FDS Team

Institute of Nuclear Energy Safety Technology, Chinese Academy of Sciences
Institute of Plasma Physics, Chinese Academy of Sciences
School of Nuclear Sci. & Tech., University of Sci. & Tech. of China

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Overview of PbBi cooled Reactor development and ADS Program in China

Presented by Y.BAI

Contributed by FDS Team

Institute of Nuclear Energy Safety Technology, Chinese Academy of Sciences

Institute of Plasma Physics, Chinese Academy of Sciences

School of Nuclear Science and Technology
University of Science and Technology of China

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Contents

- **Introduction**
- **CLEAR Reactor Conceptual Design**
  - CLEAR-I (Lead-bismuth cooled validation reactor)
  - CLEAR-II (ADS experimental reactor)
  - CLEAR-III (ADS demonstration reactor)
- **R&D Activities for CLEAR Reactor**
  - KYLIN series PbBi loop Design and Construction
  - Materials Corrosion Tests in PbBi Circulation
- **Summary**

Fission Power Development and new problems

(Prediction on Future Fission at 2050, China)

Scenario	Ratio A	Ratio B	Nucl. Power	Capacity (Approximate Scale)
Low Level	10%	6%	120GW	Double in France
Mid. Level	20%	12%	240GW	Sum in US, France and RF
High Level	30%	18%	360GW	Sum all over the world

A: fraction of nucl. power in total electricity capacity

B: fraction of nucl. power in total primary energy capacity

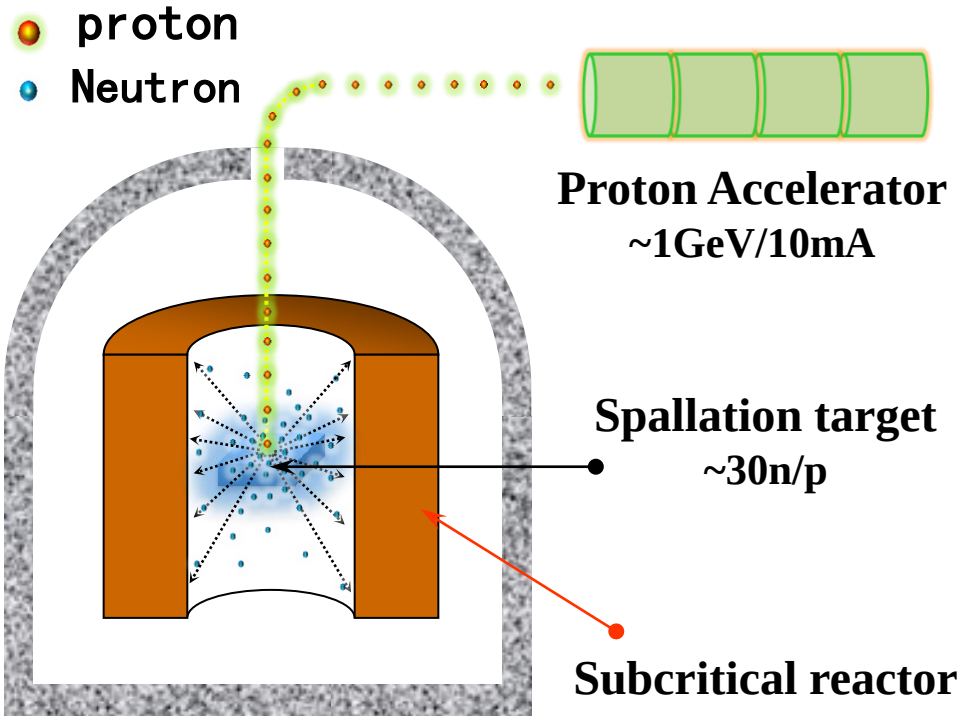
- **Nuclear fuel supply ?**
- **Radioactive waste disposal ?**
- **Safety problem ?**

Advanced Nuclear Fuel Cycles

- **Report of ADS(Accelerator Driven Subcritical system) and FR(Fast Reactor) in Advanced Nuclear Fuel Cycles NEA/ OECD**
  - **ADSs are better at burning waste than fast reactors**
  - **ADSs employing a fast neutron spectrum and solid, fertile-free fuel with the primary mission of transmuting transuranics or minor actinides**
  - **ADS could support more PWR waste transmutation**
- **The strategy of sustainable fission energy in China were suggested consoled by Chinese Experts of Academician**
  - **The Fast Reactor is better used for Nuclear fuel breeding and the ADS is better used for transmutation**

Accelerator Driven Subcritical system (ADS)

- Accelerator supplies spallation neutrons to driven the fission reactions in subcritical reactor.
- Energy from the reactor provides electricity to the accelerator



Main function :

1. **Energy production:** n + U/Pu/MA ➔ Energy
2. **Fuel breeding:** n + U^{238}/Th^{232} ➔ Fissile
3. **Waste transmutation:** n + MA/FP ➔ less-harmful nucleus

Significant Challenges of ADS

Accelerator Performance

- Achievable beam power
- Reliability and required maintenance

Spallation Target Performance

- Very high heat power
- Radiation damage
- Heavy liquid metal corrosion

Subcritical Reactor

- High power density and asymmetry distribution
- Fast neutron spectrum

Characteristics of PbBi Eutectic (LBE)

Advantages

- Excellent neutron properties, higher neutron flux for transmutation
- Good thermal conductivity, a lower operation temperature
- Low chemical activity, no fire with water and air, more safety
- As liquid metal spallation target, no radiation damage

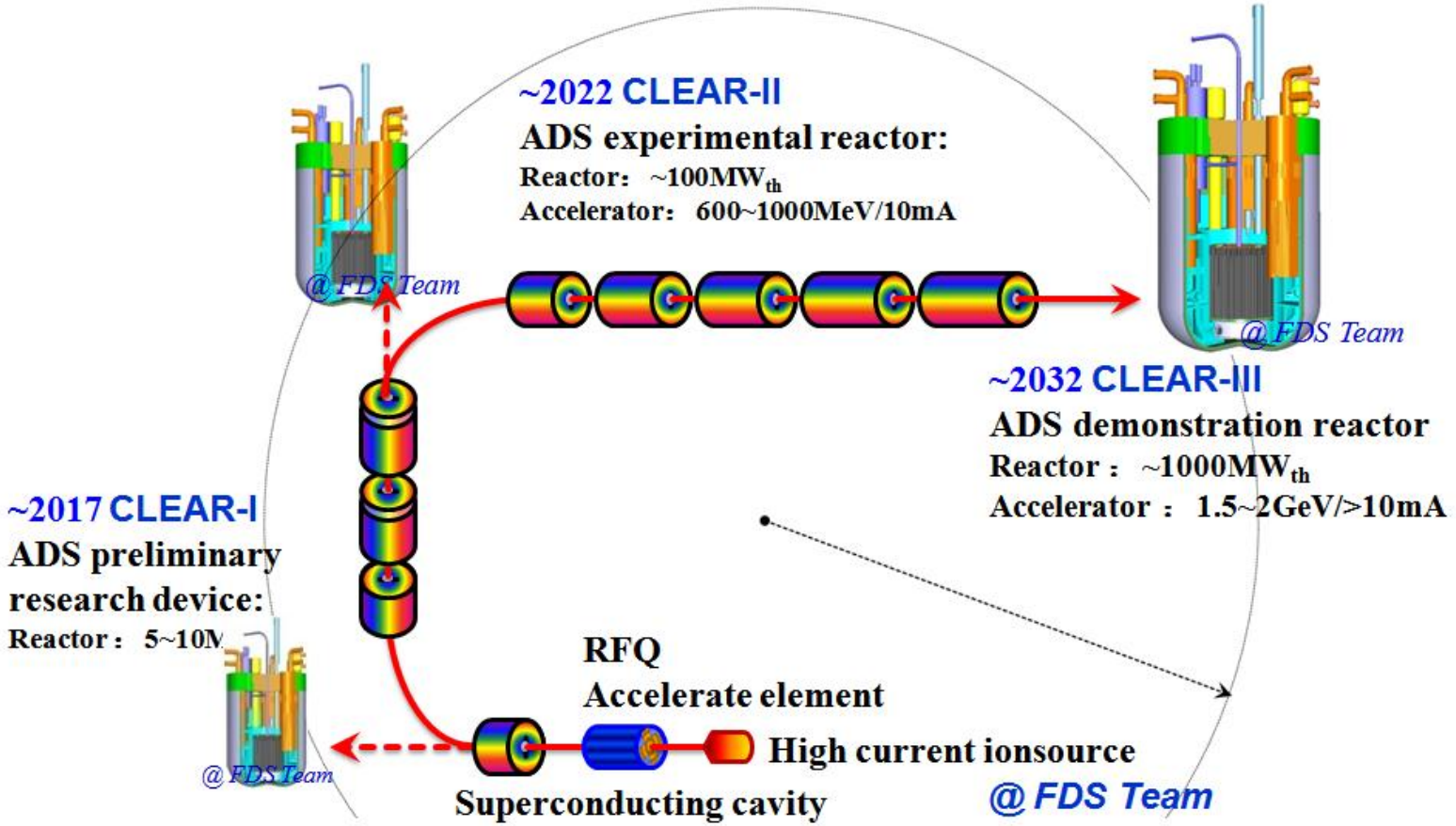
Challenges

- Compatibility of LBE with structure materials
- Special flow and heat transfer characteristics of LBE

➢ **Liquid PbBi Eutectic has the good potential as the target and coolant for reactor.**

Roadmap of ADS Development in China

- Chinese Academy of Sciences (CAS) has been carried out an ADS Project, and plan to construct demonstrated ADS transmutation system ~ 2032 .
- China LEad Alloy cooled Reactor (CLEAR) is selected as the reference design



CLEAR Series Reactor Development Plan

❖ CLEAR-I(~2017): ADS verification facility

It consists of a 10MW$_{th}$ PbBi cooled reactor coupled with a proton accelerator, which can be operated on critical and subcritical state.

❖ CLEAR-II(~2022): ADS experimental reactor

It consists of a ~100MWth PbBi cooled reactor, a proton accelerator with ~600-1000MeV/~10mA, and a PbBi spallation target.

❖ CLEAR-III (~2032): ADS demonstration reactor

It consists of a ~1GWth PbBi cooled reactor, a proton accelerator with 1.5GeV/~10mA and a PbBi spallation target.

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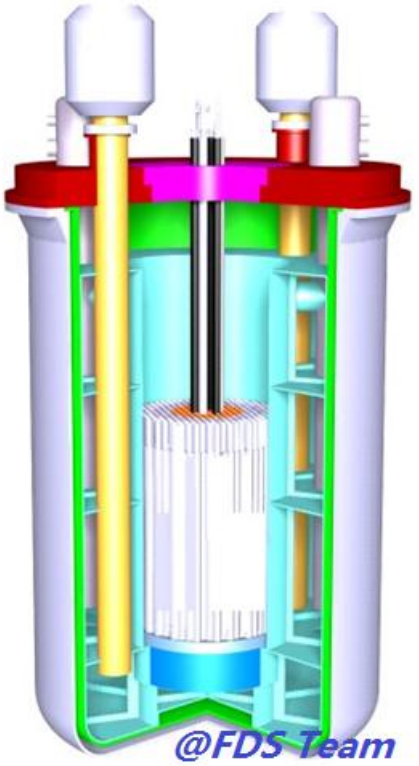
CLEAR-I Project

- **A Validated Accelerator Driven System will be built before 2017 by CAS to test the PbBi cooled reactor and ADS coupling technology**
  - **Proton accelerator(~50MeV)**
  - **Liquid metal spallation target**
  - **The Lead-bismuth cooled reactor(~10MWt)**
- **The reactor will be operated in critical and subcritical modes, thermal power is ~10MW in critical operation mode**
- **Object: to test the PbBi cooled reactor technology**
  - **Design, construction, control and operation technology;**
  - **Neutronics, thermalhydraulics, and safety characteristics;**
  - **Materials and fuel test of LBE cooled reactor.**

CLEAR-I Design Parameters

Parameter		Values
Thermal power (MW)		10
Core	Activity height (m)	1.0
	Activity diameter (m)	1.5
	Fuel (enrichment)	UO_2(19.75%)
Cooling system	Primary Coolant	LBE
	Inlet/Outlet Temperature	300/400
	Coolant drive type	Natural circulation
	Heat exchanger	4
	Second coolant	Water
	Heat sink	Air cooler
Material	Cladding	316 Ti
	Structure	316L



CLEAR-II Project

- **Design object:**
  - **Build experimental ADS system and provide technical support for the ADS demonstration reactor.**
  - **A test Platform for ADS integral test and materials experiment, fuel test.**
  - **High neutron flux test reactor for ADS DEMO and fusion reactor materials.**
- **Construction time： ~2022**

Accelerator power	K_{eff}	Core power(MW)	Flux spectrum ($n/cm^2/s$)	Target	coolant	Fuel
0.6-1GeV/10mA	0.95-0.98	~100	FR 10^{15}	LBE (First Window Then windowless)	LBE	MOX (MA)

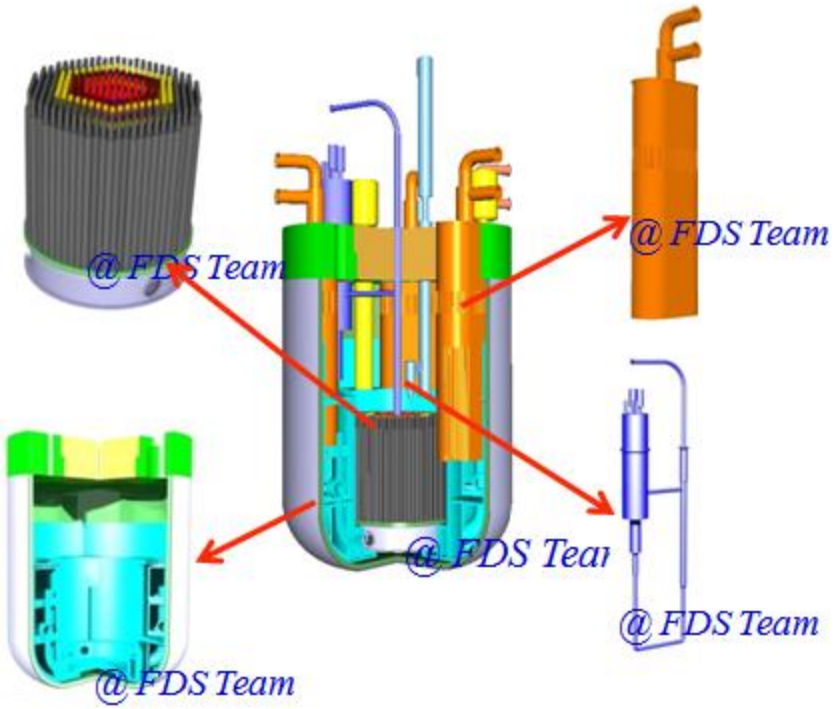
CLEAR-III Project

- **Design object： Demonstrate the technologies of transmutation of nuclear waste technologies of commercial ADS**
- **Construction time：~2032**

Accelerator power	K_{eff}	Core power(MW)	Flux spectrum ($n/cm^2/s$)	Target	coolant	Fuel
1.5GeV/>10mA	~0.98	~1000	FR $5x10^{15}$	LBE (windowless)	LBE	MA/Pu

CLEAR-III Design Parameters

Design objective	Waste transmutation
Accelerator power	15MW(1.5GeV/~10mA)
Keff	~0.98
Thermal power	~1000 MW
Spallation target	Windowless Pb-Bi Target
Fuel	TRU+Zr
MA Transmutation	400kg/y
Coolant	Liquid Pb-Bi



Contents

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KYLIN Loops and Verification facilities

Loop name	Type	Function	Temperature	Time
KYLIN-I	TC*	Compatibility test under flowing PbBi	450-480^{O}C	2010
KYLIN-II	FC	Compatibility, flowing behavior, oxygen control unit and purification system	350~550^{O}C	2010-2012
KYLIN-III	FC	Thermal-hydraulics of target and reactor	300-600^{O}C	2014
KYLIN-S^{T}	Static	Compatibility test in the static PbBi	200~800^{O}C	2010
KYLIN-R^{T}	Flowing	Compatibility test in the rotation flowing PbBi	480~600^{O}C	2010

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

Series of PbBi experimental loops and verification facilities are going to design and built in Institute of Nuclear Energy Safety Technology (INEST).

Thermal Convection PbBi Loop--KYLIN-I

Design Objectives:

- Thermal convection loop
- Obtain corrosion behavior of SS316L /T92 and CLAM (China Low Activation Martensitic) steel

Major parameters:

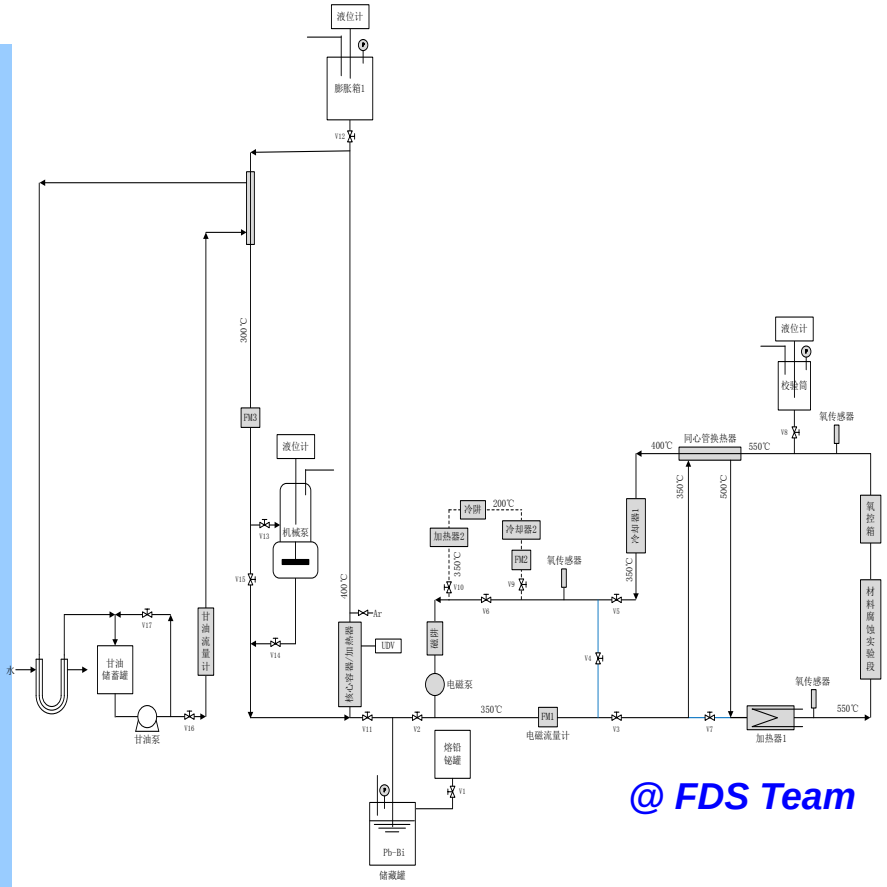
- Loop size : 0.5m×0.5m
- Structural Material : SS316L
- Inner/out-diameter : 42/32mm
- Temperature : 450 ~ 480℃
- Volume of PbBi : ~2L
- Atmosphere : Ar (99.999%)

This loop had been built in May 2010.

KYLIN-II: Middle-scale Forced Convection LBE Loop

Design Objectives:

- **Materials experiment**
  - High temperature corrosion
  - Stress corrosion
  - Purification of LBE
  - Oxygen measurement and control
- **Thermal-hydraulics experiment**
  - Fuel bundle simulation experiment
  - Gas lift experiment
  - Secondary coolant loop
- **Safety experiment for LBE**
  - Chemical reaction experiment
  - Pressure suppression experiment



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KYLIN-II loop will be constructed at the end of 2012.

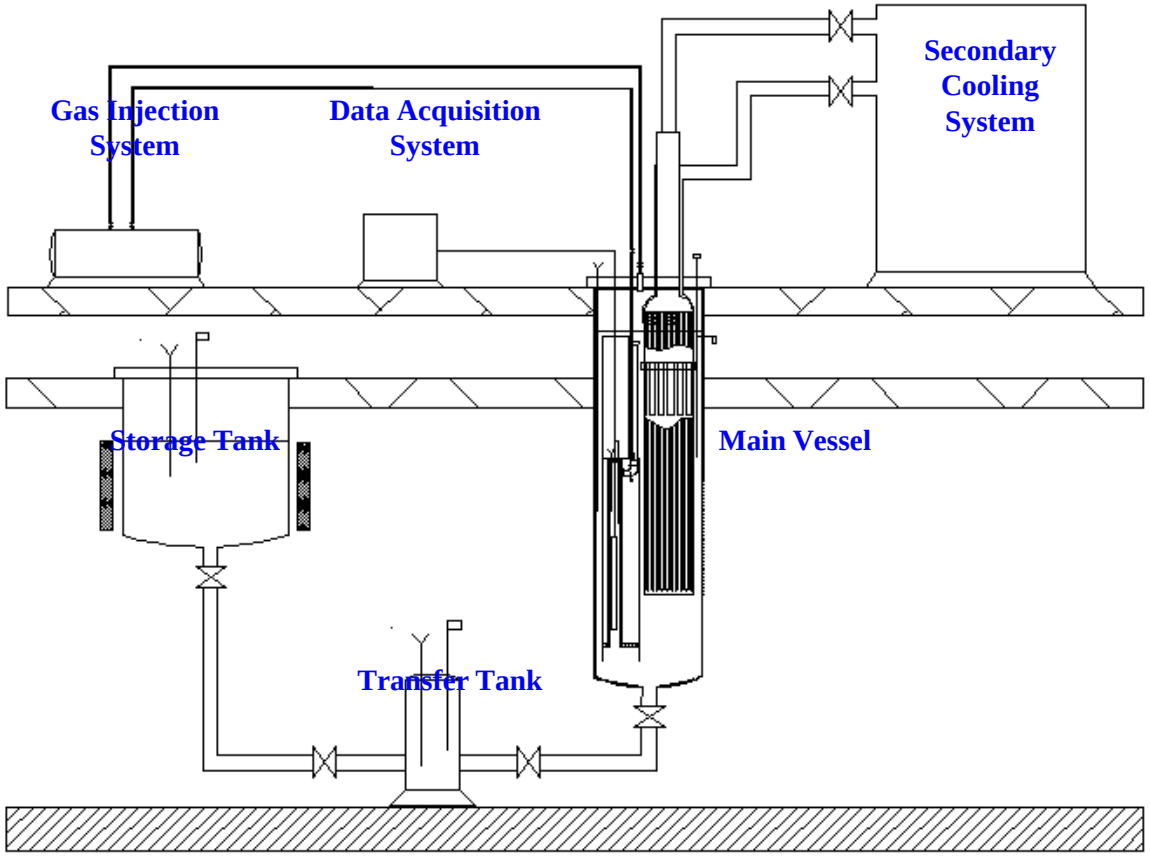
Large-scale LBE loop for thermal-hydraulics verification –KYLIN-III

Design Objectives:

- Reactor core thermal-hydraulics verification experiment for CLEAR-I

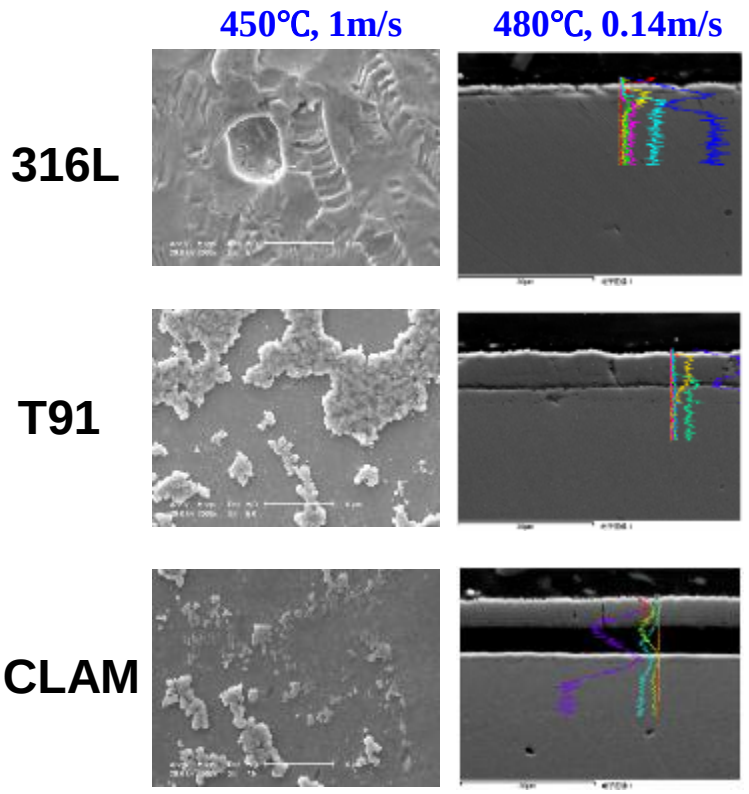
Main Components:

- Main vessel
- LBE storage tank
- LBE transfer tank
- LBE heating system
- Data acquisition system
- Gas injection system
- Secondary cooling system

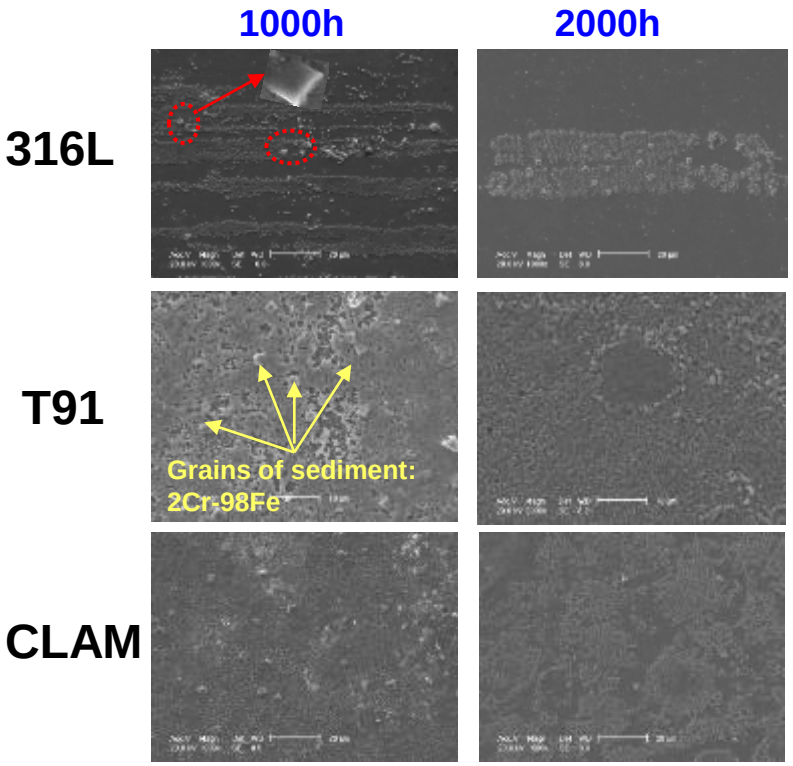


Corrosion experiments in PbBi

■ Flowing experiments



■ Static experiments（450ºC）



➢ Series of experiments have been performed on martensitic and austenitic steel.

Summary

- **Lead alloy cooled reactor has a good potential for nuclear waste transmutation, which has been selected by CAS as the ADS reference reactor design;**
- **The "ADS transmutation system Program" had been lunched in China, which is planed to build ADS demonstration system through three phases. For the first phase, PbBi cooled reactor CLEAR-I will be built ~ 2017.**
- **CLEAR reactor construction is a very challenge work, widely international cooperation on reactor design and technology R&D is welcome.**

The End

Thanks for your attention !

Website: www.fds.org.cn

E-mail: fds@ipp.ac.cn