SAFETY FEATURES OF ADVANCED NUCLEAR REACTORS

Contents

- APR+ Safety Features
- AP1000 Safety Features
- Plan for IPOWER

APR+ Safety Features

APR+ Overall Specification (project name)

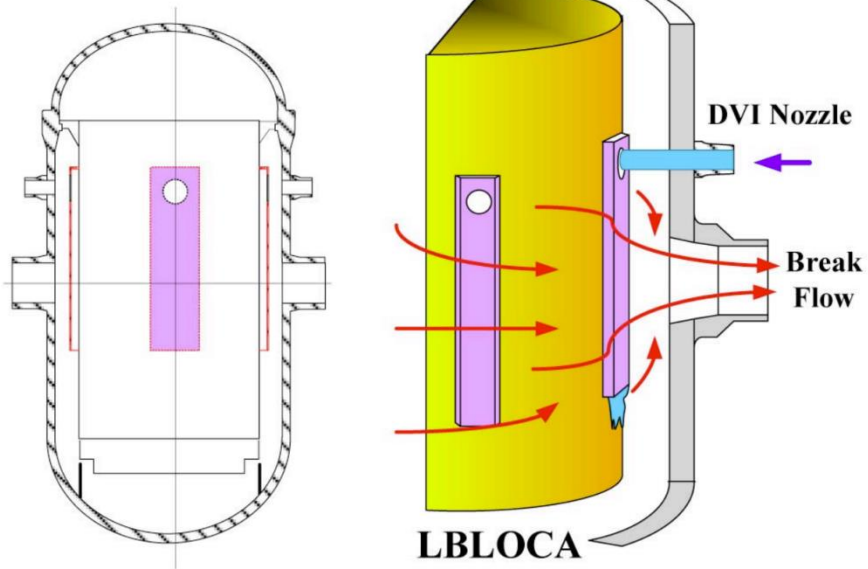
- Developer: KHNP
- Thermal power: 4290 MWth
- Electrical power: 1505 Mwe
- Design life: 60 years
- Construction period: 36 months
- Core damage frequency:
  - $<1.0 \cdot 10^{-6}$/year
- Construction plan
  - Shin Kori 7
  - 2022/2023 ?

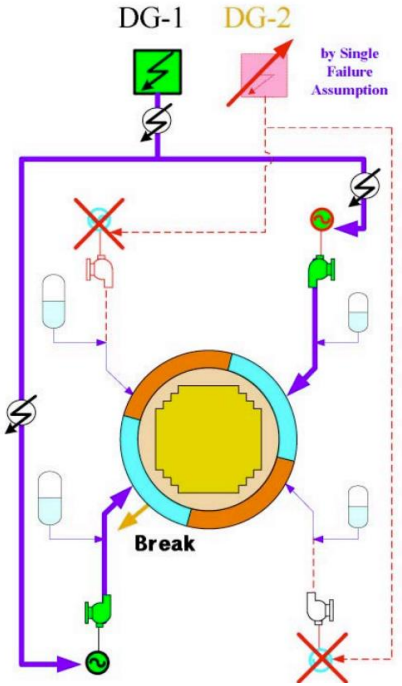
Primary Characteristics

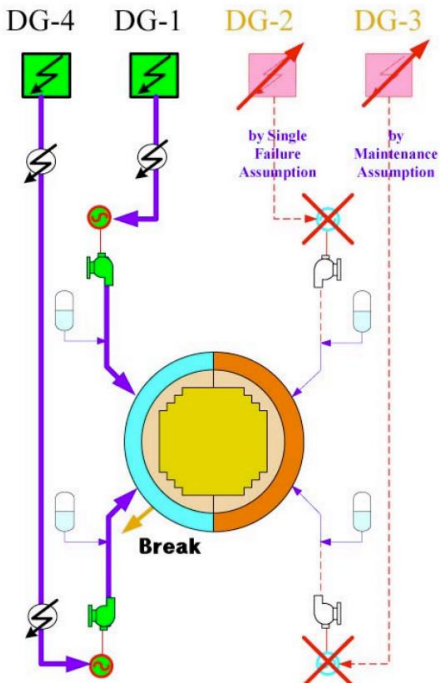
Category	APR1400	APR+
Developer	KHNP	KHNP
Power output (MWe)	1,400	1,500
Design life	60 years	60 years
Safe Shutdown Earthquake (SSE)	0.3 g	0.3 g
Core Damage Frequency (CDF)	6.22 E-6	1.0 E-6
LOOP (RCP/SG)	2 Loop (4/2)	2 Loop (4/2)
Fuel Assembly ▪ Number of fuel assemblies ▪ Fuel assembly type ▪ Height of fuel assembly	 241 16×16 12.5'	 257 16×16 12.5'
Emergency Core Cooling System (ECCS) ▪ Safety injection ▪ Composition ▪ IRWST	 Direct Vessel Injection(DVI) SIS(4), Accumulator(4) Fluid Device Yes	 Direct Vessel Injection(DVI) SIS(4), Accumulator(4) Fluid Device Yes
Containment Building ▪ Type ▪ Cooling method	 Single Active	 Single Active
I&C	Full Digital	Full Digital
Emergency D/G (EDG)	2	4

APR+ Safety Features

- New Safety Features
  - DVI+
    - Prevention of ECC bypass (ECBD, Emergency Core Barrel Duct)
  - 4 electrical trains of safety injection system
    - 3 safety systems are available with the single failure assumption
    - N+2
  - FD+
    - Fluid Device: passively control the safety injection flow rate
    - Advanced SIT

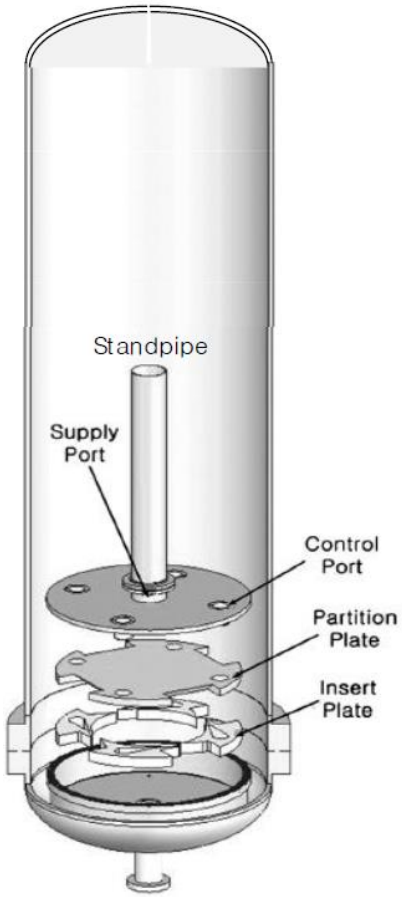




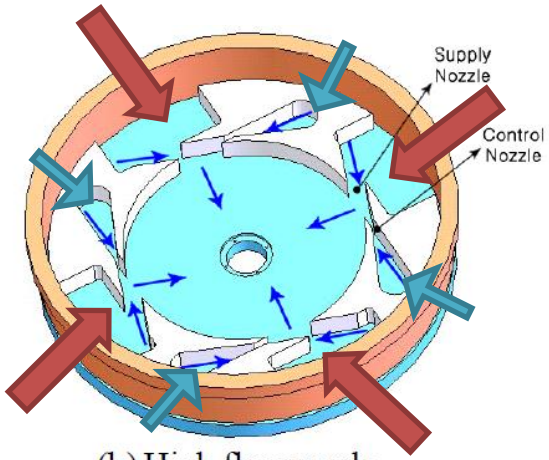


APR+ Safety Features

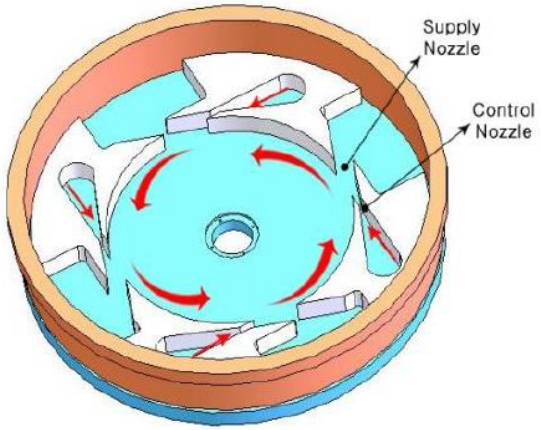
- New Safety Features
  - Fluidic device

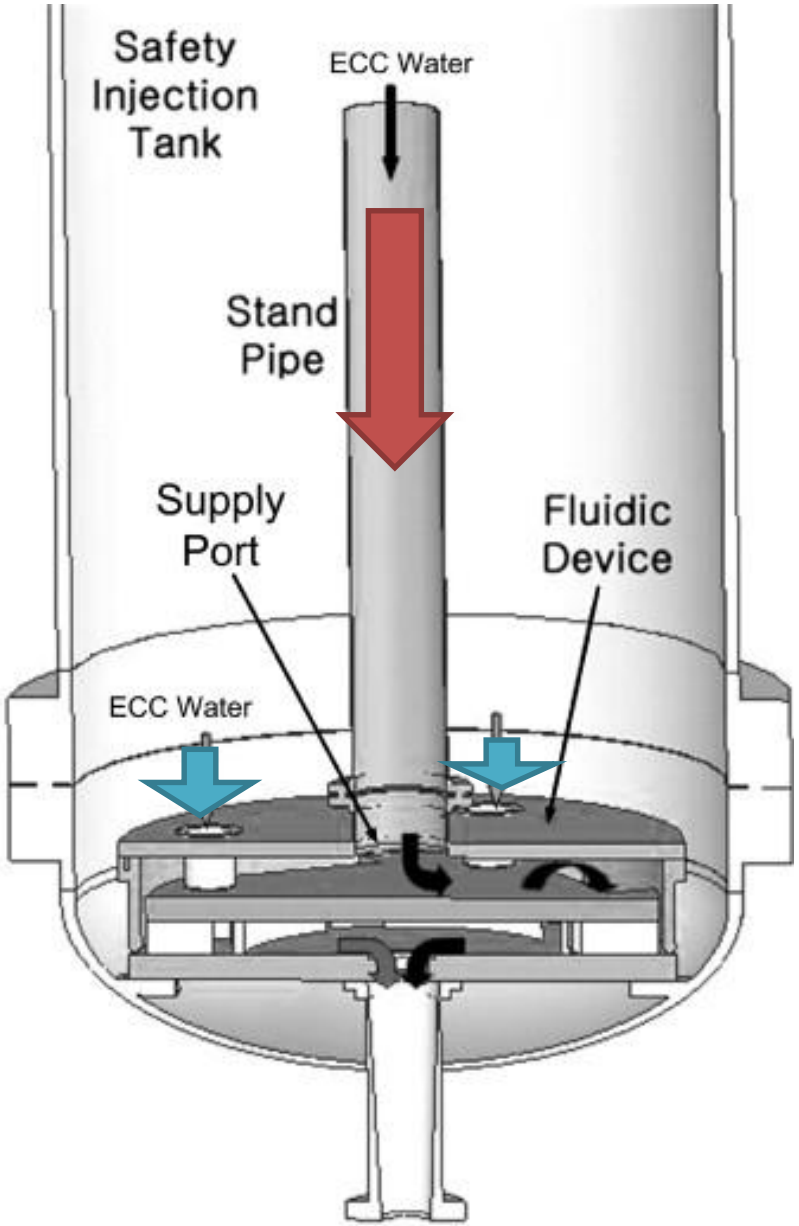


Vortex Chamber



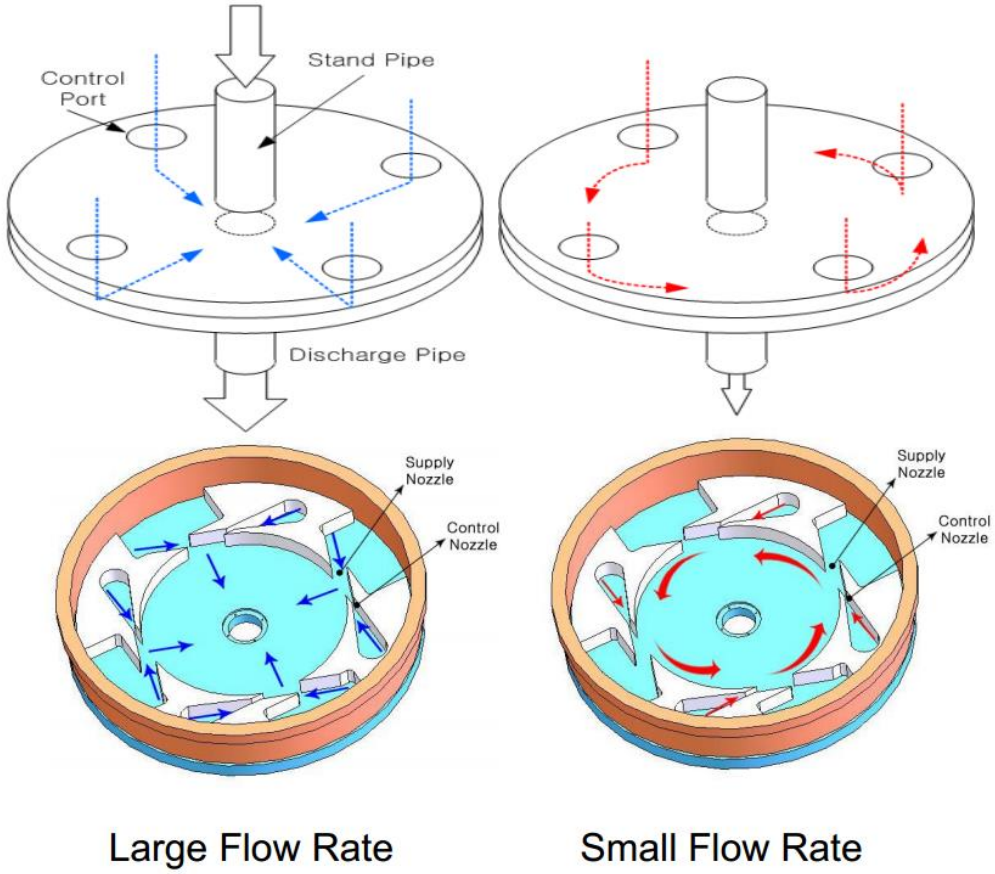
(b) High flow mode

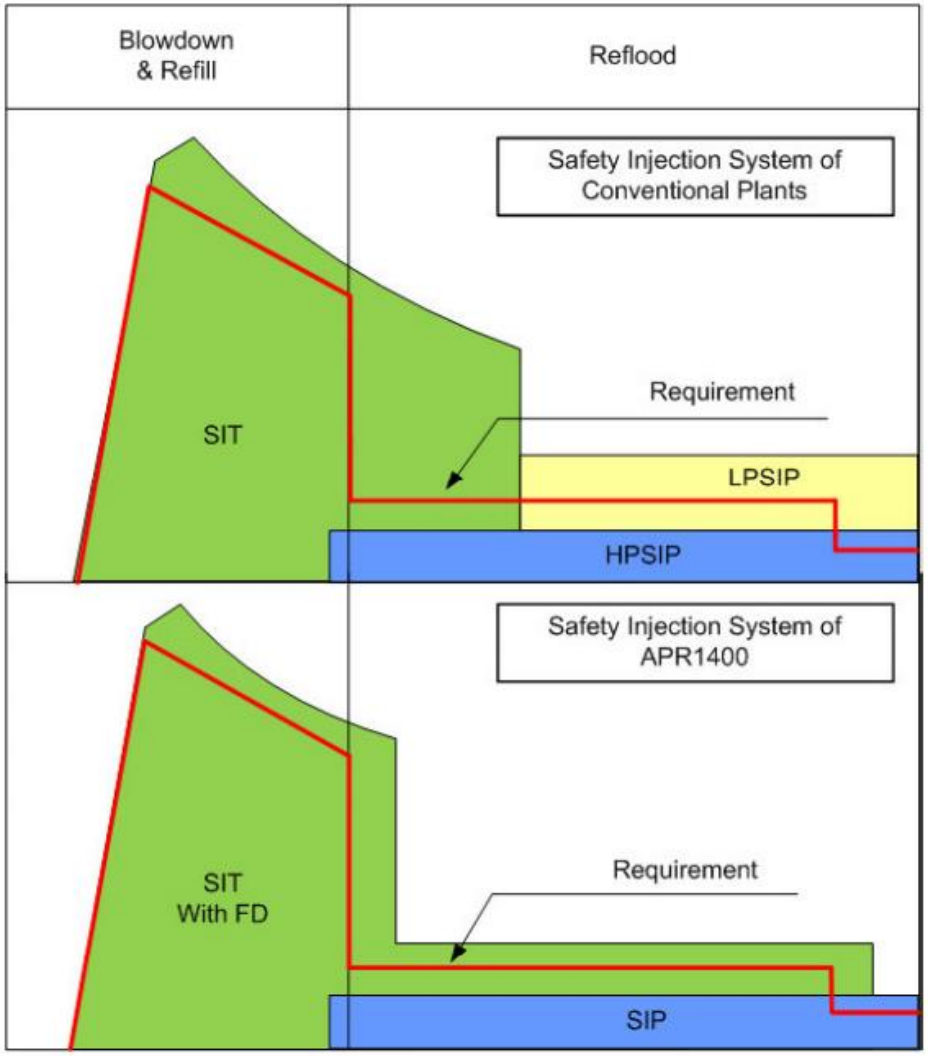




APR+ Safety Features

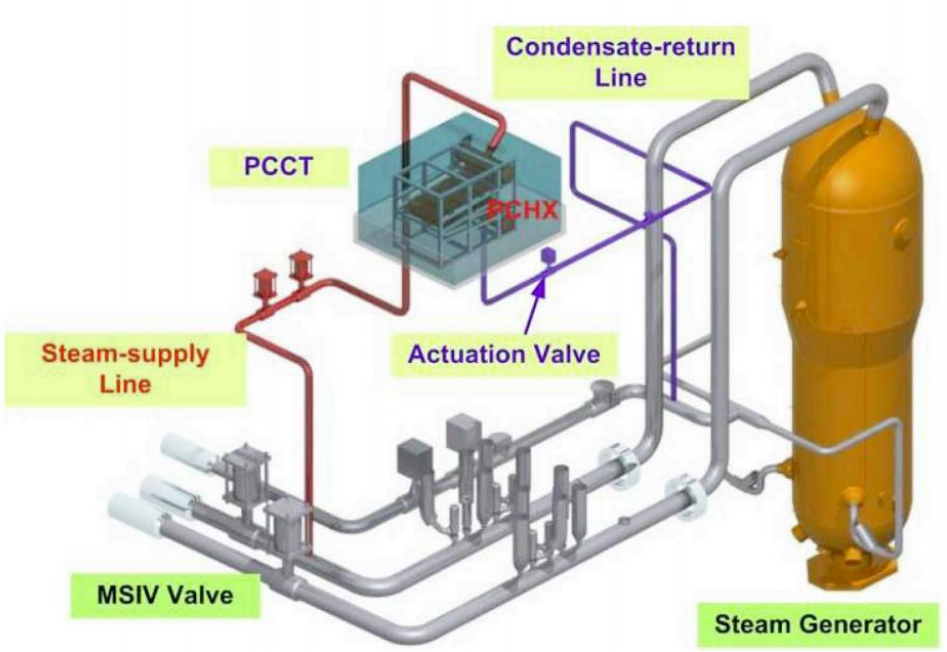
- New Safety Features
  - Fluidic device

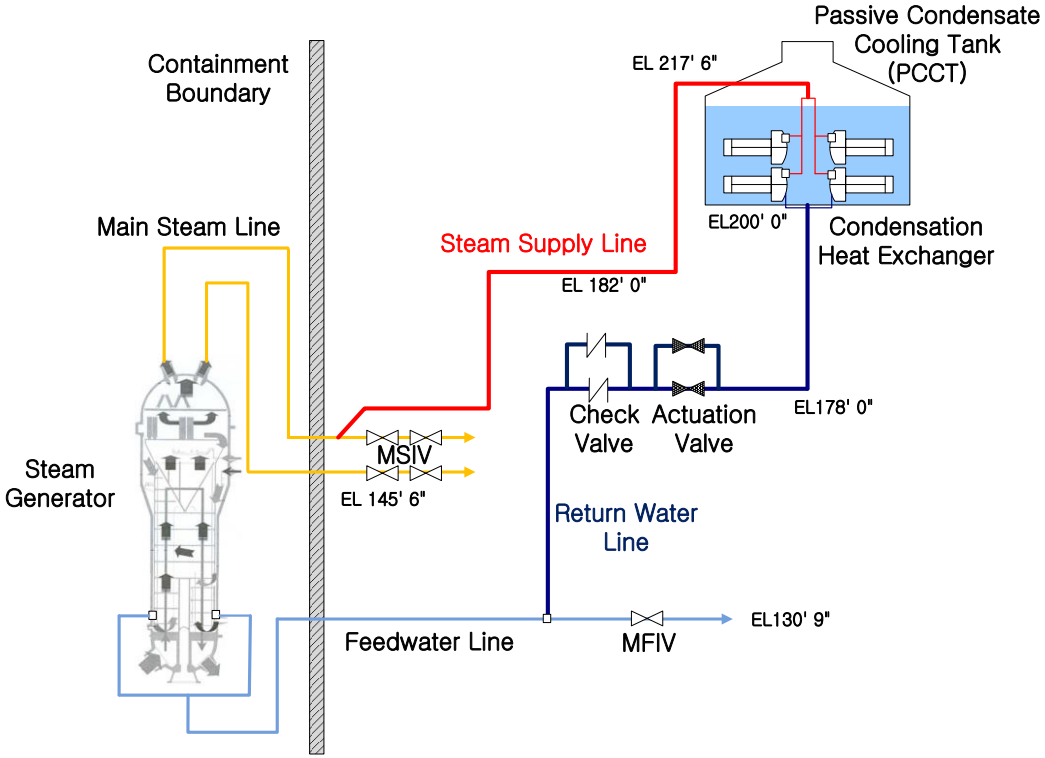




APR+ Safety Features

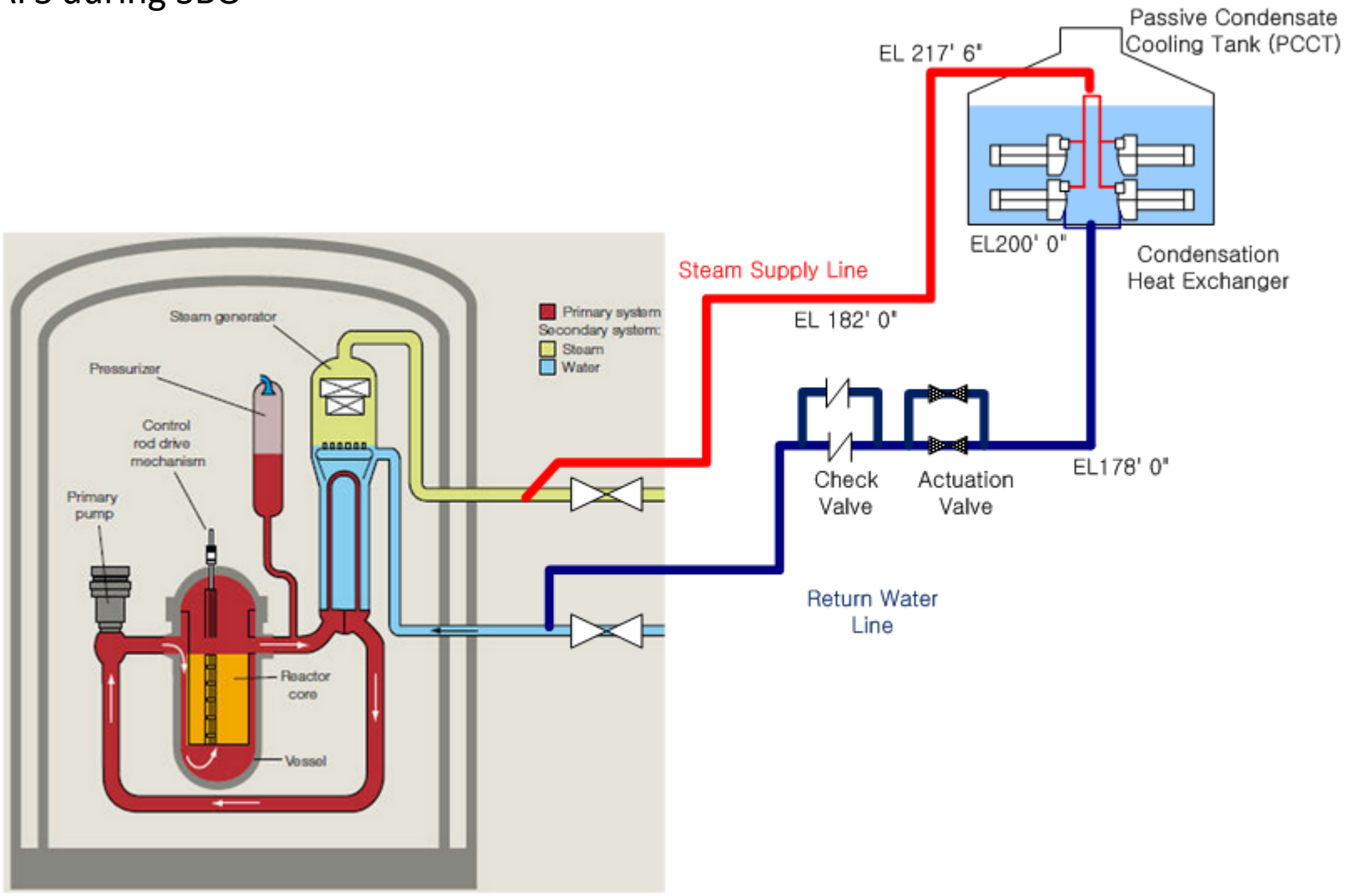
- New Safety Features
  - Passive Auxiliary Feedwater System (PAFS)
    - Replacement of previous active auxiliary feedwater system
    - Reduced core damage frequency
    - Independent two-trains for two steam generators
    - Driving force: gravity, free convection, condensation
    - Over 8 hours operation capability during SBO
    - 100% volume heat exchanger per SG





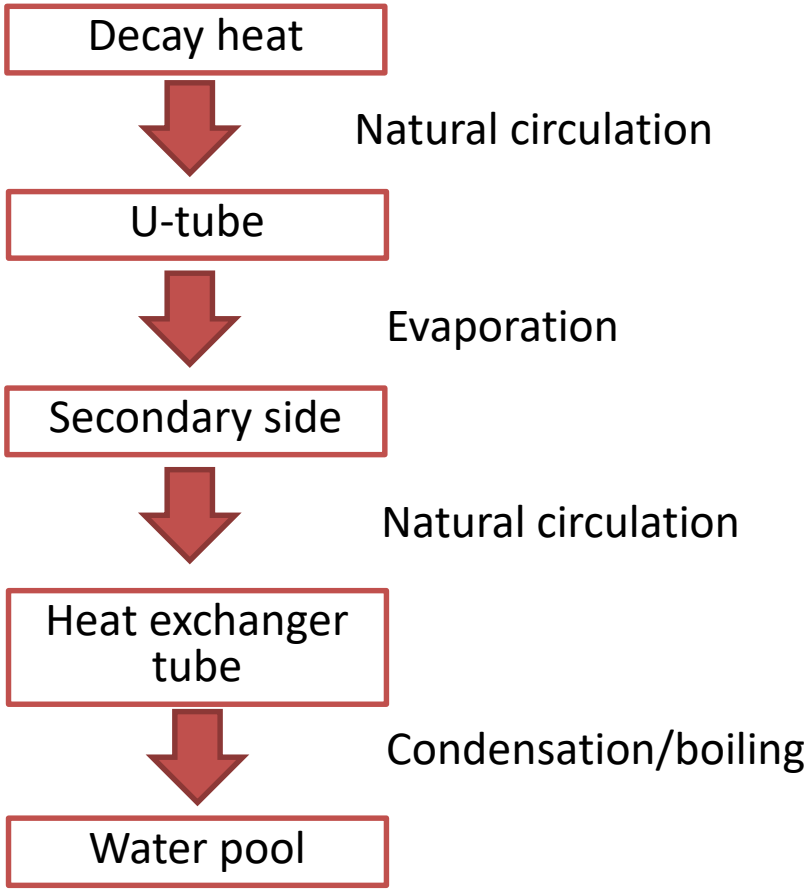
APR+ Safety Features

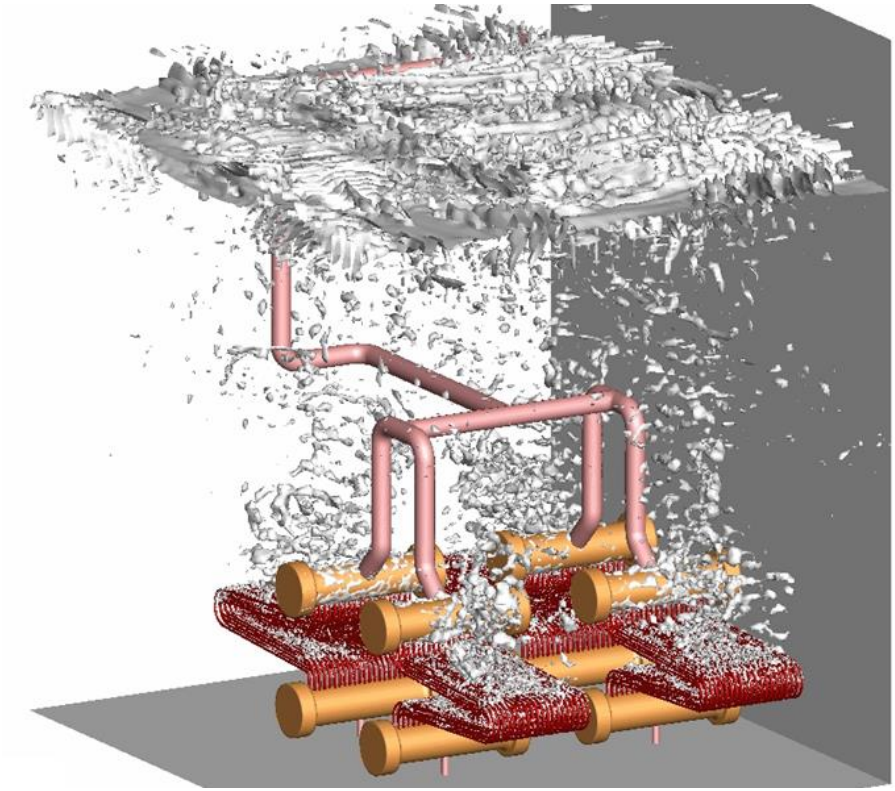
- New Safety Features
  - PAFS during SBO



APR+ Safety Features

- New Safety Features
  - During SBO

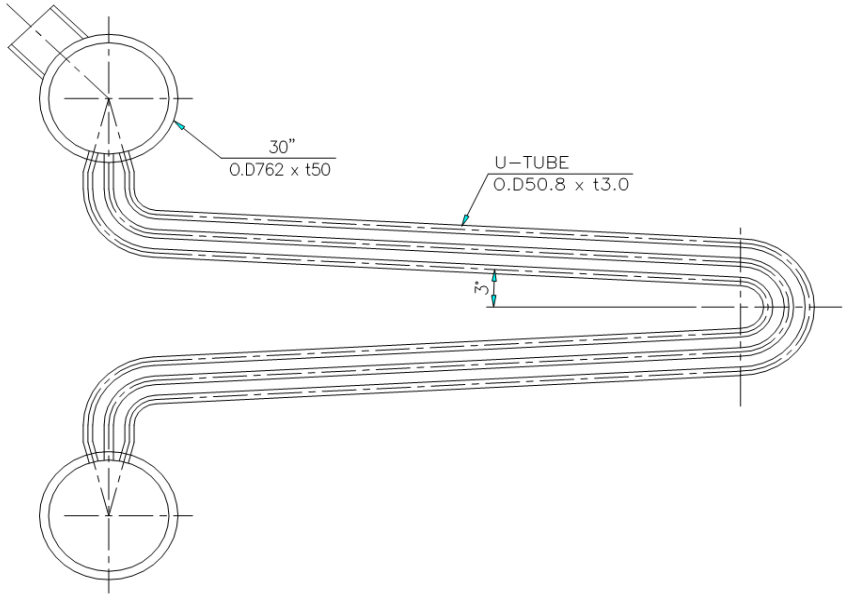




APR+ Safety Features

- New Safety Features
  - Safety issues
    - Condensation/boiling heat transfer rate
    - Water hammer ⇒ differential shock

Water Hammer (differential shock)



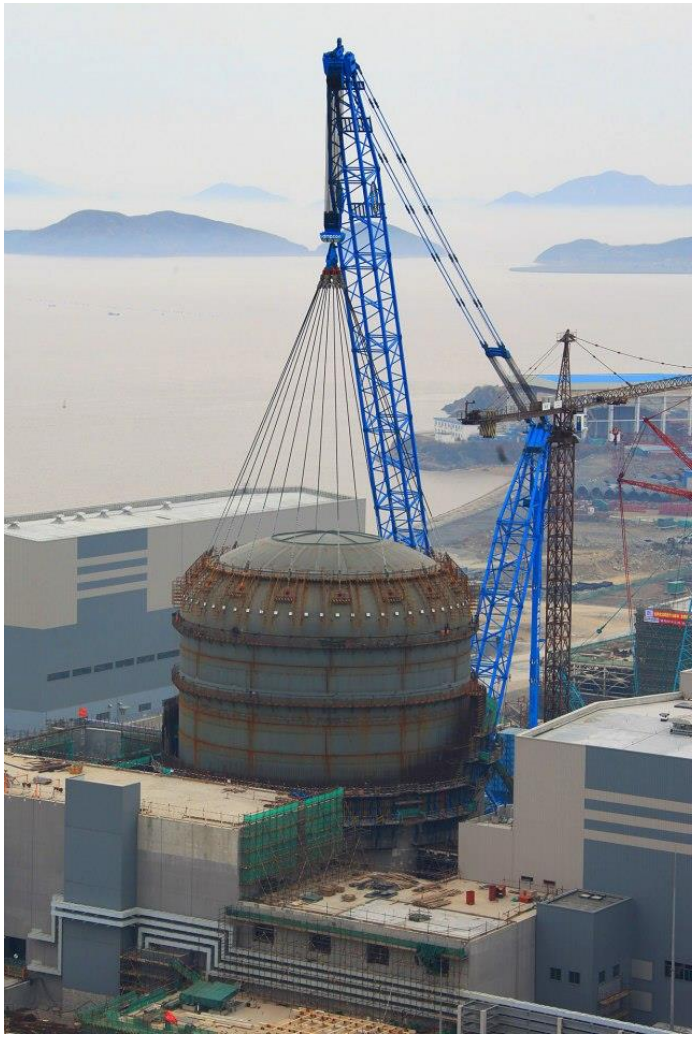
- Velocity of Steam is 10-100 times greater than the velocity of liquid
- Steam moving over the condensate will start manufacturing waves
- Waves will grow until they block the pipe completely forming a “Slug”
- Stopping only when suddenly impacted by equipment, tee, elbow, valve, or any bend in the piping

APR+ Safety Features

- New Safety Features
  - ECBD, Emergency Core Barrel Duct
  - Electrical 4 trains of safety injection system
  - FD+
  - PAFS

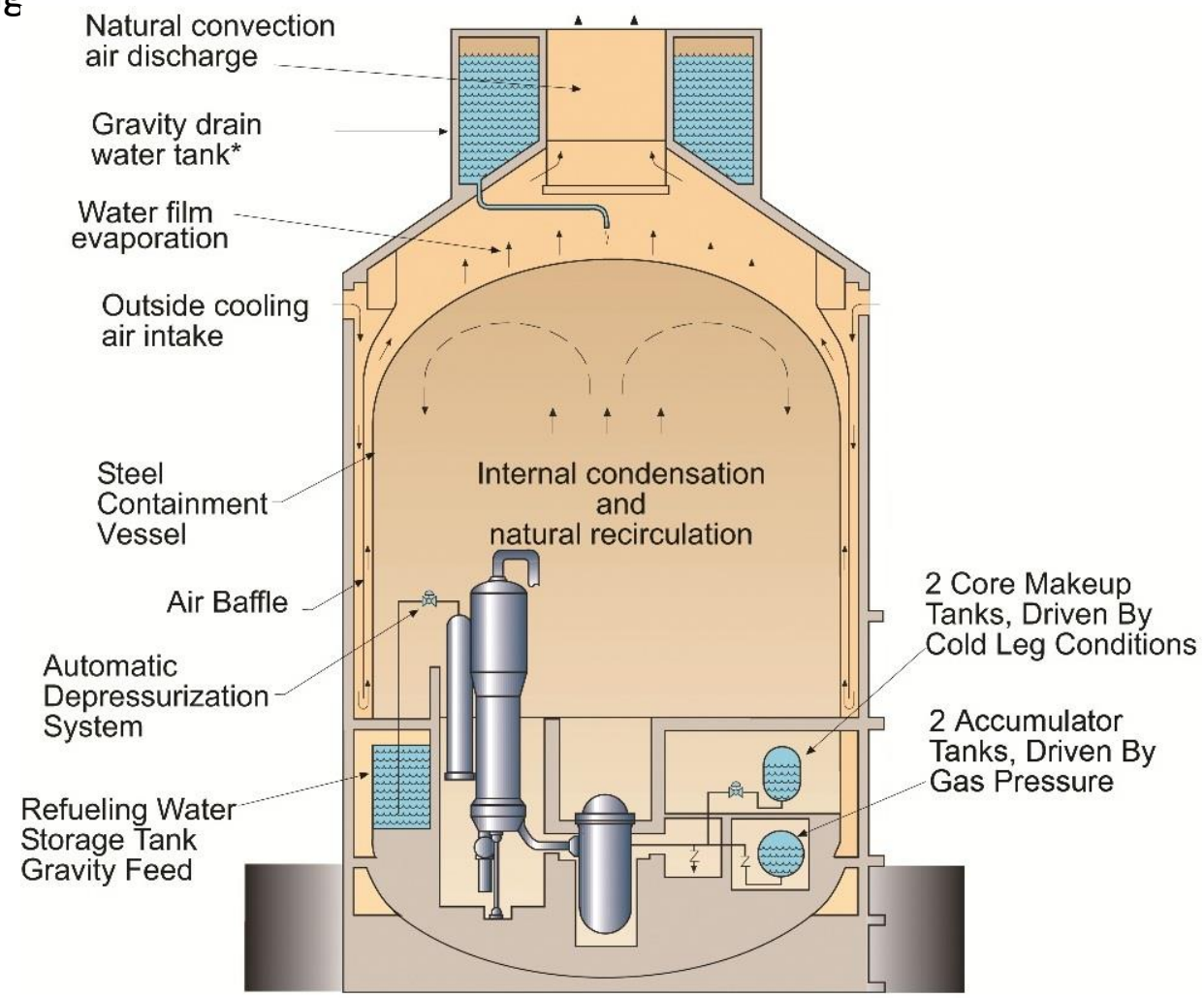
AP1000 Safety Features

- AP1000 Overall Specification
  - Developer: Westinghouse, USA
  - Thermal power: 3415 MWth
  - Electrical power: 1117 MWe
  - Design life: 60 years
  - Construction period: 36 months
  - Core damage frequency:
    - $<5 \cdot 10^{-7}$/year
  - Under construction
    - In China: 4 units
    - In US: 4 units



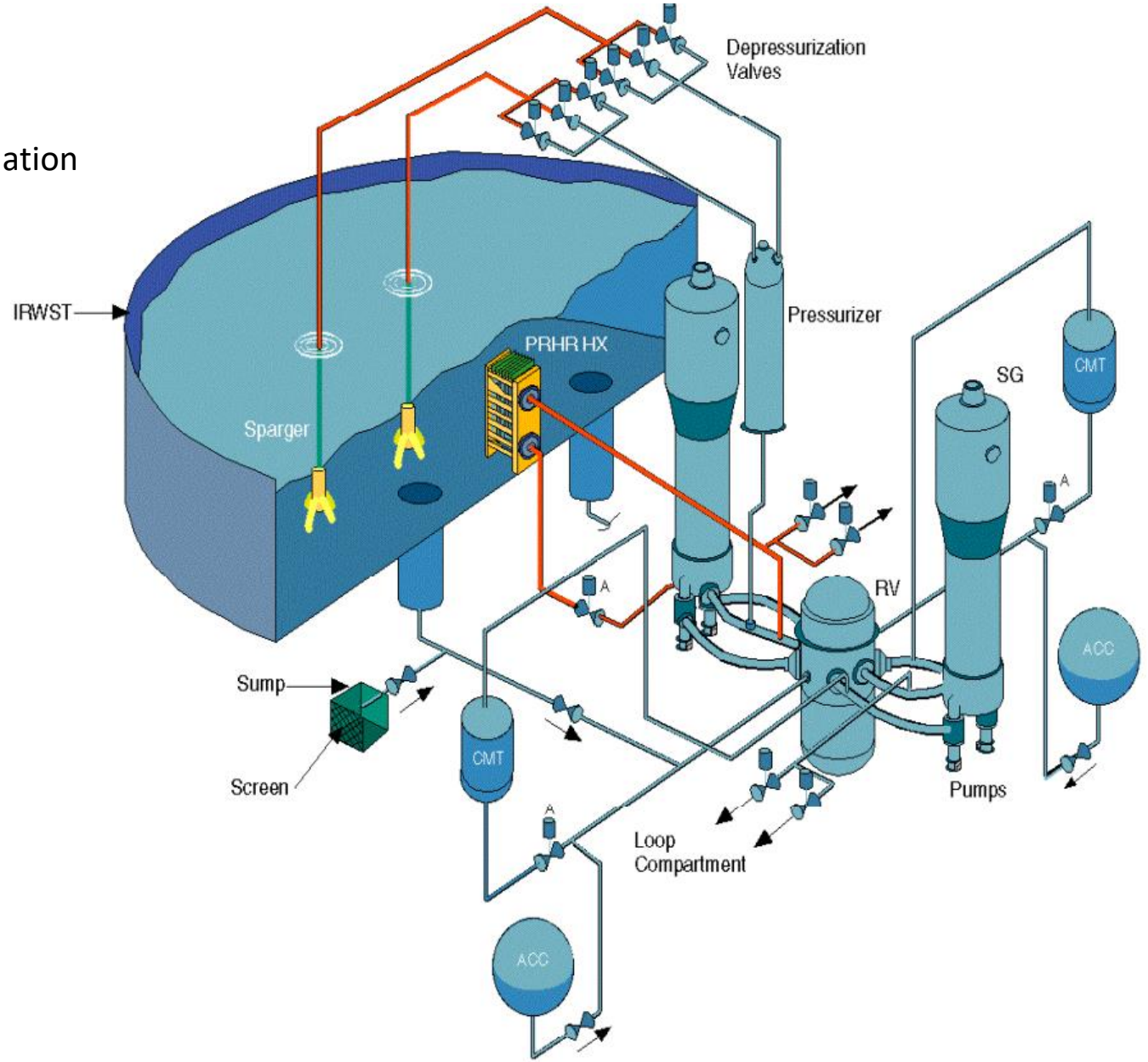
AP1000 Safety Features

- New safety features
  - PCC: Passive containment cooling
    - Steel containment
    - Concrete shield
    - Safety concern?
  - CMT: Core make-up tank
  - PRHR: Passive residual heat removal system
  - ADS: Automatic depressurization system
  - Accumulator tanks
  - IRWST: In-containment Refueling Water Storage Tank



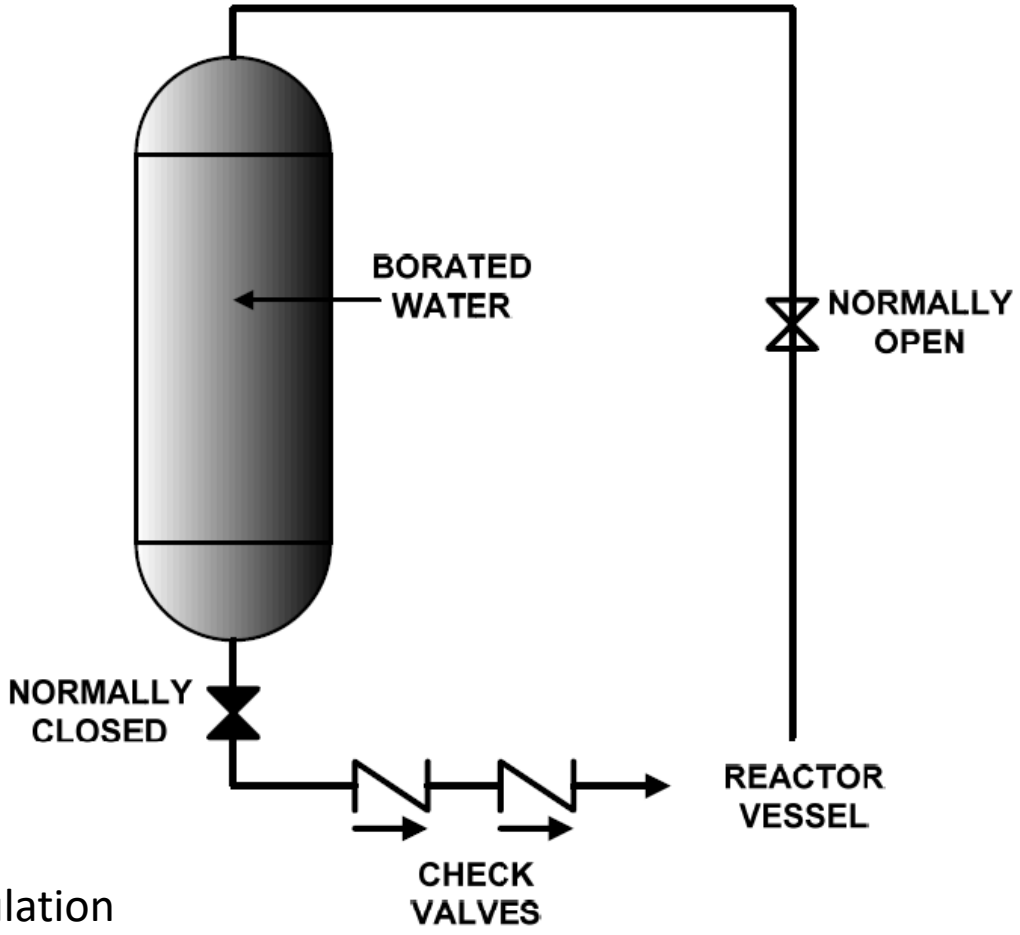
AP1000 Safety Features

- New safety features
  - CMT: Core make-up tank
    - Full pressure
    - Injection by natural circulation
    - Replace HPSI pumps
  - PRHR: Passive residual heat removal system
  - ADS: Automatic depressurization system
  - IRWST: In-containment Refueling Water Storage Tank



AP1000 Safety Features

- New safety features
  - CMT: Core make-up tank
    - Full pressure
    - Injection by natural circulation
    - Replace HPSI pumps
    - Filled with cold borated water
    - Connected at the top and bottom by balance lines.
    - Always at primary pressure
    - Natural circulation is established when valves are open
    - Cold borated water enters reactor
    - Hot primary water flows to CMT head.



High pressure safety injection by natural circulation

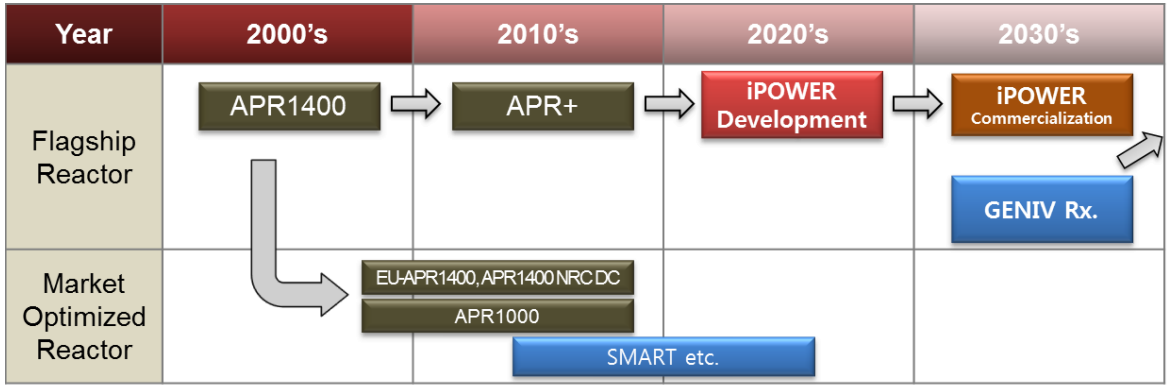
AP1000 Safety Features

- New safety features
  - SBO: Station Black-Out
    - Passive core cooling
    - Passive containment cooling
  - LOCA
    - Passive core cooling

❖ iPOWER (Innovative Passive Optimized Worldwide Economical Reactor)

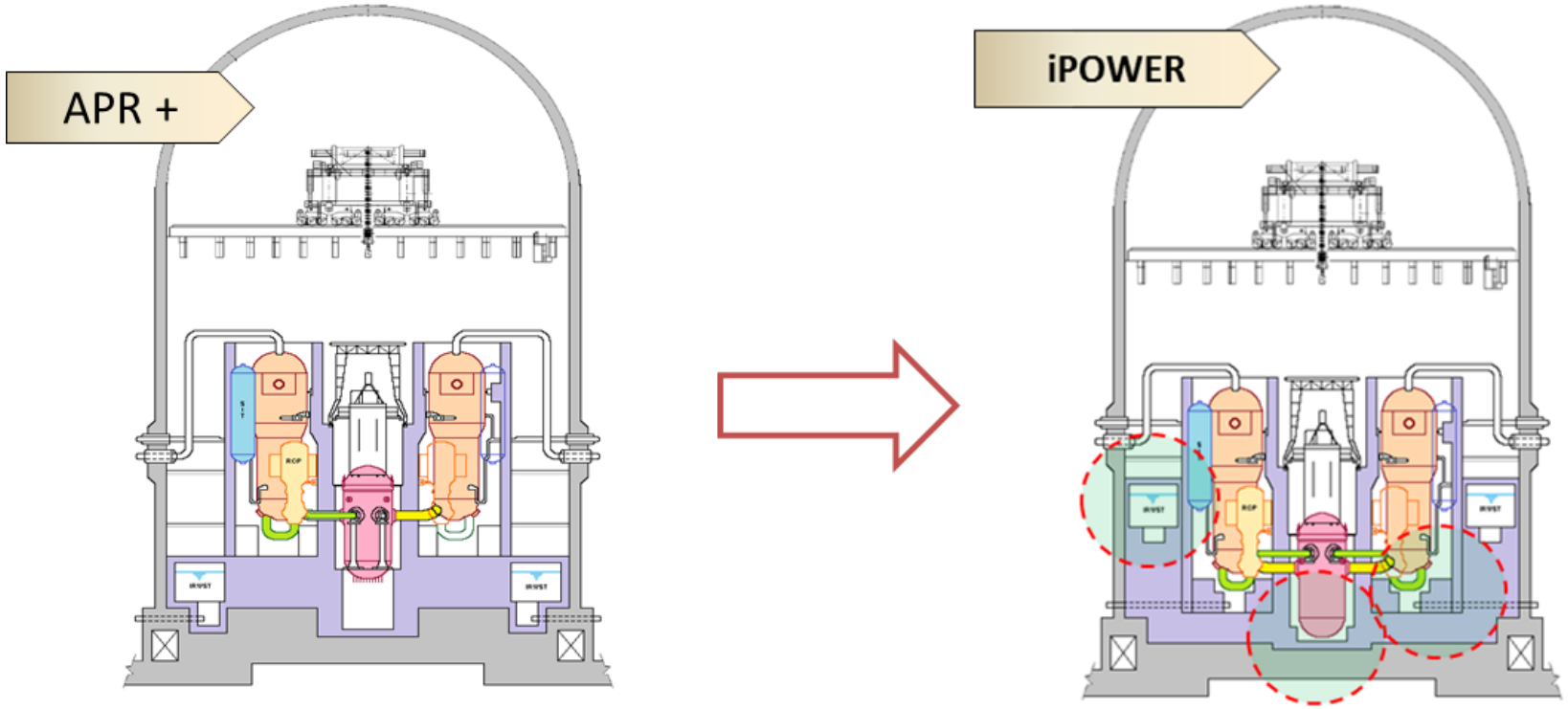
● Background

- To secure the competitiveness of Korean NPP in 2020's



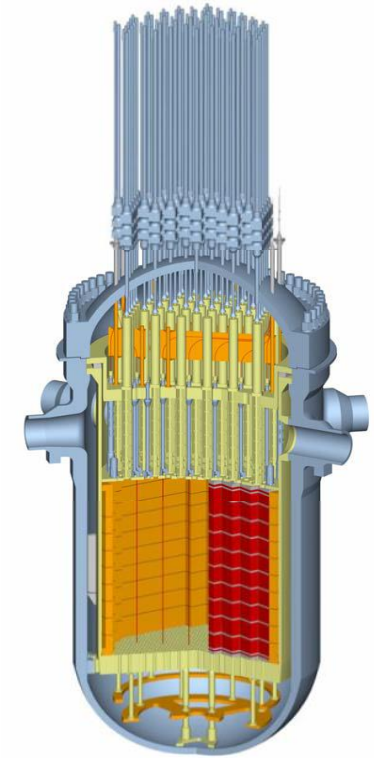
Category	Development Strategy
Design life	Longer than 80 years
Power output	1200~1500MWe (1250MWe)
CDF	< 1 X 10^{-7} /RY (5 X 10^{-8} /RY)
Containment Failure Frequency	~ 0 (<1 X 10^{-9} /RY 이하)
Operator's grace time	> 72 hours (1 week)
Safety System	Fully passive

- iPOWER (Innovative Passive Optimized Worldwide Economical Reactor)
  - RCS and General arrangement
    - 2-loop PWR with pre-stressed concrete containment
    - **Top-mounted ICI**
    - **Elevated IRWST for gravity feed**

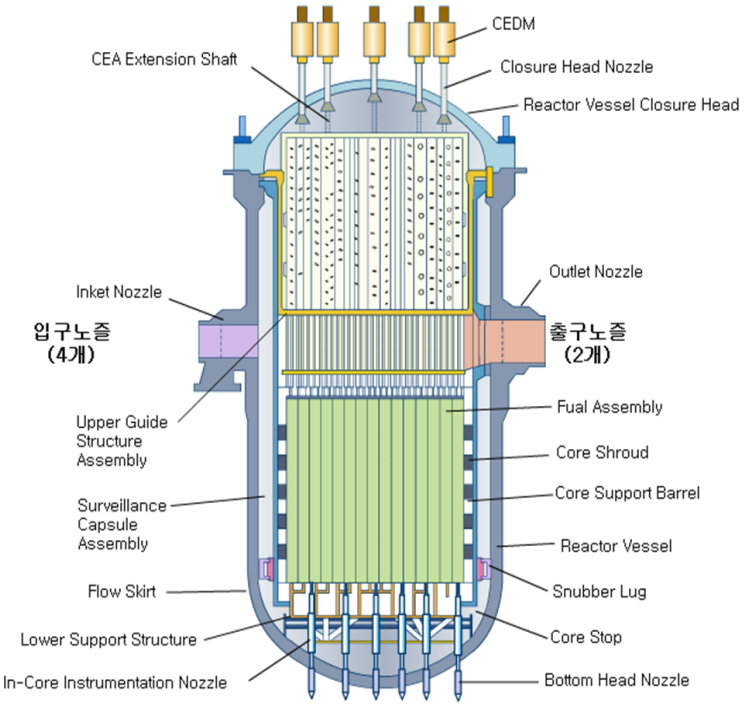


❖ iPOWER (Innovative Passive Optimized Worldwide Economical Reactor)

- **Top-mounted ICI**



Top Mounted ICI
(AP1000, EPR, APWR)

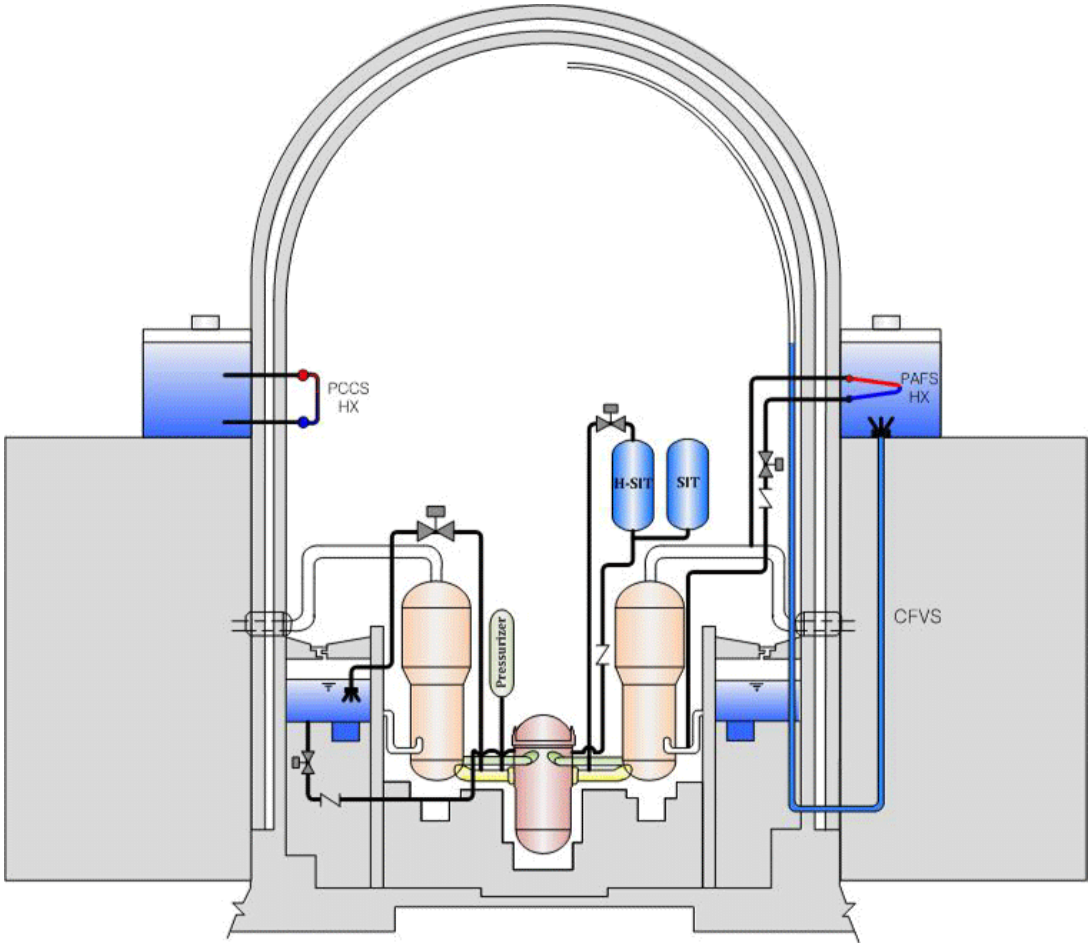


Bottom Mounted ICI
(APR1400, APR+)

iPOWER (Innovative Passive Optimized Worldwide Economical Reactor)

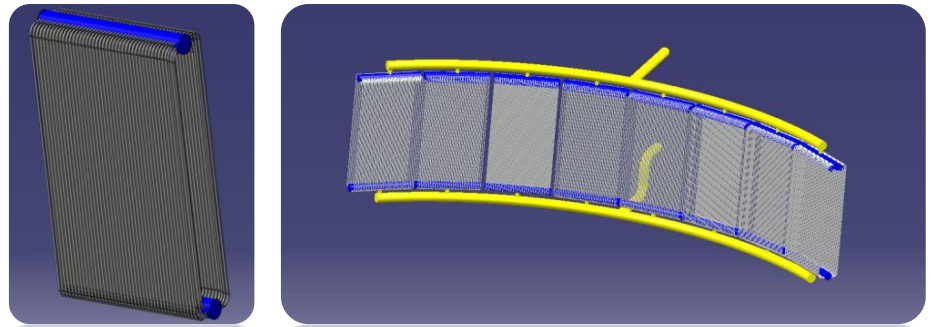
- Passive safety features
  - Passive containment cooling
  - Passive safety injection system
  - Passive residual heat removal system
  - Passive filtered ventilation system
  - Passive spent fuel pool cooling

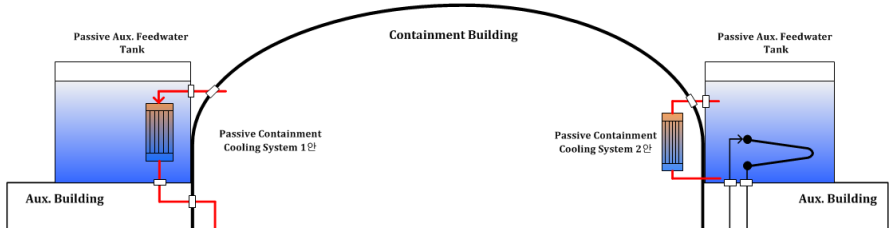
- No Pump
- No Electricity
- No Operator Action
- No Failure

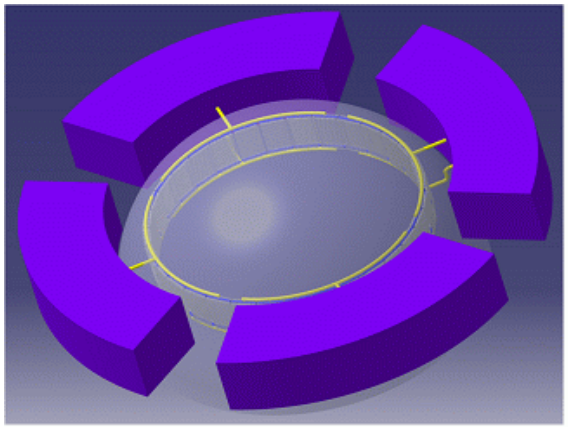


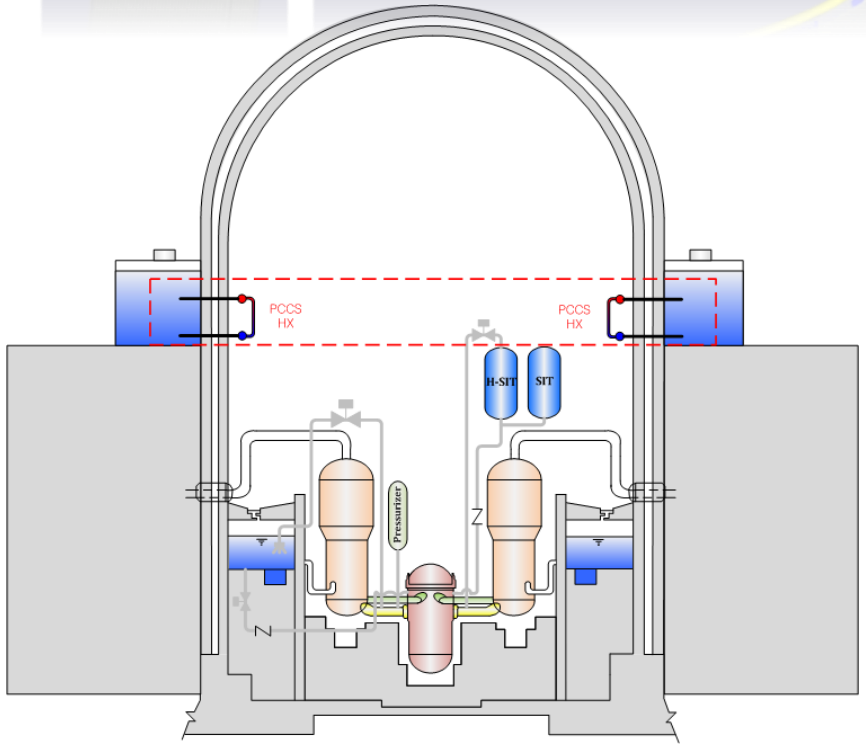
iPOWER (Innovative Passive Optimized Worldwide Economical Reactor)

- Passive safety features
  - Passive containment cooling
  - Mission time: > 72 hours (up to 1 week)
  - 4 independent trains (33% × 4)









❖ iPOWER (Innovative Passive Optimized Worldwide Economical Reactor)

● Passive safety features

▪ Passive safety injection system (PECCS: Passive Emergency core cooling system)

– Hybrid SIT

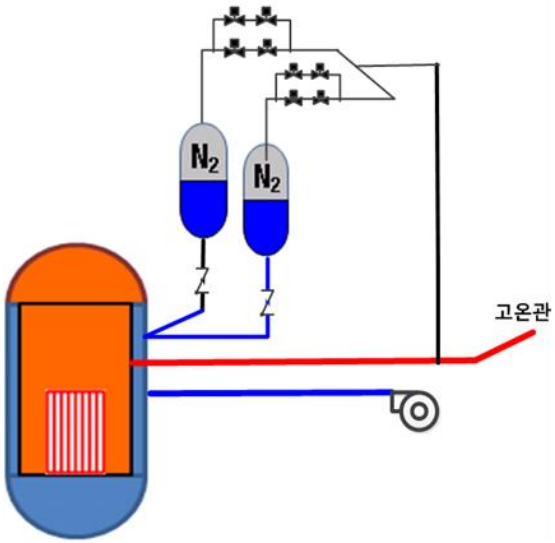
➢ Depressurization event (LOCA): conventional SIT

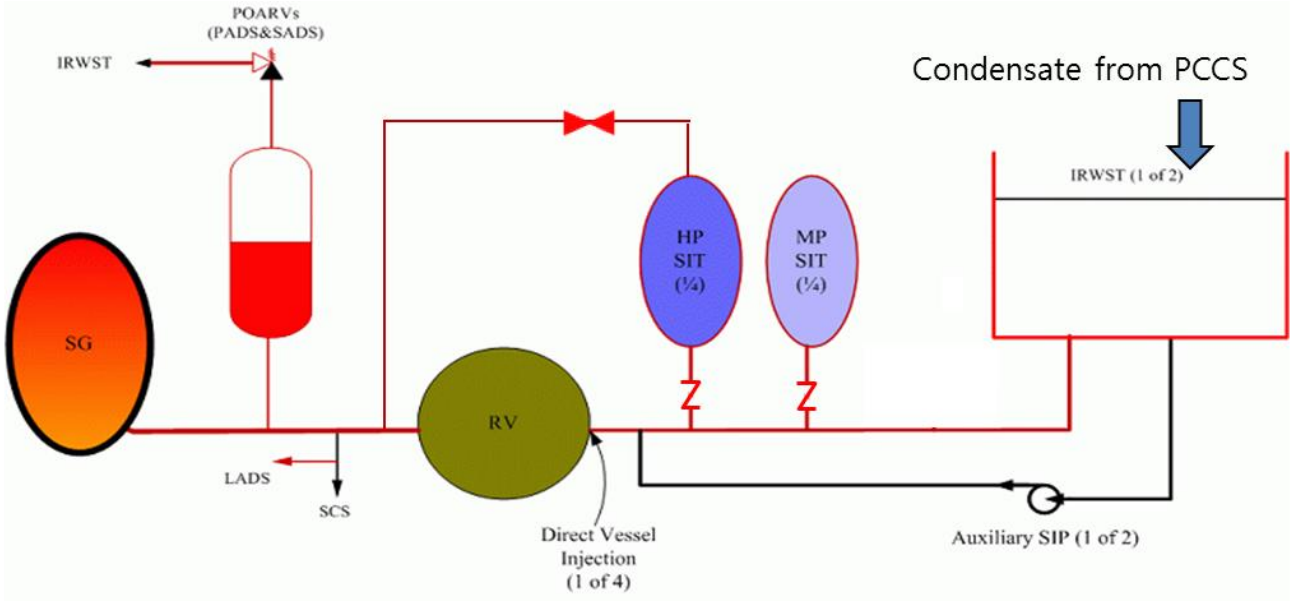
➢ High pressure event (SBO): pressure equalization between RCS and SIT

• Gravity feed of safety injection water

– Elevated IRWST

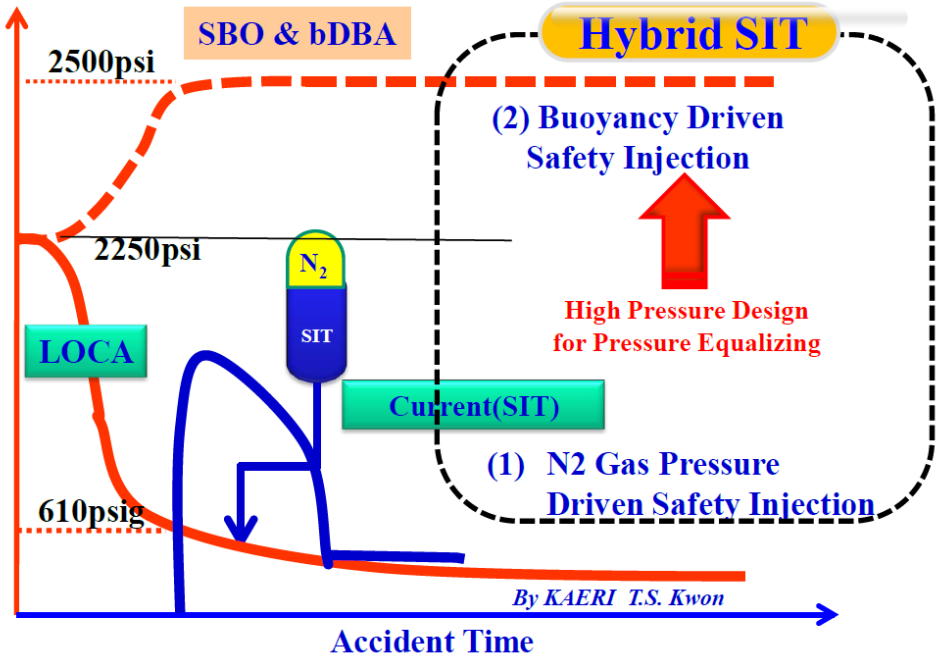
➢ Gravity driven low pressure safety injection

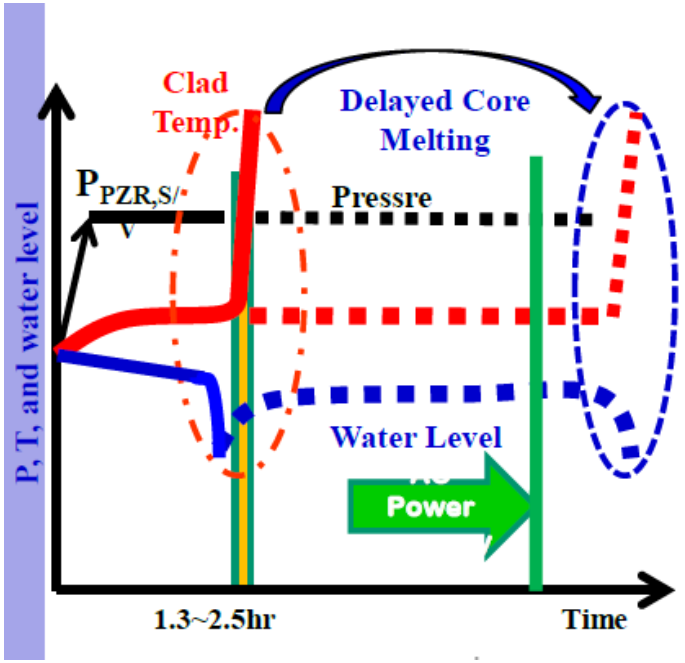




❖ iPOWER (Innovative Passive Optimized Worldwide Economical Reactor)

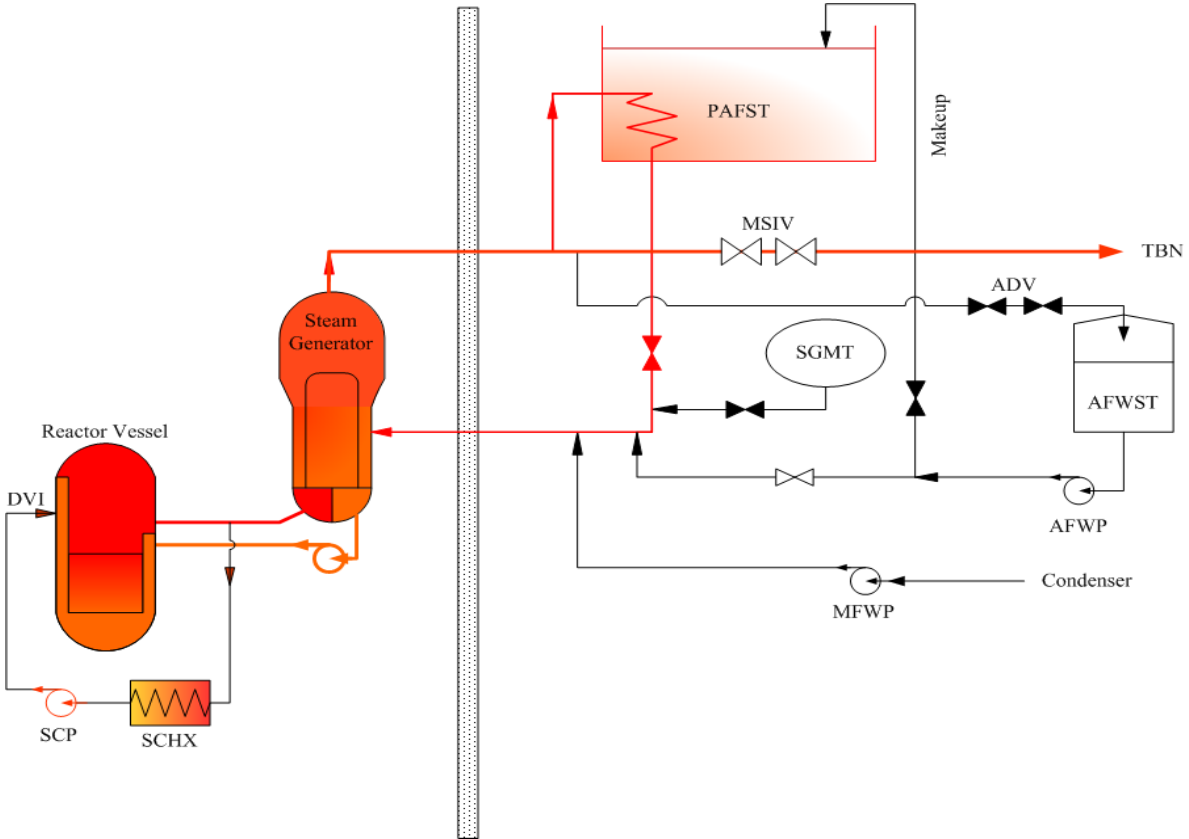
- Passive safety features
  - Passive safety injection system (PECCS: Passive Emergency core cooling system)
    - Hybrid SIT





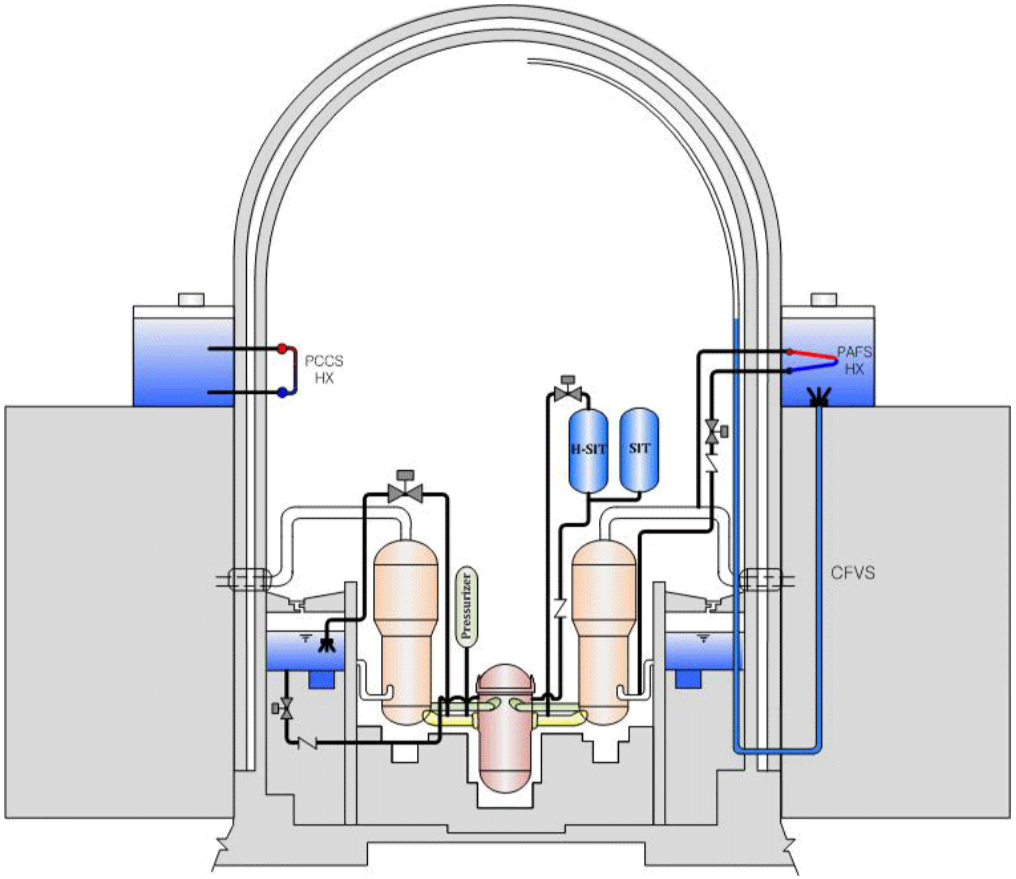
iPOWER (Innovative Passive Optimized Worldwide Economical Reactor)

- Passive safety features
  - Passive residual heat removal system
    - PAFS + auxiliary feedwater pump (for backup)
    - Shutdown Cooling System



iPOWER (Innovative Passive Optimized Worldwide Economical Reactor)

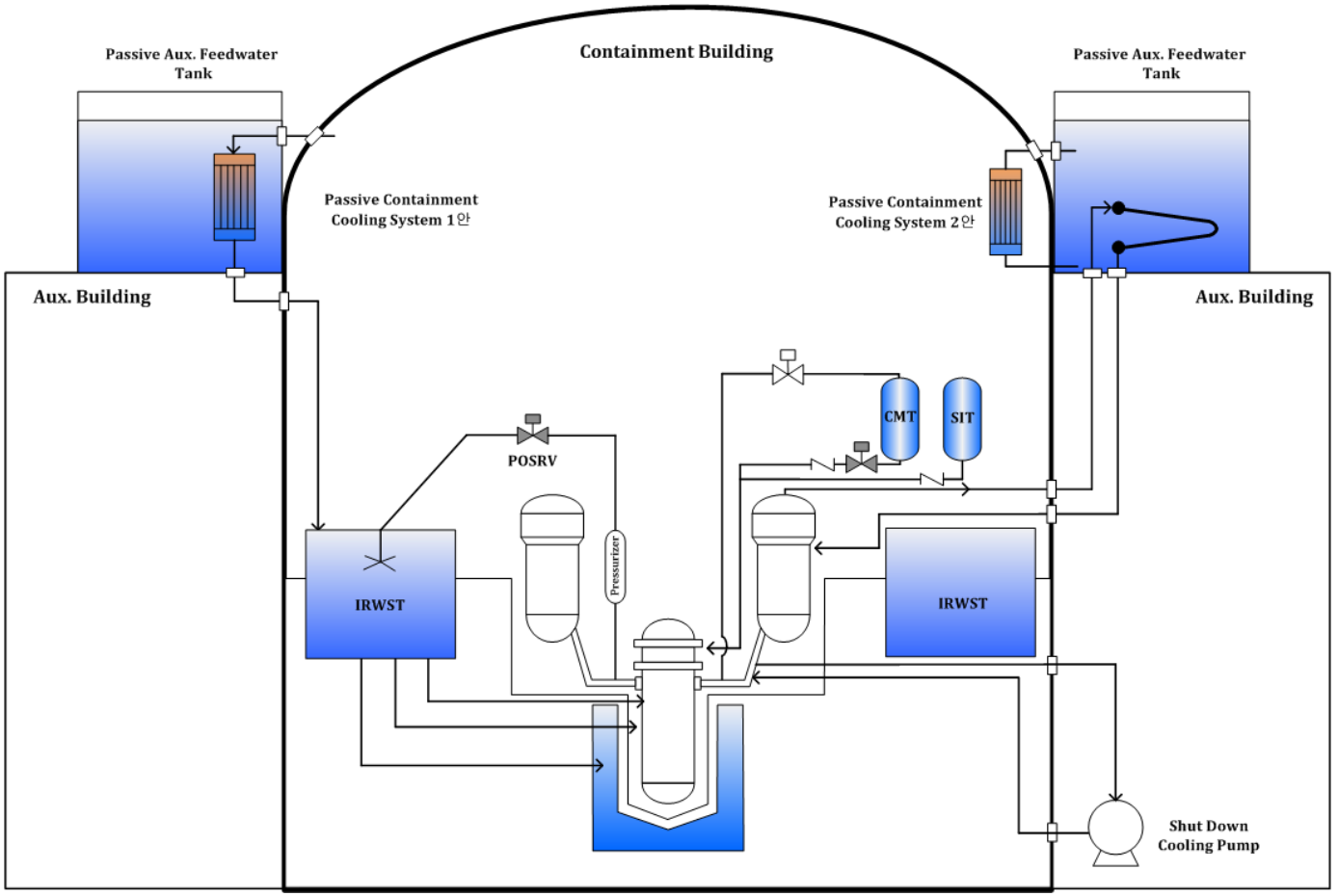
- Passive safety features
  - Passive filtered ventilation system
    - Containment filtered ventilation system
    - Water valve: zero failure probability
  - Passive spent fuel pool cooling
    - Water supply using PAFS water tank



❖ iPOWER (Innovative Passive Optimized Worldwide Economical Reactor)

● Passive safety features

▪ Passive IVR/ERVC

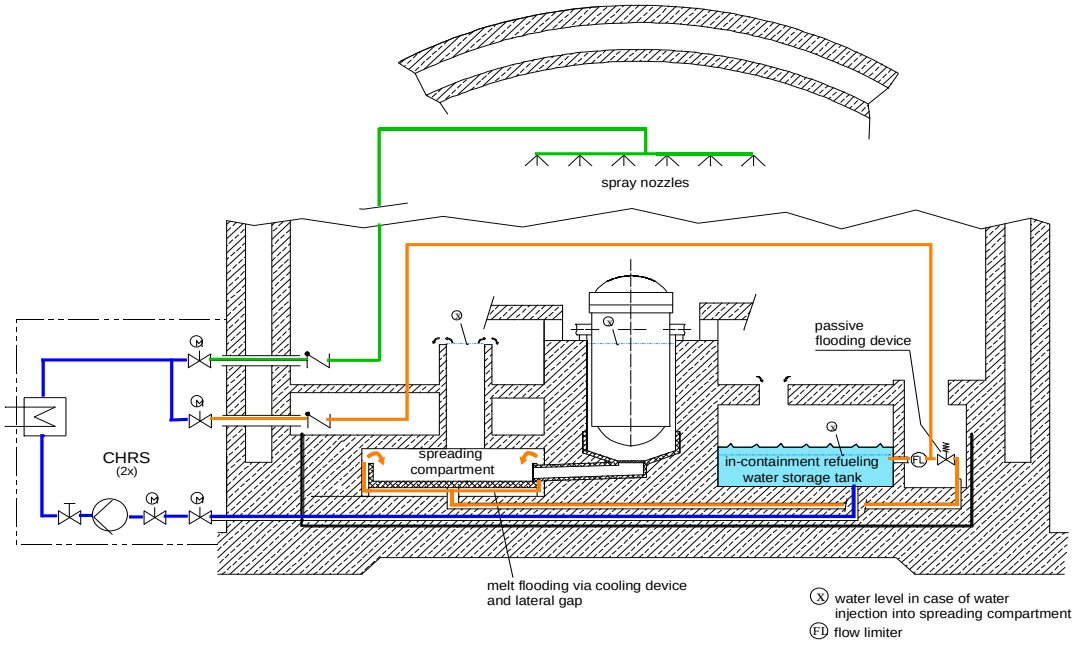


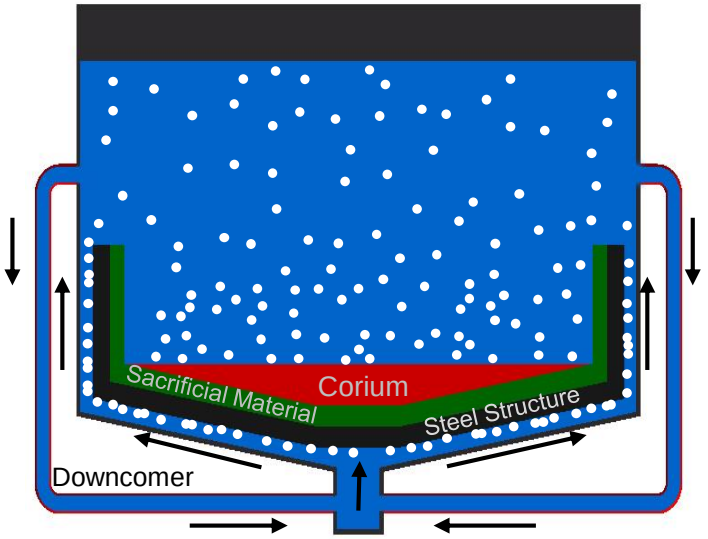
iPOWER (Innovative Passive Optimized Worldwide Economical Reactor)

Passive safety features

Core catcher

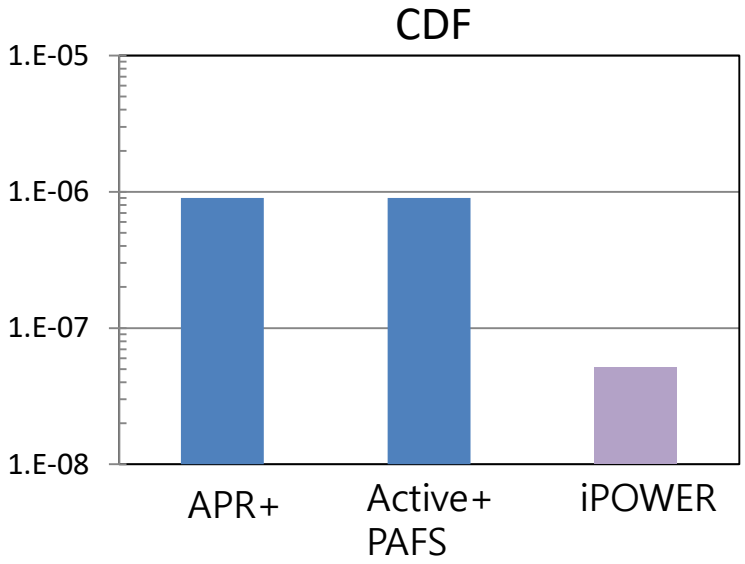
- A core catcher is a device provided to catch the molten core material (Corium) of a nuclear reactor in case of a nuclear meltdown and prevent it from escaping the containment building.
- Passive water supply using IRWST





❖ iPOWER (Innovative Passive Optimized Worldwide Economical Reactor)

- PSA
  - CDF < 1 X 10^{-7} /RY
  - LRF < 1 X 10^{-8} /RY
- Plan
  - Conceptual design: 2014~
  - Basic design: ~ 2022



추진 전략

From KHNP presentation material

- **핵심기술 개발 후 원자로 설계 착수**
  - **혁신적 설계 개념의 구현성 입증 필요**
- **기초연구 추진을 통한 인력양성 병행**
  - **APR1400 개발시의 학계의 CARR 역할 필요**