Institute of Nuclear Energy Safety Technology, CAS · FDS Team

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Conceptual Design of China Lead-based Mini-Reactor CLEAR-M10d

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Contributed jointly by FDS Team

Institute of Nuclear Energy Safety Technology (INEST)

Chinese Academy of Sciences (CAS)

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Contents

China's Plan on Nuclear Energy (Plan up to 2020)

- **Nuclear power plant in China (by August, 2019)**
  - *45 reactors (~ 45.9 GWe) in operation*
  - *13 reactors (~16.6GWe) under construction*

~4%

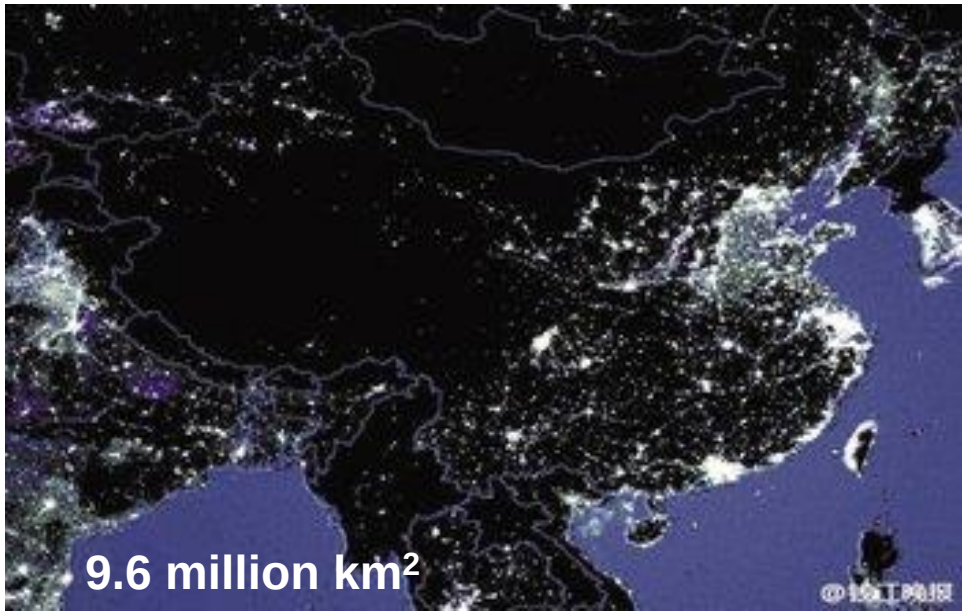
- **National plan of developing nuclear energy before 2020**
  - *58 GWe in operation*
  - *30 GWe under construction*

~5%

- **National plan for nuclear and radiation safety before 2020**
  - *More R&D are required to enhance nuclear safety, especially in the basic research of nuclear safety*
  - ***~79.8 billion RMB investment plan (~13 billion US $)***

Small-scale Energy Supply Demand in China

- **Remote area** : ~12% of land area is desert without electricity supply
- **Offshore unit :** ~1/4 of gas and oil reserve in the sea, waiting for exploitation
- **Distributed power supply:** independent industry, with wind or solar energy
- **Emergency electricity supply** : Natural disaster in some provinces



High Requirements

- ☐ **Independent**
- ☐ **Flexibility**
- ☐ **Sustainability**
- ☐ **Economical**

Characteristics of Lead-based Reactor

❖ Safety advantages

- **Neutronics：** Negative coefficient, Floating core debris
- **Thermal-hydraulics:** Low pressure, no LOCA, natural circulation
- **Chemistry:** Chemical inertial, no reaction with water and air, no hydrogen explosion

❖ Sustainability advantages

Low neutron absorption, Low moderation, enable sustaining hard neutron spectrum

High efficiency in fuel utilization

Burning long-lived, high-level actinide wastes

Major China Lead-based Reactor Program

1980s-1990s	2000s	2010s
"863" program "973" program	ITER International/Domestic Research Program	Strategic Priority Research Program of CAS National Major Science and Technology infrastructure

- **National High-Tech. Project : Fusion-fission hybrid reactor**
  INEST/FDS in charge of Lead-based hybrid reactor
- **ITER Project : Fusion reactor**
  INEST/FDS in charge of China lead-based liquid blanket
- **Strategic Priority Research Program of CAS : ADS system**
  INEST/FDS in charge of lead-based sub-critical reactor
- **China Lead-based Mini-Reactor (CLEAR-M)**
  Supported by national/local government project and Industry investment

~30 years lead-based reactor R&D experiences

Y. WU , FDS Team. Design and R&D Progress of China Lead-based Reactor for ADS Research Facility , Engineering , 2016, 2(1):124-131.

Contents

Proposal of a Small Modular Lead-based Reactor CLEAR-M10d

❖ 10MW class lead-based nuclear reactor

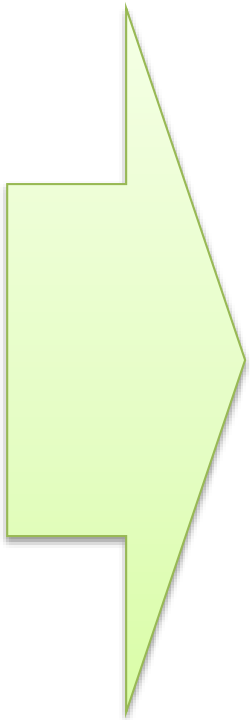
- ✓ **Small modular**
  - Easy to transport and install
- ✓ **Inherent safety**
  - Exclusive severe accident
- ✓ **Long refueling period**
  - Better economy
  - Environmentally friendly

Design Basis

Safety

Long refueling period

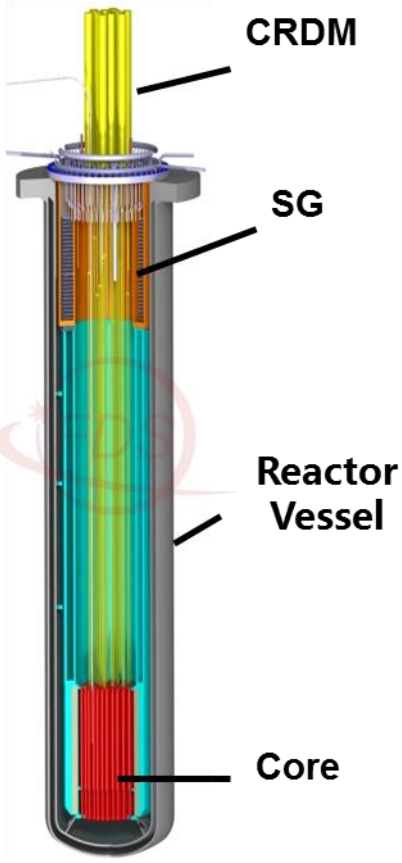
Small modular



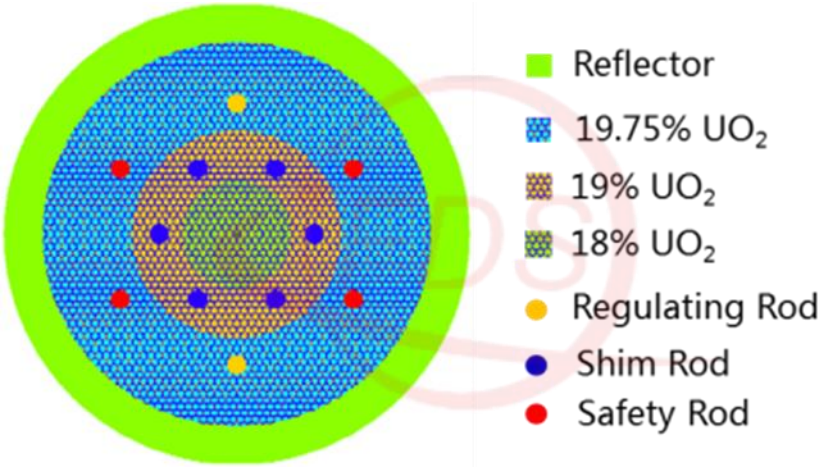
- **Pool type double wall reactor**
- **Pb as coolant (to exclude Po issue)**
- **Diversity, redundant, passively decay heat remove system**
- **Less maintenance requirement for primary system components (natural circulation)**
- **Less cladding corrosion (lower core velocity)**
- **Relatively less reactivity change**
- **Size and weight limited (mainly for vessel diameter)**
- **Quickly installation (Simple configuration of primary system)**

Lead-based Mini-Reactor CLEAR-M10d

Parameter	Values
Thermal power	35MWth
Electrical power	14MWe 10MWe+17MWt
Fuel	Ave.18.5% UO2
Core life	10~20 years
Core inlet / outlet temperatures	375/495℃
Reactor vessel length-to-diameter ratio	4:1



Reactor Core Design

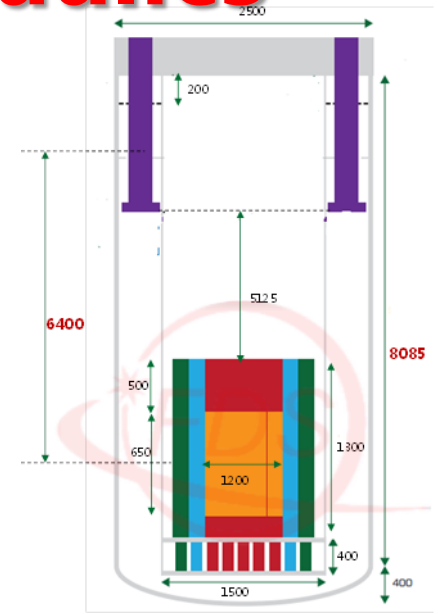


Layout of CLEAR-M10d core

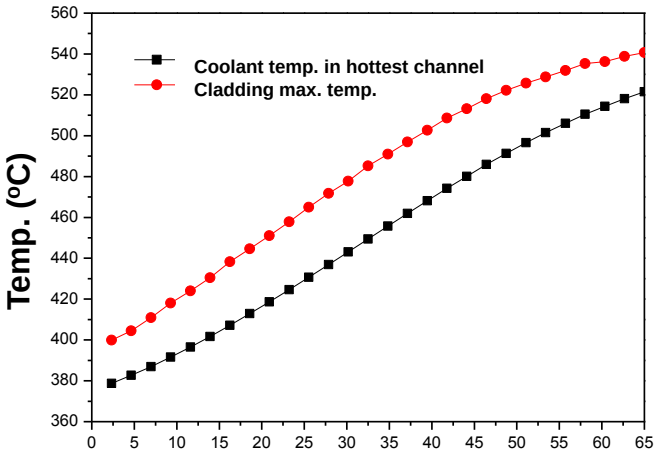
Parameter	Value
Enrichment of fuel	19.75%/19%/18%
Number of fuel pins	3500
Diameter of fuel pin	16 mm
Cladding thickness	1 mm
Burnup	~62000 MWd/tU

Core Thermal-hydraulics

Items	Unit	Value
Thermal power	MW	35
Coolant	-	Pb
Inlet /outlet temp. of core	℃	375/495
Diameter of Pins	mm	16
Pitch to diameter		1.2
Height of active zone	mm	790
Diameter of active zone	mm	1200
Average velocity of core	m/s	0.46
Max clading temp.	℃	540.6
Max fuel temp.	℃	1559

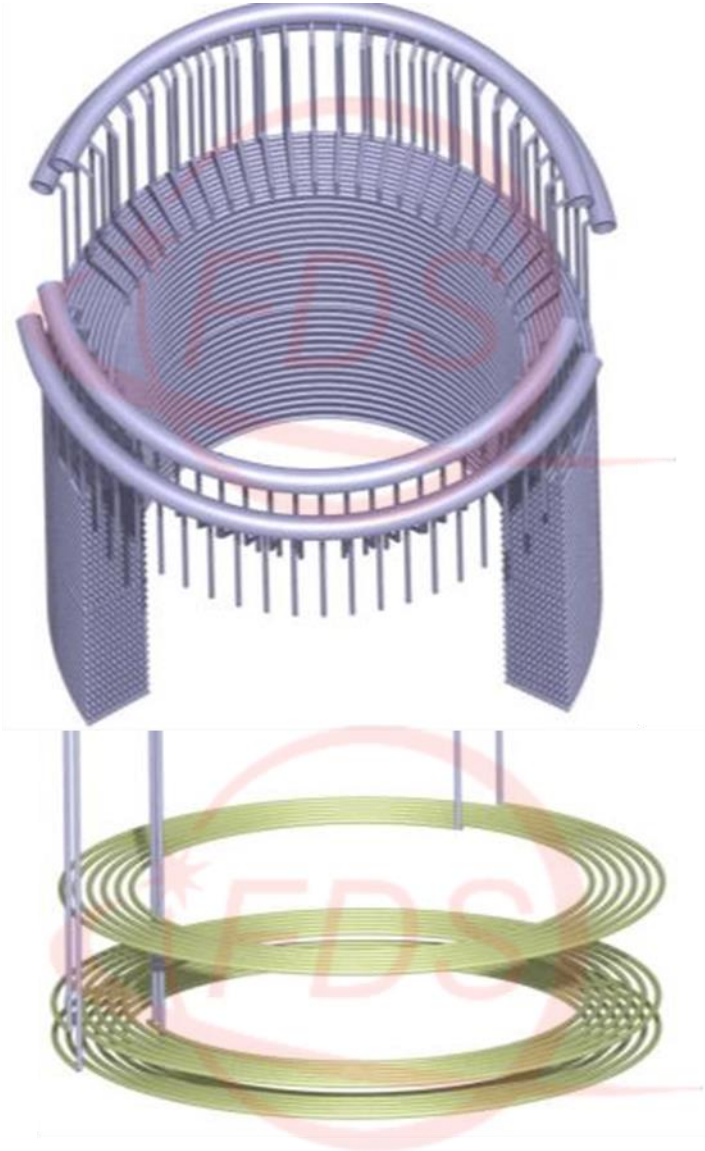


Main parameter of primary systerm



Temperature distribution along fuel pin

Spiral Steam Generator

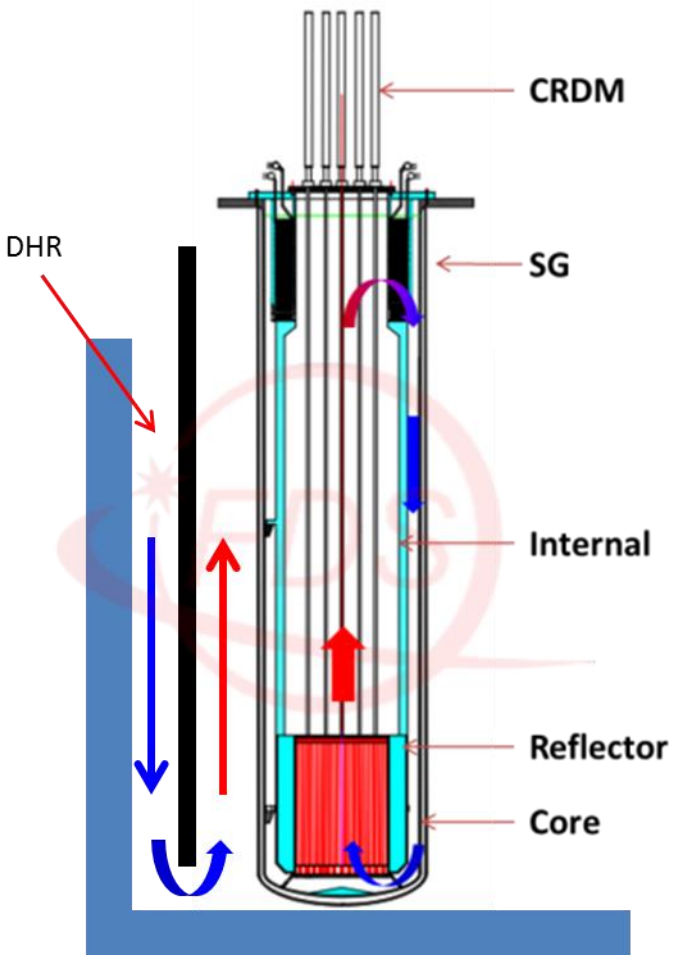


Item	Shell side	Tube side
Power	35MW	
Medium	LBE	H_2O
Temperature	495/375℃	330/450℃
Pressure	--	13MPa
Pressure drop	0.4kPa	--
tube	Φ17×1.5mm ; L=21.2m	
Tube bundle Active height	~1460mm	
Outer diameter	Φ1750mm	

Passive decay heat removal system

- **DHR1: Secondary loop (in normal condition)**
- **DHR2: Reactor vessel air cooling system (passive operation)**

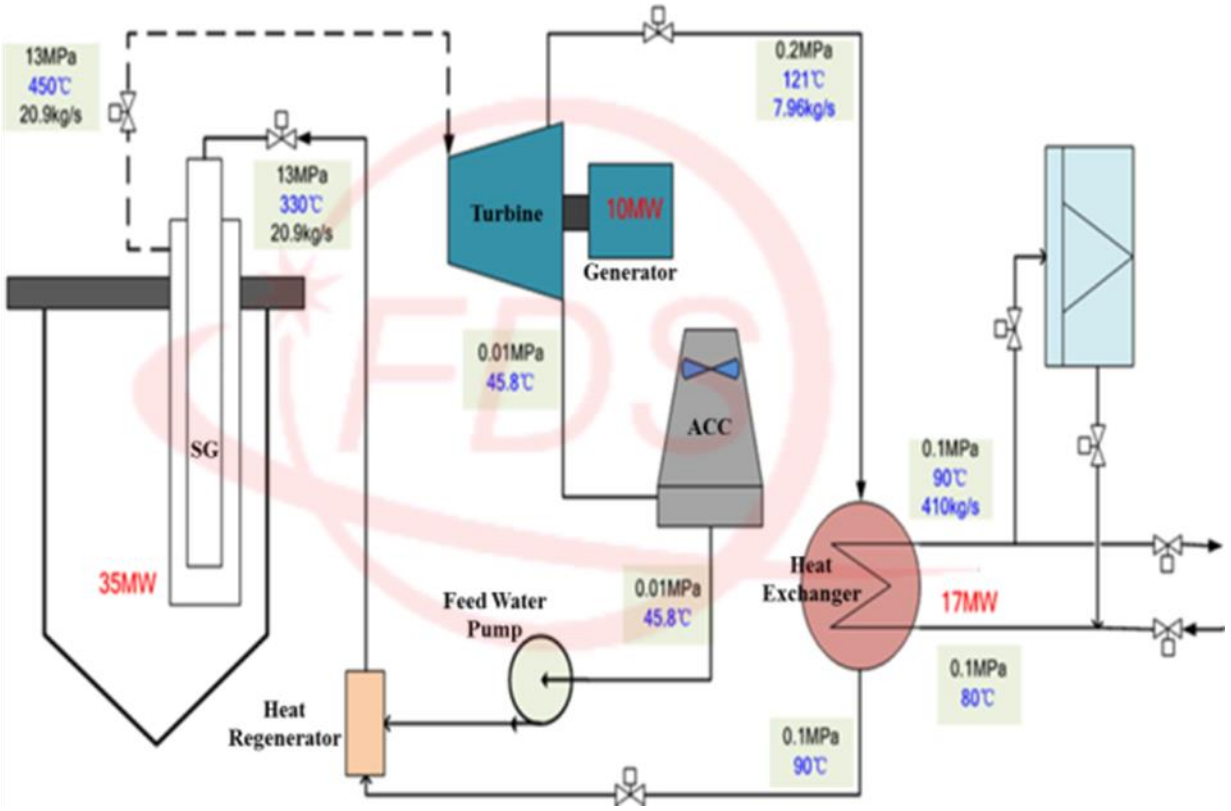
Item	Parameters for RVACS
Coolant Circulation	Natural Circulation
Heat Sink	Atmosphere
Power	525 kW(1.5%FP)
Chimney	10m height



Heat and Power Cogeneration System

- **Heat and power cogeneration mode (~4 months): （power）10MW，（heat）17MW**
- **Power generation mode（~8 months）：（power）14MW**

Parameter	Value
Thermal power	35MWt
Electric power	10MWe
Thermal supply	17MWt
The system efficiency	78%
The inlet temperature of turbine	450℃
The inlet pressure of turbine	13MPa



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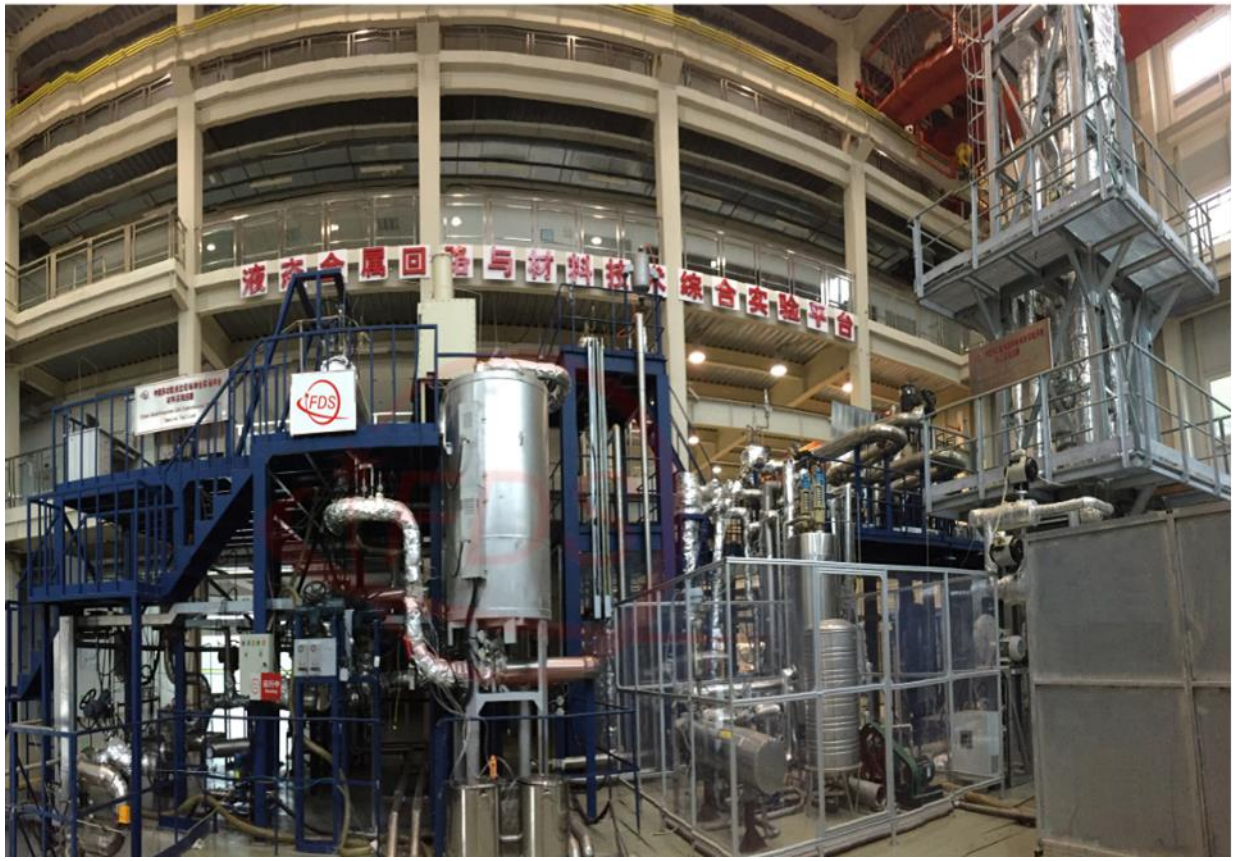
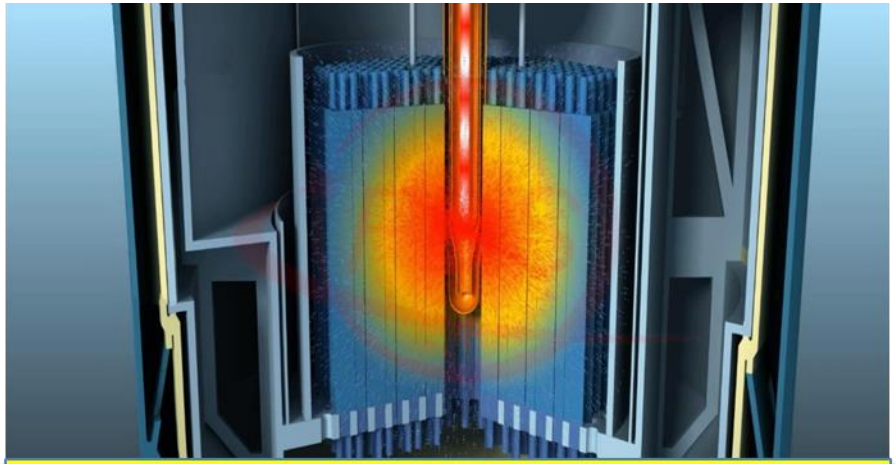
Key Technologies

- Coolant Technology
- Key Components
- Materials and Fuel
- Operation and Control



Three Integrated Test Facilities



Digital Simulation CLEAR-V

Physics Test CLEAR-0

Engineering Validation CLEAR-S

Further Implementation Activities

- ✓ **Industrial park for lead-based reactor**
  - laboratory under construction
- ✓ **China Industry Innovation Alliance of Lead-based Reactors (CIIALER)**
  - president member INEST/FDS Team, over 100 enterprises
- ✓ **International Co-operative Alliance for Small LEad-based Fast Reactors (CASLER)**
  - chair INEST/FDS Team, over 20 members

Contents

Summary

1. Lead-based reactor has many attractive features and may play an important role in the future energy supply.
2. 10MWe China Lead-based Mini-reactor CLEAR-M has been proposed with three features of
   - Inherent safety, exclusion of severe accidents
   - Small modular, easily to transport
   - Long duration, refueling period
3. Wider and deeper international collaboration is encouraged.

Thanks for Your Attention!

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