena at the component level, to support qualification of design choices, and to provide essential experimental data for computational code validation.

2. CIRCE-NEXTRA

The *new*cleo R&D programme includes a range of testing activities carried out on some of the existing ENEA Brasimone test facilities, refurbished or adapted on purpose. Among these, the CIRCE facility plays a central role within the CIRCE-NEXTRA programme (Newcleo rEvamped eXperiments, Testing, and steam generator tube Rupture Analysis).

While retaining the main vessel and parts of the auxiliary systems, the CIRCE facility is being extensively upgraded, including a completely redesigned cover that integrates primary components. The NEXTRA test program focuses on:

— endurance tests on the primary pump, which is equipped with extensive instrumentation to collect valuable data for reactor operation;

— Steam Generator Tube Rupture (SGTR) tests, which are meant to substantiate *new*cleo's approach to safety demonstration against this challenging accidental scenario.

To meet the testing requirements, the primary system includes (FIG. 3):

— Steam Generator (SG) mock-up connected to devices designed to induce tube rupture;

— a circulation pump installed coaxially with the SG mock-up;

— an inlet conduit and heating system simulating the reactor core;

— internal structure, shaped to ensure similarity with reactor flow path;

— an overpressure protection system (OPS).

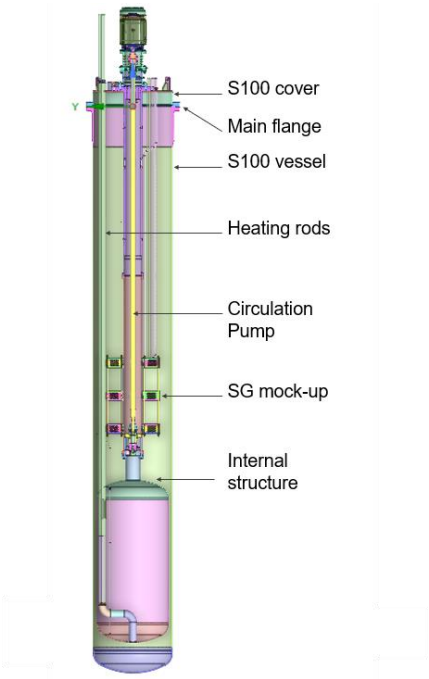

FIG. 3. Notional sketch of CIRCE-NEXTRA primary system.

SGTR events create complex and challenging transient conditions, featuring a variety of thermal-hydraulic phenomena, fluid-structure interactions, and intense mechanical loadings. The CIRCE-NEXTRA programme will provide a platform to test procedures, equipment and instrumentation under such accident scenarios, in addition to giving valuable insight into the relevant phenomenology and supporting code validation.

3. PRECURSOR

The Precursor project represents the last big milestone of the non-nuclear part of *new*cleo R&D programme, before the LFR-AS-30 demonstrator nuclear reactor comes into play.

The general purpose of this integral test facility is to provide an experimental demonstration of the overall thermal-hydraulic behaviour of the LFR-AS-30 reactor under both steady-state and transient conditions (operational and, to a limited extent, accidental), at a reduced scale that is sufficiently representative of the reactor design, and integrated with the Balance of Plant steam-turbine secondary system. The scaled power is 10 MW, i.e. 1/9th of the LFR-AS-30 rated thermal power.

The facility will serve as an experimental platform for studying reactor behaviour during operational and (certain) accidental transients. The experimental results are expected to significantly increase the Technical Readiness Level (TRL) of the design solutions developed for *new*cleo's LFRs.

The primary system main components are (FIG. 4):

— a core simulator (eCore) consisting of 19 bundles of electrically heated rods;

— three Steam Generators, each integrated with an axial circulation pump;

— three bayonet-tube Dip Coolers, serving as interfaces between the primary system and the secondary side of the Decay Heat Removal (DHR) system;

— the amphora-shaped inner vessel, peculiar to the *new*cleo LFR design;

— the main vessel.

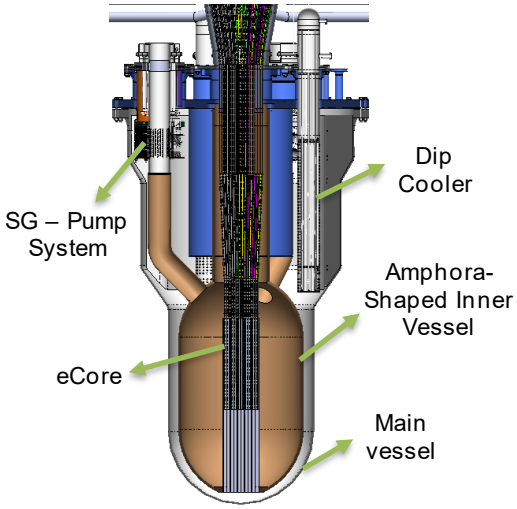

FIG. 4. Notional sketch of Precursor primary system.

Following the identification of key phenomena to be studied—prioritizing integral effects and pool thermal-hydraulics—the system and its components were scaled to preserve key features such as temperature distributions, pressure drops, flow distribution, characteristic time, etc. Thermal-hydraulic phenomena to be investigated include flow patterns, thermal mixing and stratification, inter-wrapper heat transfer, lead level oscillations in the lead pool, natural circulation, etc.

Since the facility is intended to study both normal operation and safety-related transients, the secondary loops of both the SGs and the DHR systems play a critical role and need to be highly representative of the corresponding systems in the LFR. For instance, certain tests will demonstrate the overall plant transient response to malfunctions on the secondary system. Other tests will demonstrate the operation of the DHR system, and particularly its ability to effectively cool the core in the short-term and prevent lead freezing in the long term.

4. CONCLUSIONS

OTHELLO, CIRCE-NEXTRA and Precursor facilities represent key milestones in *new*cleo's R&D program, with integrated and complementary objectives. Component-level characterization is primarily conducted in the OTHELLO loop, while system thermal-hydraulic behaviour and the interaction between the different components are investigated in Precursor, aiming at reproducing the global plant behaviour. CIRCE-NEXTRA addresses the investigation on SGTR transients and the demonstration of related safety procedures. Other test facilities such as NACIE, HELENA, and others being developed by *new*cleo, will address remaining objectives of the thermal-hydraulic experimental programme and further reinforcing and accelerating the development and licensing of *new*cleo reactors.

REFERENCES

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