**Profile LFR-40**

**CIRCE**

**ITALY**

## GENERAL INFORMATION

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| NAME OF THE FACILITY | CIRCulation Eutectic |
| ACRONYM | CIRCE |
| COOLANT(S) OF THE FACILITY | Molten lead-bismuth eutectic |
| LOCATION (address): | Italian National Agency for New Technologies, Energy and Sustainable Economic Development, C.R. ENEA Brasimone, Italy |
| OPERATOR | ENEA |
| CONTACT PERSON (name, address, institute, function, telephone, email): | Ing. Mariano Tarantino, ENEA UTIS-TCI C.R. Brasimone 40032 Camugnano (Bo) Tel. +39 0534 801 262, Head of Thermal Fluid Dynamic and Facility Operation Laboratory mariano.tarantino@enea.it |

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| **STATUS OF THE FACILITY** | In operation |
| Start of operation (date): | 2014 |

**MAIN RESEARCH FIELD(S)**

- ☐ Zero power facility for V&V and licensing purposes
- X Design Basis Accidents (DBA) and Design Extended Conditions (DEC)
- X Thermal-hydraulics
- X Coolant chemistry
- X Materials
- X Systems and components
- X Instrumentation & ISI&R

## TECHNICAL DESCRIPTION

### Description of the facility

CIRCE basically consists of a cylindrical vessel (Main Vessel S100) filled with about 70 tons of molten Lead-Bismuth Eutectic (LBE) with argon cover gas and recirculation system, LBE heating and cooling systems, several test sections welded to and hung from bolted vessel heads for separate-effects and integral testing, and auxiliary equipment for eutectic circulation. The facility is completed by a LBE storage tank (S200), a small LBE transfer tank (S300) and the data acquisition system. The main vessel S100 consists of a vertical vessel 8500 mm height, connected by gates to the other vessels. It is externally equipped with electrical heating cables, installed at the bottom and on the lateral surface. A skimming line and a passive pressure safety system are also present in the main vessel, in order to guarantee the LBE top level and to prevent accidental overpressure. The ICE test section consists of the following main components:

- *Downcomer*: is the volume between the test section and the main vessel, which allows the hydrodynamic connection between the outlet section of the main HX and the inlet section of the feeding conduit.
- *Feeding Conduit:* is the inlet pipe of the test section, which allows the hydrodynamic development of the upward primary flow rate towards the flow meter.
- *Flow Meter*: is a Venturi-nozzle flow meter. Bubble tubes are adopted to measure the pressure difference through the throat of the nozzle. The flow meter is directly connected to the HS, without a bypass, thus measuring the primary flow rate through the pin bundle.
- *Fuel Pin Simulator* (FPS): is a mechanical structure needed to take on the Heat Source (HS). It is connected in the lower section to the flow meter and in the upper section to the insulation volume by means of the coupling flange.
- *Fitting Volume*: is placed in the middle part of the test section, allowing the hydraulic connection between the HS and the riser.
- *Riser*: is an insulated pipe (double wall pipe with air in the gap) connecting the fitting volume with the separator. A nozzle is installed in the lower section to allow the argon injection inside this pipe.
- *Separator*: is a volume needed to connect the riser with the HX. It allows the separation of the LBE flowing downward into the HX from the Argon flowing in the test section cover gas through the free surface. Moreover, the separator assures that the overall LBE flow rate flows directly into the HX (shell – side) before falling down in the downcomer. In addition, the separator works as an expansion vessel, allowing for fluid expansion during transient operations.
- *Hero Heat Exchanger:* corresponds to the heat sink of the system. It consists in seven double-walls bayonet tubes (with stainless steel powder filling the gap) fed by pressurized water (180 bar). It has a thermal duty of about 500 kW.
- *Decay Heat Removal System*: corresponds to the heat sink of the system in the case of DHR scenario, when the HX is unavailable. It is hydraulically de-coupled by the primary system being placed into the downcomer. The DHR heat exchanger has been designed to have a thermal duty of 40 kW, which represents 5% of the ICE nominal power (800 kW). It is fed by air at atmospheric pressure.

In particular a fuel pin bundle simulator (FPS), has been installed in the CIRCE pool. It has been conceived with a thermal power of about 1 MW and a linear power up to 25 kW/m, relevant values for a LMFR. It consist of 37 fuel pins (electrically simulated) placed on a hexagonal lattice, deeply instrumented. The Hero heat exchanger, (Heavy liquid mEtal pRessurized water cOoled tube) is an innovative heat exchanger mock-up (1:1) representative of a steam generator of the prototypical GEN IV lead cooled nuclear power plant ALFRED (Advanced LeadFast Reactor European Demonstrator). Its main task is to verify the feasibility as well as to characterize its thermo hydraulics performances. For this purpose the HX is deeply instrumented allowing to obtain accurate measurements in order to investigate all the phenomena of interest in different operational conditions (head losses, conductive and convective flow regimes, thermohydraulic instability etc.). During this experimental campaign the developed oxygen control system will be also tested with the goal to ensure on-line monitoring of the oxygen content in HLM pool system. The oxygen control system basically consist in a solid phase mass exchanger based on PbO spheroids for the control of the oxygen content and in three oxygen sensor based on YSZ electrolyte cell installed in the CIRCE main vessel at three different positions for the on-line measurement of the oxygen content dissolved in the melt. Moreover an extractive oxygen gas analyser is installed for on-line monitoring of the oxygen content in the cover gas. Two filtering devices are installed in the coldest and hottest region of the pool respectively. One of the filtering sections, placed at the outlet section of the main Heat Exchanger is coupled with a suitable differential pressure transducer aiming to get information related to the plugging of the filtering section during the CIRCE operation.

**Acceptance of radioactive material**

No

## Scheme/diagram

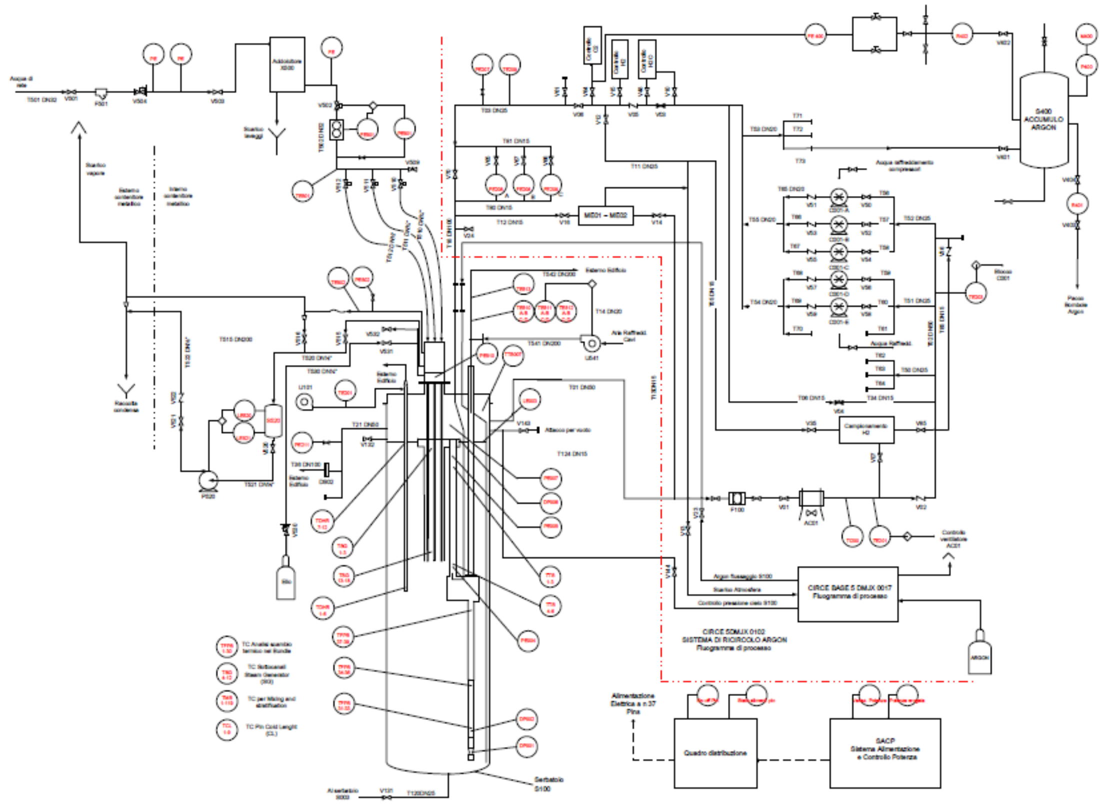

*FIG. 1. Piping & Instrumentation Diagram of CIRCE facility in ICE/HERO Configuration*

## 3D Drawing/photo

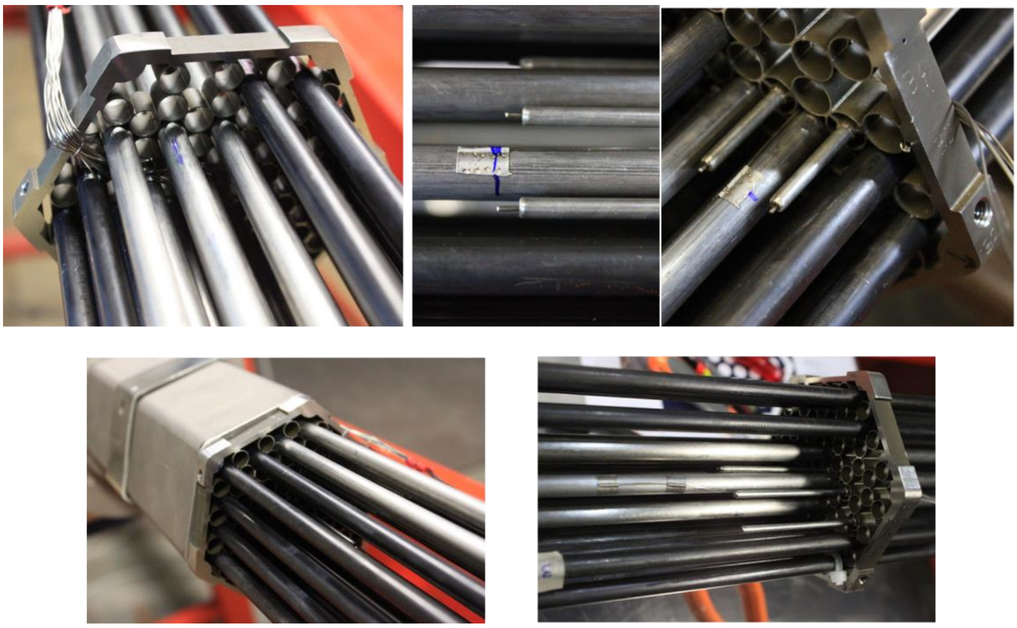

*FIG. 1. Fuel pin bundle simulator and related instrumentations*

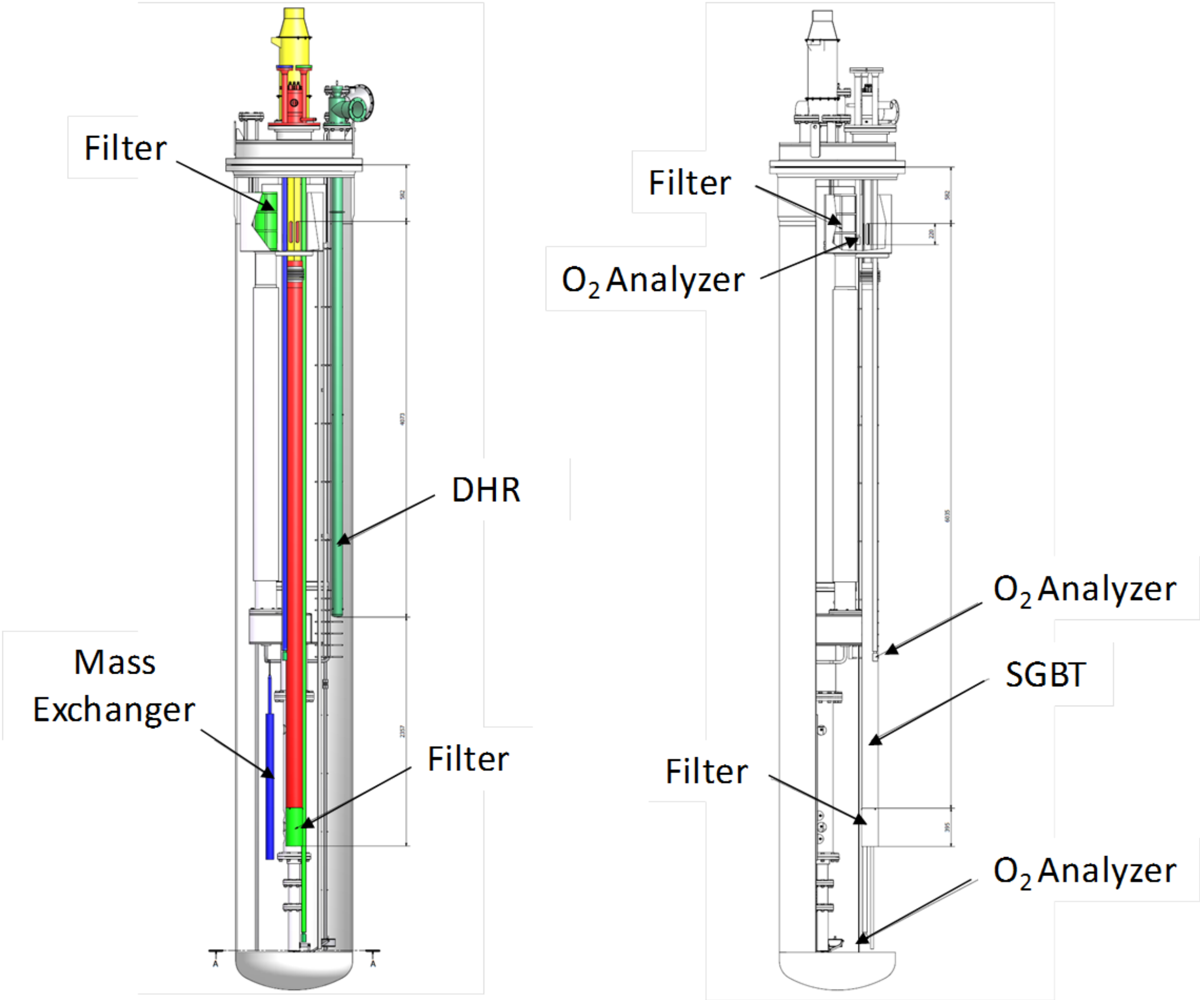


*FIG. 3. 3D Scheme of the CIRCE pool in ICE/HERO Configuration*

**Parameters table**

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| Coolant inventory | Max LBE inventory up to 90000 kg |
| Power | 1 MW |
| Test sections | |
| TS #1 | <u>*Characteristic dimensions*</u><br>Outside diameter 1200 mm<br>Overall height 8500 mm |
| | <u>*Static/dynamic experiment*</u><br>Dynamic |
| | <u>*Temperature range in the test section (Delta T)*</u><br>80°C -120°C trough the FPS |
| | <u>*Operating pressure and design pressure*</u><br>Operating Pressure 15 kPa (gauge)<br>Design pressure 450 kPa (gauge) |
| | <u>*Flow range (mass, velocity, etc.)*</u><br>25-70 kg/s maximum velocity in the fuel bundle of about 1 m/s |
| Coolant chemistry measurement and control<br>(active or not, | The facility is equipped with a solid phase mass exchanger based on PbO spheroids for the control of the oxygen content and with three oxygen sensor based on YSZ electrolyte cell. Moreover an extractive oxygen gas analyser is installed for on-line monitoring of the oxygen |

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| measured parameters) | content in the cover gas. Two filtering devices are installed in the coldest and hottest region of the pool respectively. One of the filtering sections, placed at the outlet section of the main Heat Exchanger is coupled with a suitable differential pressure transducer aiming to get information related to the plugging of the filtering section during the CIRCE operation. |
| Instrumentation | Thermocouples, pressure transducer, Oxygen sensor, Mass exchanger, Gas injection system, Venturi flow meter, Laser level gauge measurement system, Hot wire anemometer. |

## COMPLETED EXPERIMENTAL CAMPAIGNS: MAIN RESULTS AND ACHIEVEMENTS

A first experimental campaign (seven tests) was conducted to investigate mixing and stratification phenomena in large pool HLM facility. Protected loss of heat sink + loss of flow accidental scenario were simulated and transition from forced to natural circulation condition was investigated. Different FPS electrical powers at full power regime were investigated in the range between 600 and 800 kW.

A series of two Tests were performed aiming at the investigation of heat transfer in fuel rod bundle. In particular, Nusselt number was calculated starting from the experimental temperatures data available in two section of the fuel pin bundle (placed at different elevations) and considering the average cladding temperature on the sub-channel and the central sub-channel temperature, instead of the bulk sub-channel ones, being the only measurable The central sub-channels was assumed representative for an infinite lattice.

## PLANNED EXPERIMENTS (including time schedule)

In 2015 tests are planned in order to investigate the thermal stratification and mixing phenomena in heavy liquid metal large pool. In particular full power steady state condition under forced circulation and in DHR natural circulation condition will be reached and data about thermal stratification and pool streams mixing will be gained. Investigation of the transition from forced to natural circulation regime, as consequence of a relevant accidental scenario (e.g. protected loss of heat sink accident with (or without) loss of flow) will be performed. Different full power steady state condition and LBE mass flow rate will be investigated.

Coolant chemistry monitoring and control tests have been planned in 2015-2016.

## TRAINING ACTIVITIES

Training activities can be agreed with ENEA Brasimone RC for the operation of the experimental campaign under the supervision of ENEA qualified staff.

## REFERENCES (*specification of availability and language*)

1. MARTELLI D., FORGIONE N., ROSA M. DE, TARANTINO M., BANDINI G., "Thermal-Hydraulic Pre-Test Analysis of ICE Test Section with DHR System", XXX UIT HEAT TRANSFER CONFERENCE Bologna, Italy, June 25-27, 2012. (En)
2. MARTELLI D., BARONE G., FORGIONE N., TARANTINO M., GAGGINI P., PIAZZA I. DI, AGOSTINI P., "CIRCE Up-Grade Experimental Report" CI-T-R-79, ENEA 2014. (En)

3. BANDINI G., PIAZZA I. DI, GAGGINI P., DEL NEVO A., TARANTINO M., "CIRCE experimental set-up design and test matrix definition", ENEA UTIS-TIC Technical Report, IT-F-S-001, 28/02/2011. (En)
4. TARANTINO M., AGOSTINI P., BENAMATI G., COCCOLUTO G., GAGGINI P., LABANTI V., VENTURI G., CLASS A., LIFTIN K., FORGIONE N., MOREAU V. "Integral Circulation Experiment: Thermal–hydraulic simulator of a heavy liquid metal reactor", Journal of Nuclear Materials 415 (2011) 433–448, 2011. (En)