中广核 CGN 核能 Nuclear Power

中广核研究院 China Nuclear Power Technology Research Institute

CLFR-300, an Innovative Lead-cooled Fast Reactor Based on Natural-Driven Safety Technologies

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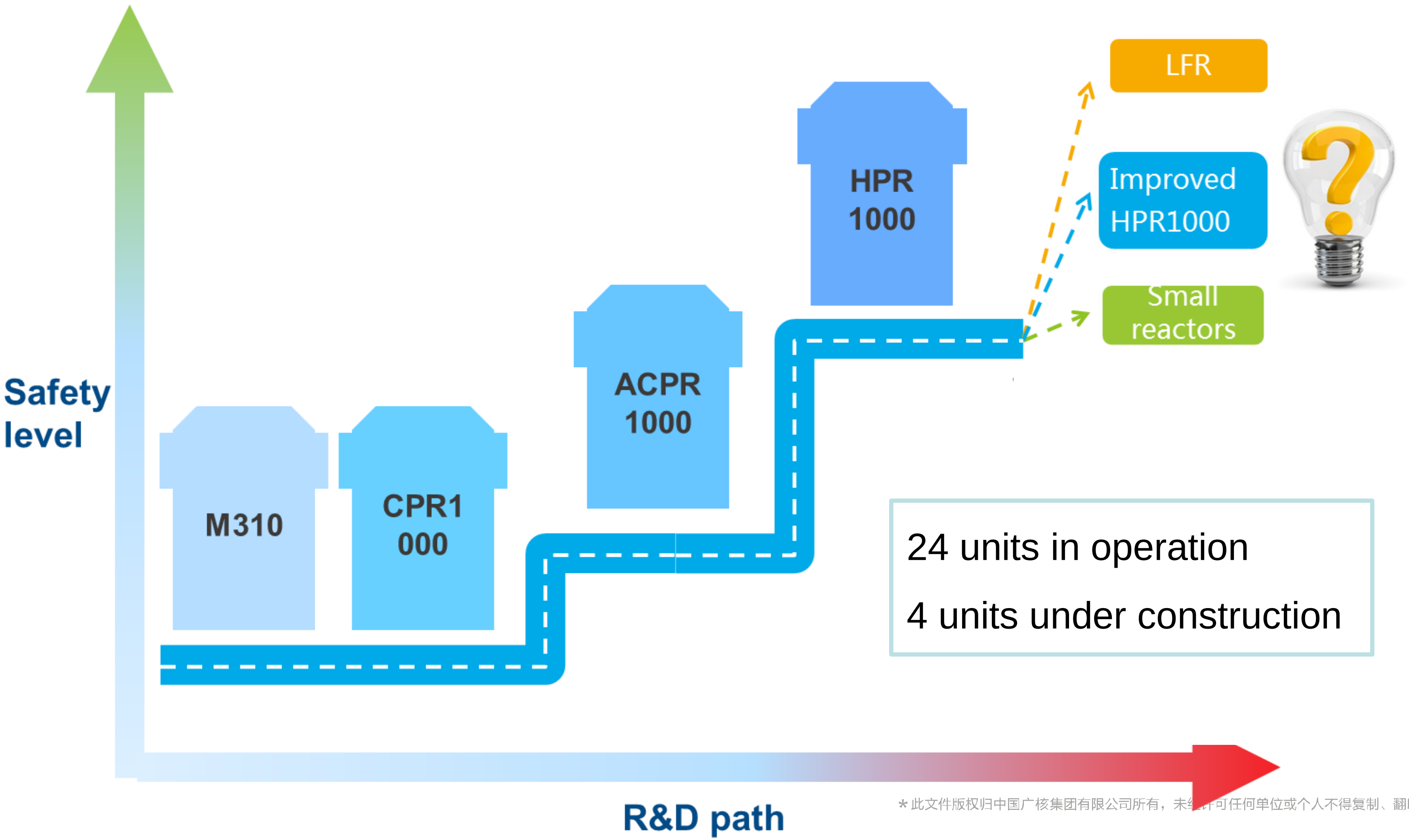
Reactor technologies development in CGN



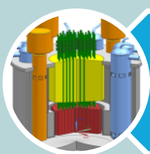
The FIVE strategic projects in CGN

华龙一号及GDA

HPR100 and GDA

小型堆研发及项目开发

Small Modular Reactor (SMR)



先进核能系统研发

Advance Nuclear Energy System （ LFR ）

自主知识产权核燃料元件研发

Advance Fuel and ATF

智能核电

Smart Nuclear Power Plant

R&D activities for LFRs in CGN/CNPRI

2009-2012

Advanced nuclear energy system tracking

- LFR
- SCWR
- HTGR
- GCFR
- MSR
- TWR
- Fusion Reactor
- SCFR
- ADS

Assessment

Safety, reliability, economy, technology maturity, development tendency, key technology, etc.

2013-2014

Research on LFR key technology

- Software platform setting up
- Preliminary research of key technology
- Experimental bench design
- Safety analysis

Conceptual design

CiADS, CLFR-10, CLFR-300

2015 to present

The strategic project — R&D in LFR

- Engineering design: system, equipment, construction, etc.
- R&D in key technology: prototype machine of main equipment, lead-bismuth purification and oxygen control technology
- Experimental benches construction: material, thermal hydraulics, overall layout, etc.
- R&D in material: fuel cladding, structure and so on.

Preliminary design

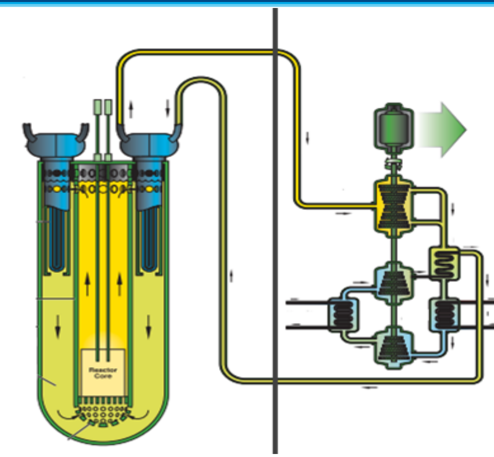
CiADS, CLFR-10

Conceptual design

CLFR-300

Why select LFR?

Advantages and Potentials of LFR	
Safety	• High boiling point • Chemically-inert coolant • Atmospheric pressure system • No pressure-driven LOCA • Retention of fissile materials • ……
Economic	• Design simplicity • Compact Nuclear Island • High power density core • High plant efficiency • Fully modular • ……
Marketability	• All plant sizes: battery-type, SMR, GWe-size • Flexibility operation ability • Non-electric applications • Potential for long-life core • Potential to close fuel cycle • ……

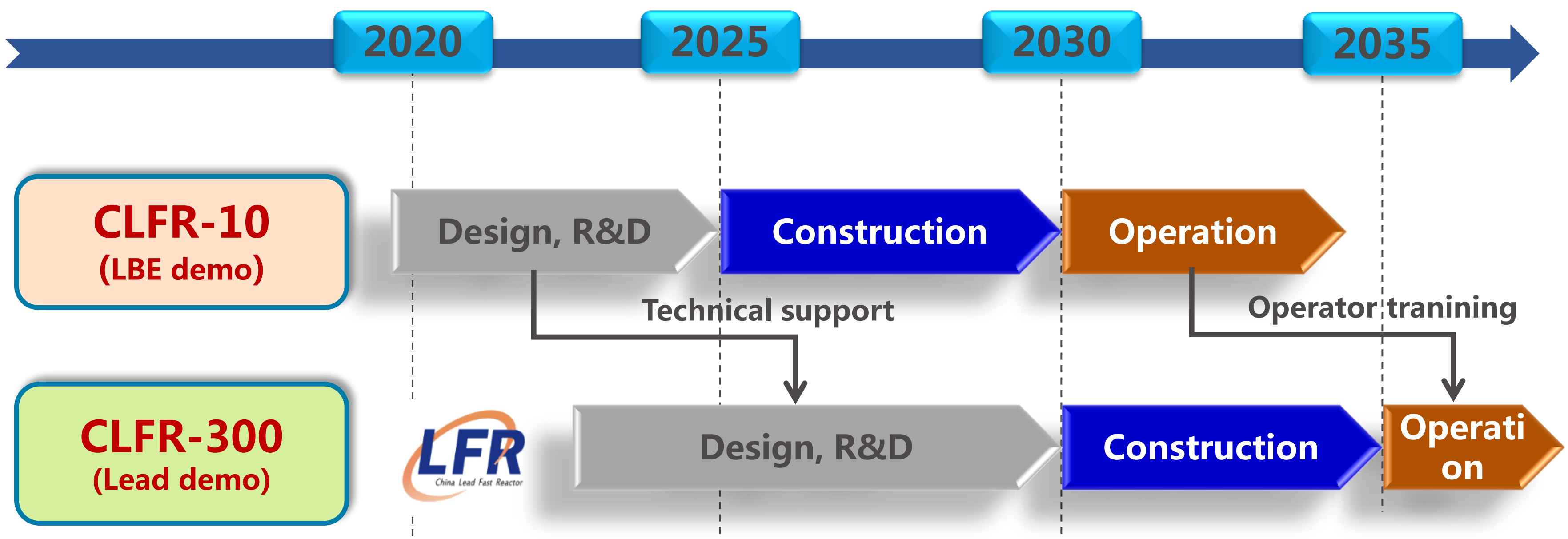


Main technical challenges

- High melting point (327℃)，to avoid condensation
- Corrosion,
- Opacity, difficult for test and monitoring interior facilities and fuel operation
- High density, reactor structure and anti-seismic design
- ……

Roadmap for CGF LFR development

Goal: Commercialize LFR in 10~15 years



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Objectives & Requirements

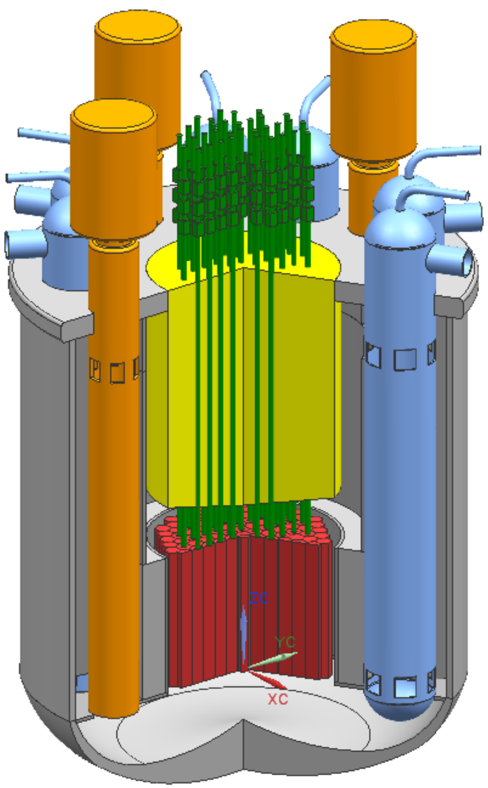
CLFR-300 development objectives

- Demonstrate the technical feasibility of LFR with a target that ready for construction by 2030
- Demonstrate the economic competitiveness of LFR with a target that the construction costs per unit of power generated can below current LWR designs
- Qualify and standard fuel and materials for commercial LFR
- Provide operating experiences with pumps, steam generations and other key components that are prototypic for commercial LFR

CLFR-300 performance requirements

Parameters	Requirement
Power	~300MWe
Plant net efficiency	≥40%
Operation life	60 years
Cycle length	≥3 years
Unit availability	≥95%
Construction time	≤36 months

CLFR-300 main parameters

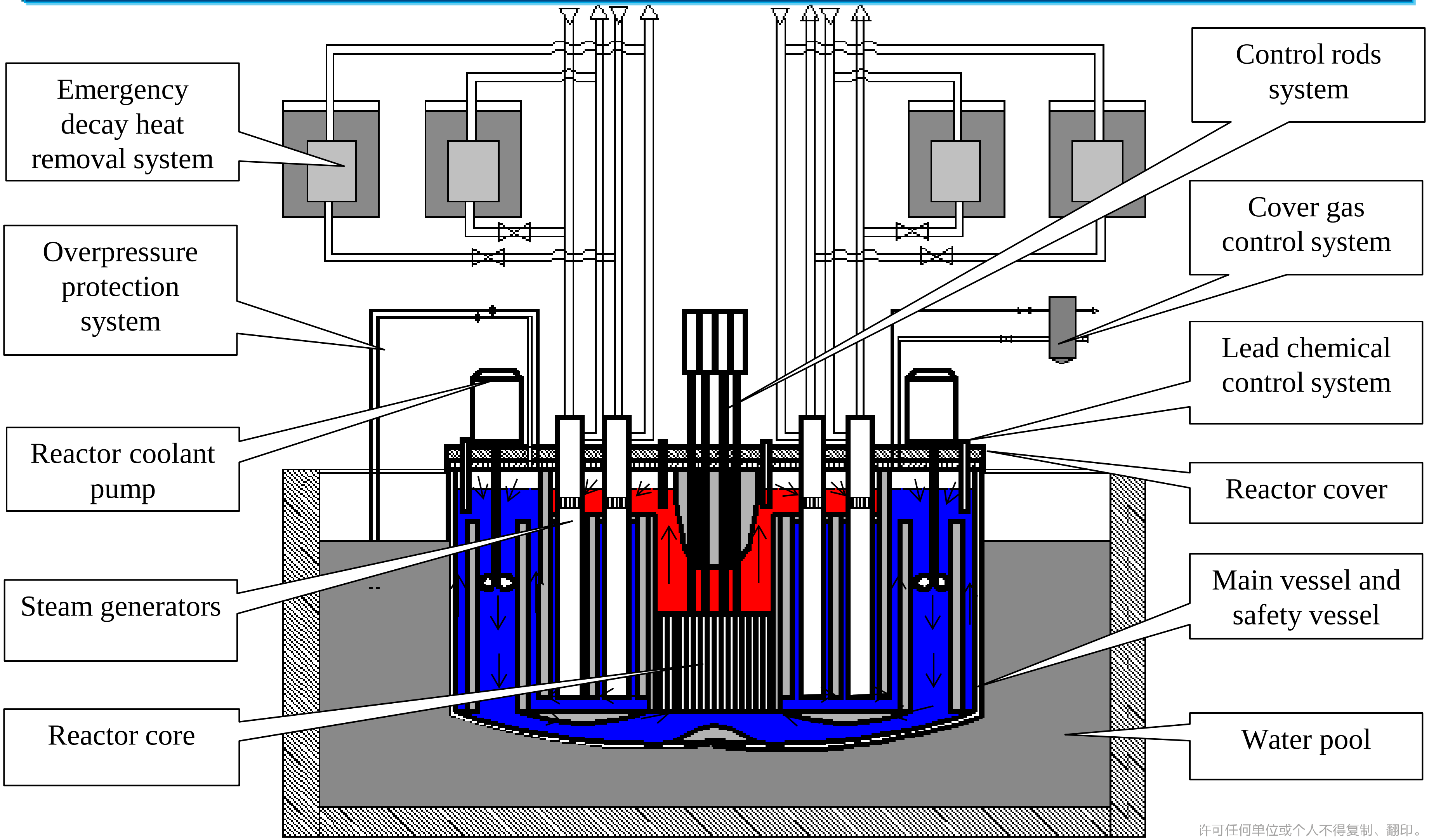


Schematic of CLFR-300

MAIN DESIGN PARAMETERS OF CLFR-300

Parameter	Value
Thermal power	740MW$_{th}$
Electric power	300MW$_{e}$
Plant net efficiency	40.5%
Fuel	UO_2 (11.7%/15.6%)
Refuelling internal	3 years
Core inlet/outlet temperature	400/500℃
Primary system	Integral pool-type with forced circulation
Primary coolant	Liquid lead
Steam generators	8×Once through steam generator(OTSG)
Reactor coolant pump	4×Mechanical pump
Secondary cooling system	Water/steam forced circulation

CLFR-300 system configuration



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Definition of Natural-Driven Safety technologies

Why need new safety concept ?

- After the Fukushima NPP accident, the public demand for nuclear power safety has increased
- However, according to traditional safety concepts, it is hard to improve the safety and economy simultaneously, because the requirements of safety and economy are conflict in most cases, such as the redundant design requirement, the large conservative margin requirement and the backup power requirement (emergency diesel engines).
- Therefore, it is necessary to develop a new safety concept to reconcile this conflict for the development of the next generation nuclear power technology.

Definition of Natural-Driven Safety technologies

Evolution of NPP safety technologies

Relying on **pump, valves** to ensure the realization of safety functions

Activity safety technology

Relying on natural laws to ensure the realization of safety functions, **but unnatural means are still needed**, such as electronic device and batteries.

Passive safety technology

Relying on natural laws to ensure the realization of safety functions, and **without any non-natural means**, such as batteries and electronic devices.

Natural-driven safety technology

!!! Strictly speaking, NDS can be included in the concept of high level passive safety technologies

Definition of Natural-Driven Safety technologies

The benefits of NDS technologies

a. **improve reactor safety performance** by providing self-protection capacity during all credible initiation events and their combinations and providing long term cooling capacity for decay heat by nature laws.

b. **improve safety systems reliabilities** by eliminating electric power requirements and any operator intervention.

c. **improve reactor economic performance** by simplifying equipment units and operation procedures of safety systems.

d. **improve public acceptability** by virtually eliminating risks of core damage and large release of radioactivity, and ruling out the requirement of evacuation of the local population.

Definition of Natural-Driven Safety technologies

Some specific technological means of NDS

Some specific technological means to realize NDS are:

- natural circulation cooling technique
- thermal expansion or thermal contraction technique
- selective fuse or quick fuse technique
- burst pressure technique
- high quality and high performance materials
- ……

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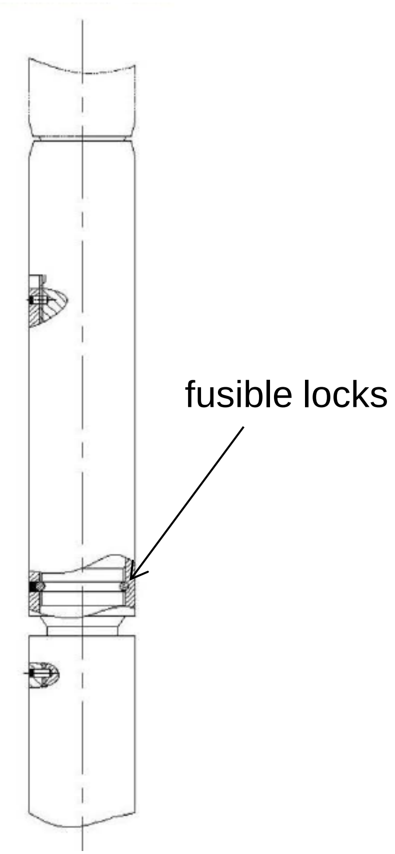
Example 1: Natural-Driven Shutdown System (NDSS)

Safety function: The NDSS is designed as the ultimate reactivity control mean for CLFR-300, which will provide shutdown protection when the safety rod system fails to actuate.

System description: The NDSS consists of absorber rods, guide tubs and controllers.

Operation: The controller is a temperature based two-position (on-off) automatic controller. There are several temperature based technologies can be used in NDSS, such as fusible locks and bimetallic strips.

Benefits of NDSS: With the NDSS, the CLFR-300 can virtually eliminate the risk of unprotected accident and make it possible to prevent anticipated transients without scram (ATWS) accidents.



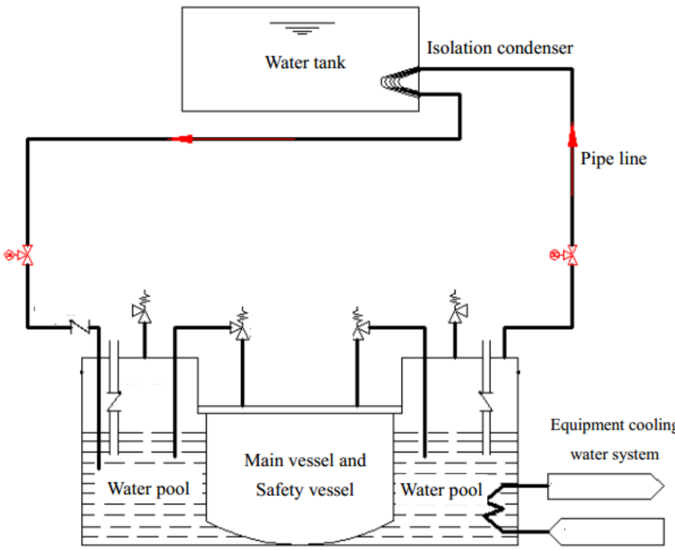
Example 2: Natural-Driven Decay Heat Removal system (NDDHR)

Safety function: The NDDHR is designed as the ultimate decay heat removal mean for CLFR-300, which will provide cooling capability when the emergency decay heat removal system fails to actuate.

System description: The NDDHR is composed of a water pool, pipe lines and an isolation condenser immersed in a water tank.

Operation: NDDHR removes the decay heat by thermal radiation from the reactor vessel to the water pool, and further due to the water boiling with steam removal through the pipe line to the isolation condenser.

Benefits of NDDHR: With the NDDHR, the CLFR-300 can virtually eliminate risks of core damage and large release of radioactivity, and rule out the requirement of evacuation of the local population.



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Conclusions

- **New challenge:** New market requirement for nuclear power has emerged, which require to improve nuclear power safety and economic performances simultaneously.
- **Suggested solution:** CGN has proposed a new safety concept named Natural-Driven Safety (NDS) to deal with new challenges. Two specific NDS systems are applied in the design of CLFR-300, including the Natural Driven Shutdown System (NDSS) and the Natural Driven Decay Heat Removal system (NDDHR).
- **Benefits of NDS:** The NDSS and the DNNHR can help CLFR-300 to improve nuclear power safety and economic performances simultaneously, and rule out the requirement of evacuation of the local population.
- **Further works:** The detail design of the CLFR-300 conceptual, as well as the NDSS and the NDDHR are on-going, and key simulation analysis and validate tests will be conducted in near later.

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谢谢

Thank you!