Overview of PbBi–Cooled Rector Development and ADS Program in China

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Most of China's electricity is produced from fossil fuels. Rapid growth in demand has given rise to power shortages, and the reliance on fossil fuels has led to much air pollution. Nuclear power has an important role for the China energy safety and environmental protection. According to the current layout of nuclear power development, by around 2040, pressurized water reactors are expected to level off at 200 GW_e. However, the nuclear fuel shortage and the spent fuel accumulation will restrict the healthy development of nuclear energy in China. So the innovative nuclear system is expected to solve these problems.

Accelerator driven sub-critical system (ADS) is an important approach to incinerate the long-lived high-level nuclear waste, which is focused by many countries. Liquid Lead–Bismuth eutectic (LBE) has many unique nuclear, thermophysical and chemical attributes that is potential candidate coolant for ADS subcritical reactors. In addition, lead and bismuth can produce copious spallation neutrons when bombarded with energetic protons. This makes LBE one of the top candidates for a high-power spallation target and coolant in an accelerator-driven subcritical system [1].

In China, the fundamental research of ADS was carried out 10 years ago supported by Ministry of Science and Technology. From 2009, Chinese Academy of Sciences (CAS) carried out a project of the ADS prophase research to develop the key technologies about superconducting accelerator, LBE loop, materials et al. In 2011, a large scaled ADS development program to transmute the nuclear waste has been launched by CAS named "advanced nuclear fission energy". In this program, CAS plan to develop the ADS system by 3 phases. In the first phase, form 2011-2017, an ADS verification facility named ADS-VF will be build. The ADS-VF consists of a LBE cooled reactor coupled with a proton accelerator and liquid metal spallation target. For the second phase in this program, an ADS experimental reactor named ADS-ER will be built by 2022. The design parameter of ADS-ER is similar with the MYRRHA project which consists of a LBE cooled reactor, a proton accelerator with 600-1000 MeV/10mA, and a LBE spallation target. The design thermal power of this ADS reactor is about 100 MW. In the third phase, an ADS demonstration reactor named ADS-DEMO will be built by 2032. The ADS-DEMO has a significant capacity for nuclear waste transmutation which consists of a LBE cooled reactor (about 1 GW_{th}), a proton accelerator (1.5 GeV/~10mA) coupled with windowless LBE spallation target.

In this ADS program, the FDS Team [2] in Institute of Plasma Physics (ASIPP) will take the responsibility of the LBE cooled reactor related work. The LBE reactor for ADS-DEMO is being designed, and the LEB reactor design for ADS-VF will be done in this year. For the ADS-DEMO reference scenario, a Lead-Bismuth cooled accelerator driven subcritical reactor

for transmutation of long-lived high-level nuclear waste named LEBCAR [3] is developed by FDS Team based on the neutronics, thermohydraulics, and mechanics analysis. In LEBCAR, a linear accelerator produces the proton beam of 1.5 GeV with 10 mA and the proton impinges on the windowless LBE target in the core central region. The LEBCAR system is rated at 1000 MW_{th} thermal power with a pool-type fast subcritical reactor. Currently, one of the fuel types considered for LEBCAR is the TRU-Zr dispersion fuel, where TRU-Zr particles are dispersed in Zr matrix. The advanced ferritic/martensitic steel is selected as the target guide pipe and fuel clad materials considered the good performance under a high corrosive and radiation environment.

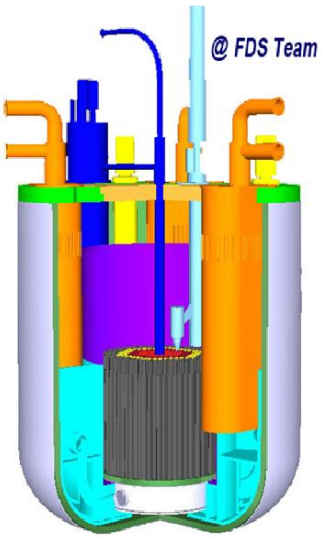

FIG. 1. The illustration of Lead-Bismuth cooled accelerator driven subcritical reactor (LBECAR).

Even though LBE has the advantages of excellent neutron properties, good thermal conductivity, low chemical activity. There are also some issues to be experimentally investigated, such as compatibility of LBE and materials, flow and heat transfer characteristics of LBE, melting technology of LBE, precision oxygen analyzer et al. Liquid lead-bismuth loops are necessary devices for the materials technology and thermohydraulics challenges. The KYLIN series of LBE experimental loops and verification facilities for the ADS system are being designed and built in Chinese Academy of Sciences. The detailed information of KYLIN loops is listed in TABLE 1.

TABLE 1. KYLIN SERIES LBE EXPERIMENTAL LOOPS FUNCTION AND DEVELOPMENT PLAN.

Loop name	Type*	Function	Temperature	Time
KYLIN-I[4]	TC	Compatibility test under flowing PbBi	480-550^{o}C	Completed
KYLIN-II	FC	Compatibility, flowing behavior, oxygen control unit and purification system	480~700 ^{o}C	2010-2011
KYLIN-III	FC	thermal-hydraulics of target and reactor	300-600 ^{o}C	2014
KYLIN-ST	ST	Compatibility test in the static PbBi	200~800 ^{o}C	2010
KYLIN-RT	RT	Compatibility test in the rotation flowing PbBi	480~600 ^{o}C	2010

*TC—Thermal Convection, FC—Forced Convection, ST—Static Test, RT—Rotation Test

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