CLEAR-S: An Integrated Non-nuclear Test Facility for China Lead-based Research Reactor

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Abstract: China LEAd-based Reactor (CLEAR) was selected as the reference reactor for Accelerator Driven System (ADS) system in China. CLEAR-I as the first stage of CLEAR is under designed by Institute of Nuclear Energy Safety Technology (INEST), Chinese Academy of Sciences (CAS). For verification the key components and investigate the thermal-hydraulics phenomena of CLEAR-I and even for pool type lead-based reactor, an integrated multifunctional non-nuclear test facility named CLEAR-S is under constructed and commissioning early of 2017. Note that CLEAR-S will be used to test the 1:1 prototype components for CLEAR-I, such as primary loop pump, main heat exchanger, decay heat removal system, control rod driven system, in-vessel refueling system, and to verify the design and safety analysis codes. In this paper, the design and latest construction progress has been presented for CLEAR-S.

Key Words: Liquid Lead-alloy; China Lead-based Research Reactor; CLEAR-S

1. Introduction

Lead-based reactor was identified as one of the most important candidates of the accelerator driven sub-critical systems and Generation-IV nuclear energy systems [1]. At 2011, Chinese Academy of Sciences (CAS) has initiated an engineering project which developed the ADS (Accelerator Driven System) for nuclear waste transmutation [2]. By three stages, CAS plans to planning demonstration ADS transmutation system around 2030. China LEAd-cooled Reactor (CLEAR) was chosen as the reference reactor in CAS ADS project, led by Institute of Nuclear Energy Safety Technology (INEST), CAS • FDS Team. At the first stage, INEST will design and construct the China LEAd-based Research Reactor (CLEAR-I) with 10MWth[3]. CLEAR-I represents a very important step forward to define the guidelines for neutronics and thermal-hydraulics, and to test components and material technology in an innovative LBE cooled nuclear reactor [3]. Based on the great efforts to investigate for structural materials [4][5], liquid metal technology [6][7][8][9], design of the sub-critical system [10], and advanced nuclear analysis software [11][12], the conceptual design of CLEAR-I has been completed [1] [9] and the preliminary engineering is still in the works.

CLEAR-I is a model type of the innovative lead-bismuth cooled dual-mode reactors, and there are many technology challenges to be deal with such as nuclear key components, thermal hydraulic phenomena and coolant chemistry control. So the experiment facilities need to be designed and even built to provide the essential experiment data for technology development and license application. For instance in Italy and Belgium for lead-based reactor research and development, CIRCE and E-SCAPE [13][14][15] has been built to support the thermal-hydraulics experiment verification. For the non-nuclear technology experiment facility, KYLIN series lead-bismuth experiment loops have been built in China. To support the design and construction of CLEAR-I, a large scale integrated non-nuclear pool type

facility which named CLEAR-S has completed design and under construction. CLEAR-S will become the maximal lead-bismuth pool-type facility in the world to provide a unique experimental platform for full-scale (up to 1:1) prototype components test for CLEAR-I and integral circulation thermal hydraulic test under steady and transient conditions.

This paper supplied the description, development and manufacture details of CLEAR-S. A variety of experiments will be implemented in CLEAR-S, which will be able to guide the complement of the preliminary safety analysis report (PSAR), and support the application of license, and also give reference to the design and manufacture of the lead-based reactor system and key components.

2. CLEAR-S description

2.1.Objectives and advancements

The objectives of CLEAR-S facility are to provide an integral experimental platform for full scale prototype components performance test for CLEAR-I. It can be used as the key components (1:1) verification, thermal hydraulics phenomena investigation, the coolant chemistry control, instrumentation, control technology development for CLEAR-I and lead-based reactor. Also it can be used for the experimental verifications of thermal-hydraulics design and safety analysis codes.

The following features are unique among all the worldwide pool-type heavy liquid metal test platforms.

(1) Transient experiments will be done in CLEAR-S. Results will guide the complement of the PSAR, and support the application of license. Also the experiment data will validate the CFD code, and also give reference to the design and manufacture of the lead-based reactor system and key components.

(2) The mechanical primary loop pump is firstly integrated in LBE pool-type test facility. For pump, both in steady and transient state will be done. Between LBE and the pressurized water in secondary heat transfer characteristic will also be test.

(3) For full-scale pool type LBE thermal-hydraulic phenomenon study, such as thermal coupling analysis between fuel assemblies (FA) with inter-wrapper flow and transition from forced circulation to natural circulation will be tested in this facility.

(4) The circulated LBE in the facility is about 220 tons. The pool-type reactor for the coolant chemistry control, instrumentation, and data acquisition and control technology with the reactor scale will be developed.

CLEAR-S facility will be realized by two stages. The first stage focuses on the mechanical primary loop pump, fuel assemblies, main heat exchanger, decay heat removal (DHR), and also key technologies development. The second stage focuses on the In-Vessel Fuel Handling system (IVFH), the full-scale prototype for Control & Safety Rod and Drive Mechanisms (CSRDM), the spallation target for ADS and the steam generator tube rupture (SGTR) will be combined in the pool facility.

2.2.Main function

CLEAR-S will be used to verify the 1:1 prototype components for CLEAR-I, such as pump, heat exchanger, DHR, to verify the design and safety analysis codes, and also to test the coolant key technology.

(1) Prototype components test: CLEAR-S will be used to verify the 1:1 prototype components

for CLEAR-I, such as primary loop pump, main heat exchanger, DHR, IVFH and CSRDM.

(2) Thermal hydraulic test: CLEAR-S will be used to do full-scale pool type thermal hydraulic test, such as the transition from forced circulation to natural circulation, and the phenomena of mixed convection and stratification.

(3) Key technology development: during the design, manufacture and the operation, coolant chemistry control, instrumentation, data acquisition and control technology, and SGTR technology will be developed.

2.3.Parameters and composition

The main design Parameters of the CLEAR-S facility are listed in **Error! Reference source not found.**.

Table 1: MAIN PARAMETERS FOR CLEAR-S FACILITY

	Items	**CLEAR-S**
Operating Coolant Parameters	Coolant	LBE
	Heating Power	2.5 MW
	Temperature	250~550℃
	Inventory	~220 tons
	Mass flow rate	30~100 m^3/h
Fuel Assembly Simulator (FAs)	Heating module	7
	Pin	61 Pins with wire wrapped
Main Vessel	Design stand	ASME VIII-2
	Design pressure	2 MPa
	Diameter	2000 mm
	Height	6500 mm
	Structural materials	AISI 316L

There are several sub-systems coordinated to ensure stable operation of the CLEAR-S facility, including main vessel, FAs, pump, main heat exchange, DHR, filling and draining, secondary loop, coolant chemistry control, instrumentation, electrical, data acquisition and control, IVFH, CSRDM and SGTR sub-systems etc.

3. CLEAR-S development and manufacture

CLEAR-S engineering design has been finished. The key components have already been developed. The installation work is nearly finished and the commissioning work will be done early of 2017, as showing in *FIG.1*

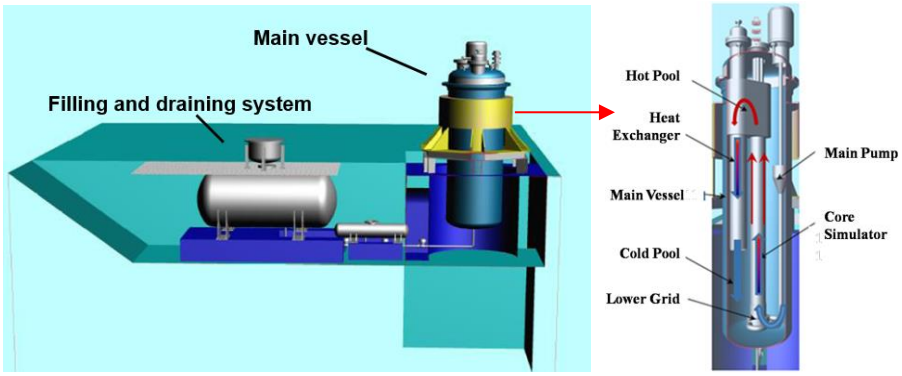

FIG. 1. CLEAR-S main part layout.

CLEAR-S main pump, Heat exchanger and DHR are 1:1 prototype components for CLEAR-I. There are 7 FAs with 61 pins inside, the same as in CLEAR-I, and the pins are heated by electric power.

(1) Primary loop pump: The primary loop pump is prototypical submerged mechanical pump. The design flow rate is 30 to 100m³/h with the max head 2.5m. It has already been tested in water and the test results were consistent with the design value, as shown in *FIG.2*.

FIG. 2. CLEAR-S Primary loop pump.

(2) Main heat exchanger and DHR: The main heat exchanger heat transfer power is 2.5 MWth, and DHR is about 0.175 MWth (about 5-7% of the nominal power). Main heat exchanger and DHR have been constructed. The hydrotest and other tests were consistent with the design value. The Heat exchanger is shown in *FIG.3*.

FIG. 3. CLEAR-S main heat exchanger.

(3) FAs: CLEAR-S FAs consists in 7 modules with a triangular lattice layout. Each module consists of 61 electrical heaters wire with a triangular lattice layout. The central FA heating power is 0.5MW and each of the other six is 0.35MW, as shown in *FIG.4*.

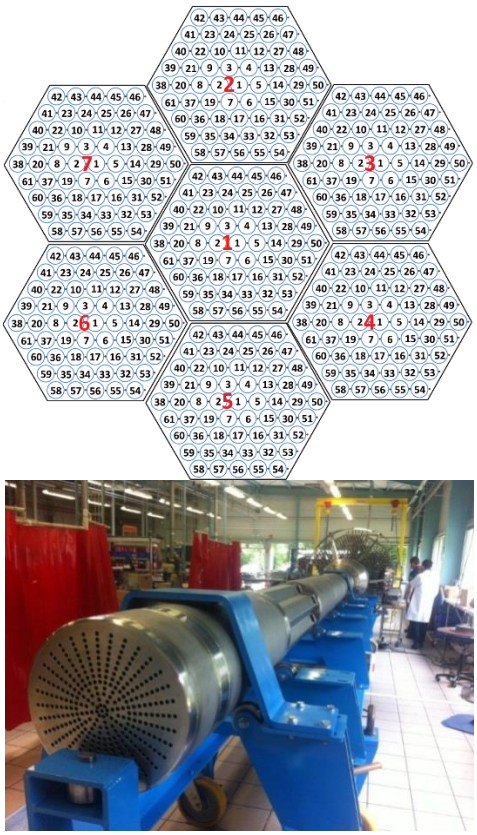

FIG. 4. CLEAR-S FAs layout and manufacture.

4. Conclusion

The CLEAR-S facility will be the largest pool-type lead-bismuth experimental facility in the world. It can be used as the key components (1:1) verification, thermal hydraulics phenomena investigation, the coolant chemistry, instrumentation, data acquisition and control technology development for lead-based reactor. Also it can be used for the experimental verifications of thermal-hydraulics design and safety analysis codes.

CLEAR-S is under construction and will be commissioning in the early of 2017, which will become an integral facility for the design and licensing of CLEAR-I and R&D work of ADS and lead-based reactor system.

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