Review

❖ Containment spray system

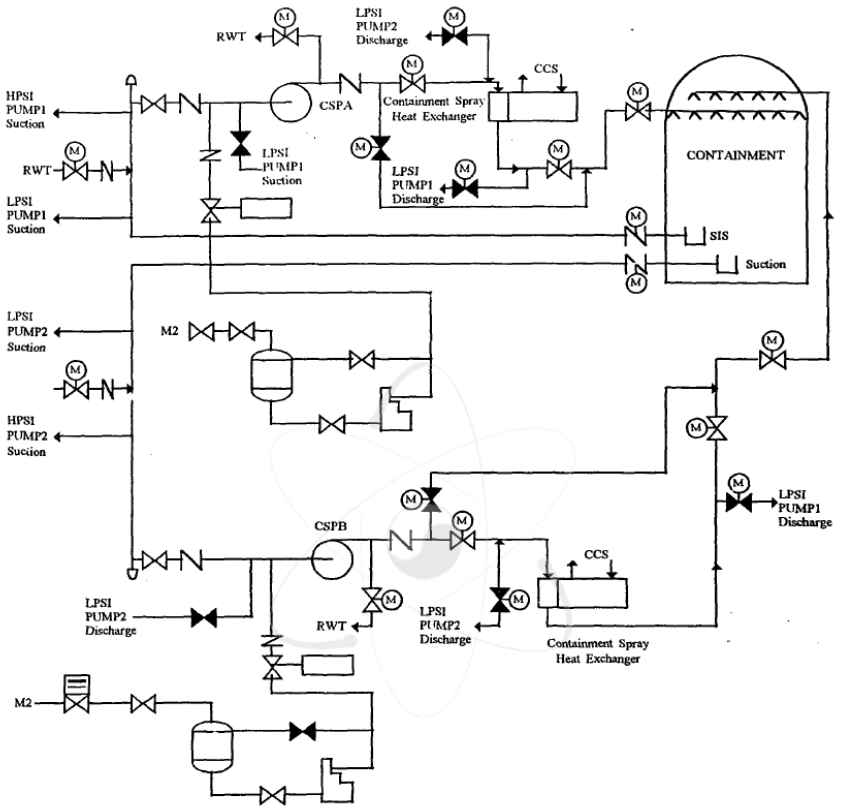
2. 설계기준

격납용기살수계통은 냉각재상실사고, 제어봉인출사고 또는 격납용기 내부에서 주증기관 또는 주급수관 파단 시 격납용기 대기로부터 핵분열물질과 열을 제거하도록 설계되어야 한다.

가. 피동적 열제거를 동시에 고려한 이 계통의 열제거 성능은 격납용기 설계압력 및 온도를 초과하지 않도록 하며, 위에서 언급한 사고 시 24시간 이내에 격납용기 압력을 계산된 최대압력의 최소 50%이하로 감소시키기에 충분하여야 한다.

나. 격납용기살수계통은 냉각재상실사고 이후 9시간 이내에 격납용기 재순환 집수조의 온도를 228°F(108.9℃) 이하로 감소시키도록 설계되어야 한다.

다. 격납용기살수계통은 비상노심냉각계통과는 독립적으로 열제거 기능을 수행하도록 설계되어야 한다.



The secondary function of the LPSI system is to complete the cool down of the RCS and to maintain the proper RCS temperatures while shutdown. This mode of operation is called shutdown cooling. In the shutdown cooling mode of operation, the LPSI system will take a suction from one of the two RCS hot legs and will discharge the hot RCS fluid to the shutdown cooling heat exchangers which are normally connected to the containment spray pump discharge header. The shutdown cooling heat exchangers transfer the RCS decay heat to the component cooling water (CCW) system. From the outlet of the shutdown cooling heat exchangers, the water is returned to the RCS via the normal LPSI discharge piping.

❖ Containment spray system

The secondary function of the LPSI system is to complete the cool down of the RCS and to maintain the proper RCS temperatures while shutdown. This mode of operation is called shutdown cooling. In the shutdown cooling mode of operation, the LPSI system will take a suction from one of the two RCS hot legs and will discharge the hot RCS fluid to the shutdown cooling heat exchangers which are normally connected to the containment spray pump discharge header. The shutdown cooling heat exchangers transfer the RCS decay heat to the component cooling water (CCW) system. From the outlet of the shutdown cooling heat exchangers, the water is returned to the RCS via the normal LPSI discharge piping.

11.2.3.3 Shutdown Cooling Heat Exchangers

The shutdown cooling heat exchangers are used to remove core decay heat during plant shutdowns and in cold shutdown. The heat exchangers are designed to maintain the RCS at the refueling temperature (approximately 140°F) 27 1/2 hours after shutdown from an extended period of full power operations. The heat exchangers also cool the containment spray water during containment spray operations.

Safety injection mode

- Injection mode
  - HPSI : 안전주입신호로 기동, 124 bars
  - SIT: 42~44 bars
  - LPSI: 안전주입신호로 기동, 14 bars

- Short-term recirculation mode
  - RWT 저수위 (7.6 %)
  - HPSI: cold leg injection
  - LPSI 정지

- Long-term recirculation mode
  - 안전주입 발생 후 4시간 이내에 정지냉각 불만족 시
  - HPSI: simultaneous injection

안전주입신호(SIAS)			
작 동 신 호	설 정 치	동시성	비고
격납용기 고-압력	133㎝H_2O	2/4	
가압기 저-압력	124kg/cm^2a	2/4	WR
수 동	수동 스위치	2/4	

저압안전주입계통은 재순환작동신호(RAS)가 발생할 때까지 계속 주입모드에서 운전된다. 재순환작동신호가 발생되면 저압안전주입펌프는 자동으로 정지되고 최소 재순환 유량관 역시 자동 격리된다. 재순환작동신호 발생과 함께 저압안전주입펌프가 자동 정지되는 것은 다음 두 가지 이유 때문이다. 첫째로, 저압안전주입계통은 더 이상 노심냉각을 위해 필요하지 않다. 이는 재순환 작동과 함께 고압안전주입의 재순환 운전으로 노심을 충분히 냉각할 수 있도록 설계하였기 때문이다.

또 다른 이유는 저압안전주입계통을 정지냉각계통으로 활용하기 위함이다. 조건만 허락한다면 가능한 한 빨리 정지냉각계통을 운전하여 발전소 안전을 확보한다. 그러나 재순환작동신호 후에도 필요하다면 여전히 저압안전주입계통으로써 운전이 가능하다. 운전원은 파단에 따라 정지된 펌프를 재기동 할 수 있다. 이때 주의해야 할 것은 재순환작동신호와 함께 저압안전주입계통이 그 흡입수원을 안전주입계통 재순환 집수조에서 취하고 있다는 점이며, 또한 최소 유량관이 격리되는 것은 격납용기 내의 재순환집수조로부터 재장전수탱크로의 역류를 막아 냉각수재고량을 최대한 확보하기 위한 설계이다.

SAFETY FEATURES OF ADVANCED NUCLEAR REACTORS

Contents

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

APR+ Safety Features

APR+ Overall Specification (project name)

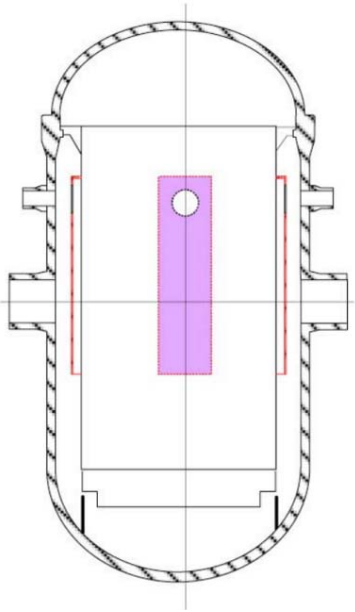
- Developer: KHNP
- Thermal power: 4290 MWth
- Electrical power: 1505 Mwe
- Design life: 60 years
- Construction period: 36 months
- Core damage frequency:
  - $<1.0 \cdot 10^{-6}$/year
- Construction plan
  - Shin Kori 7
  - 2022/2023 ?

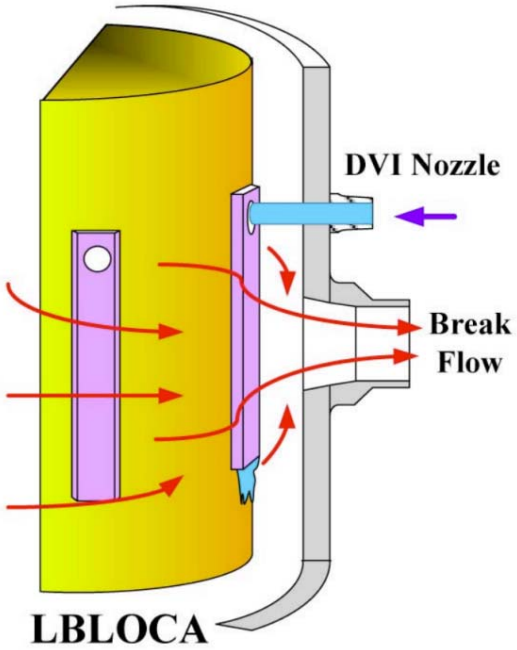
Primary Characteristics

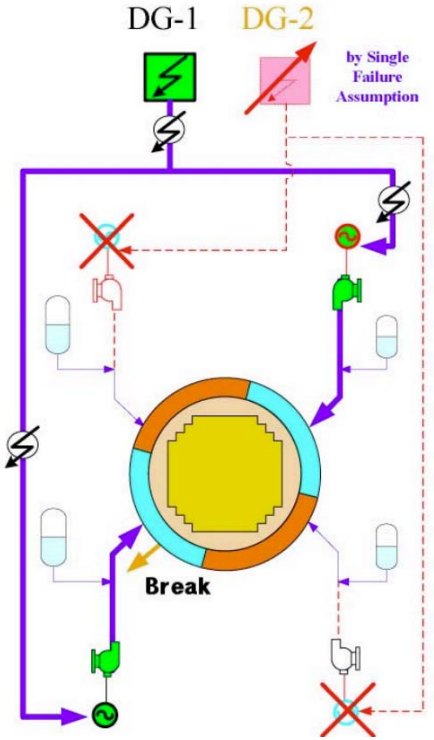
Category	APR1400	APR+
Developer	KHNP	KHNP
Power output (MWe)	1,400	1,500
Design life	60 years	60 years
Safe Shutdown Earthquake (SSE)	0.3 g	0.3 g
Core Damage Frequency (CDF)	6.22 E-6	1.0 E-6
LOOP (RCP/SG)	2 Loop (4/2)	2 Loop (4/2)
Fuel Assembly ▪ Number of fuel assemblies ▪ Fuel assembly type ▪ Height 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

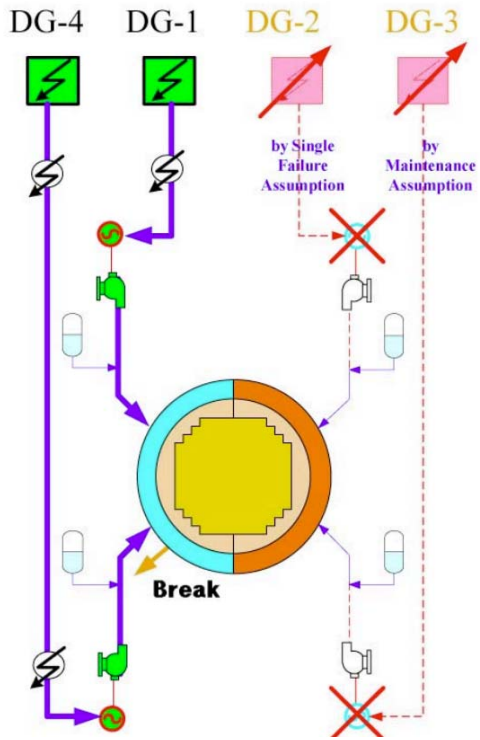
APR+ Safety Features

- 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



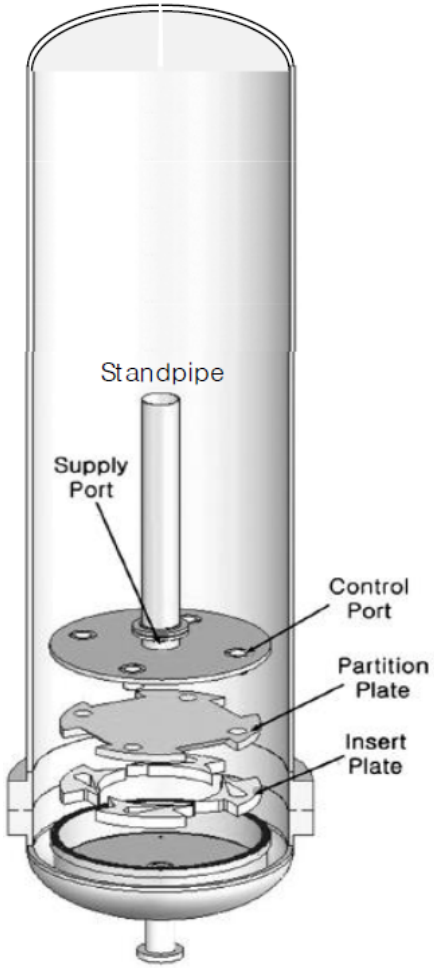




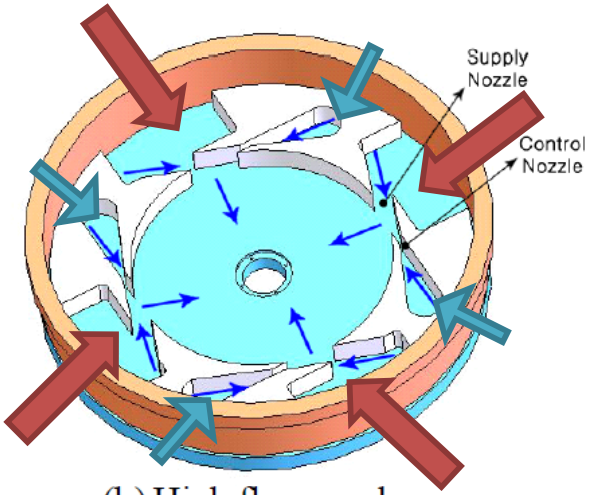


APR+ Safety Features

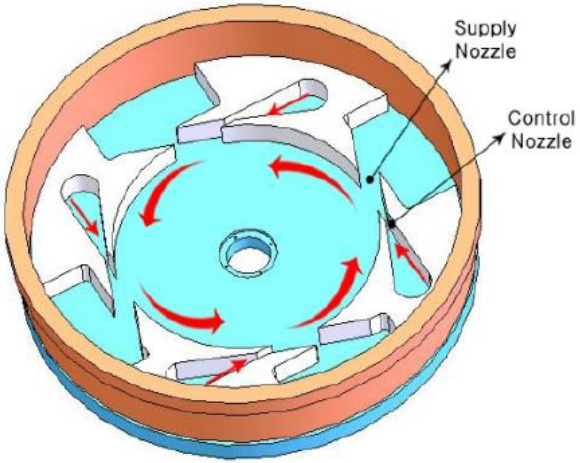
- New Safety Features
  - Fluidic device

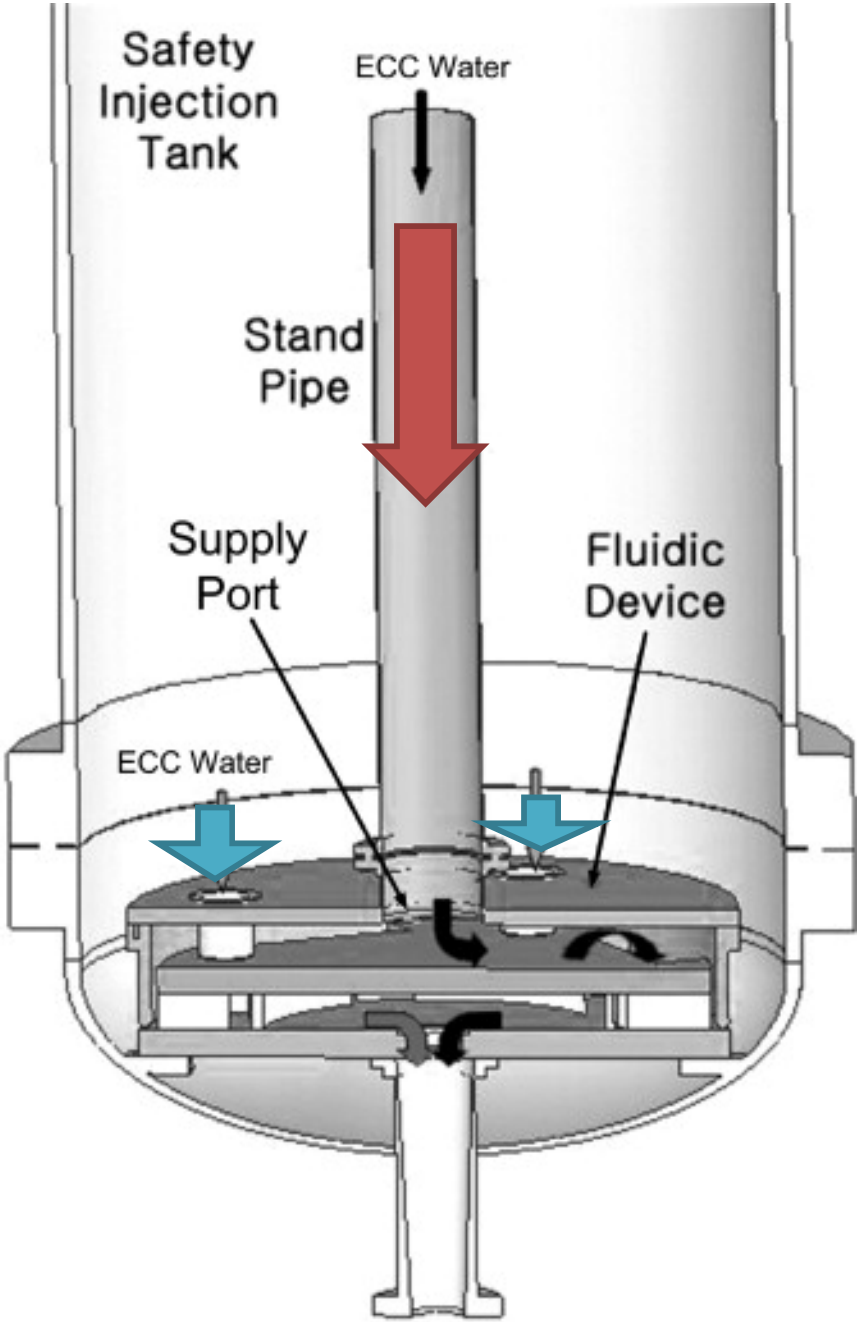


Vortex Chamber



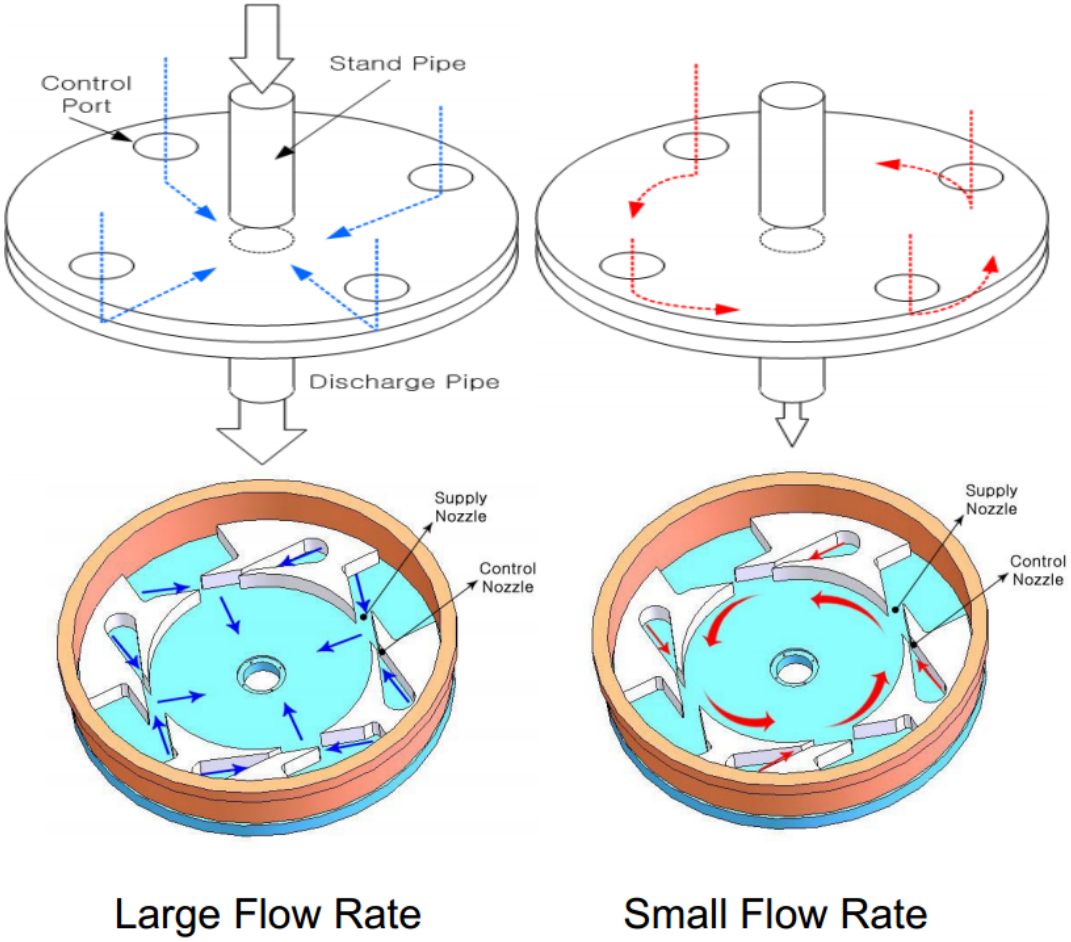
(b) High flow mode

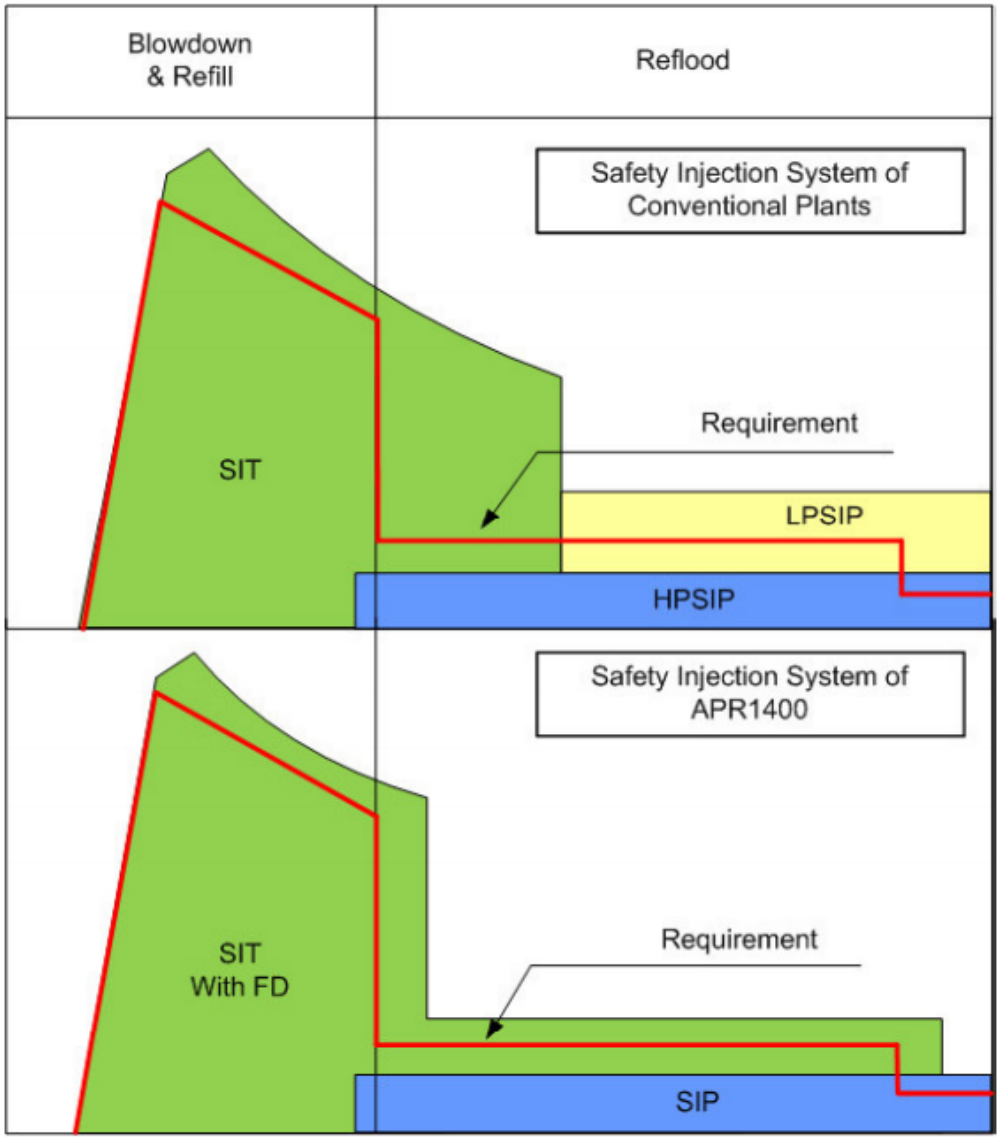




APR+ Safety Features

- New Safety Features
  - Fluidic device

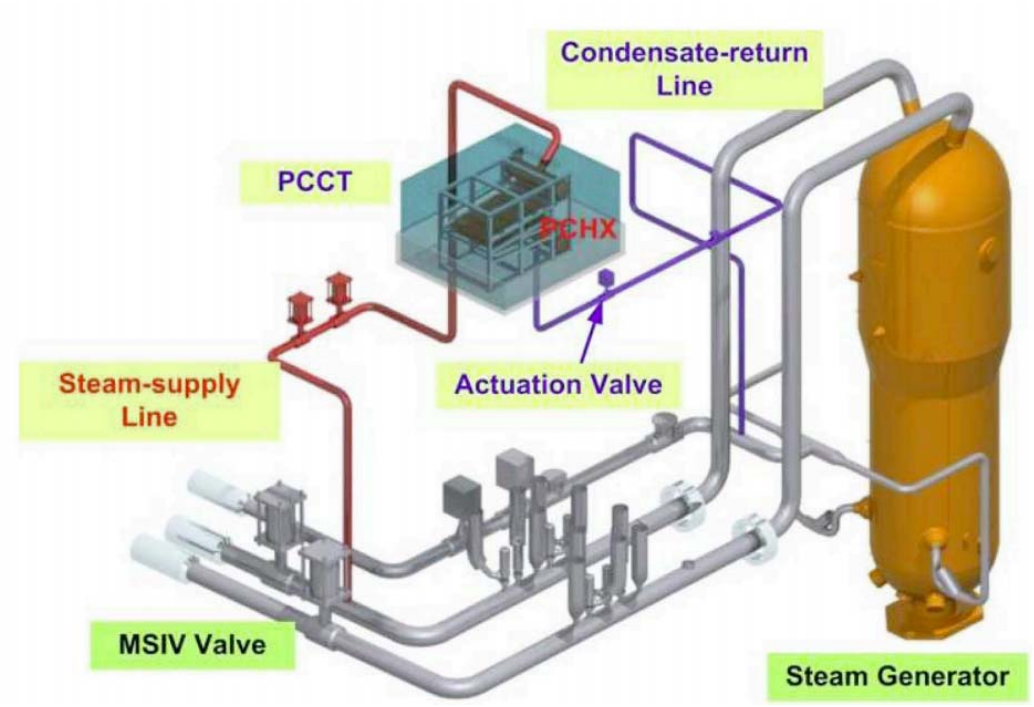


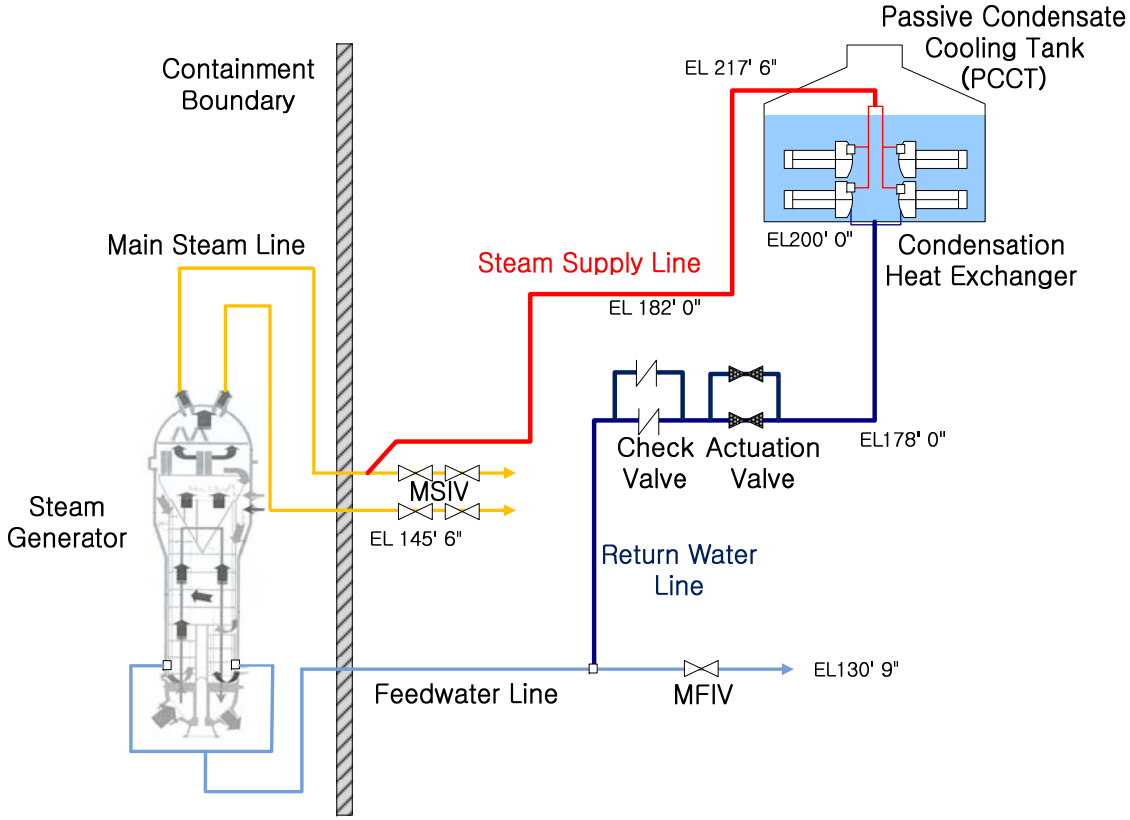


APR+ Safety Features

- 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

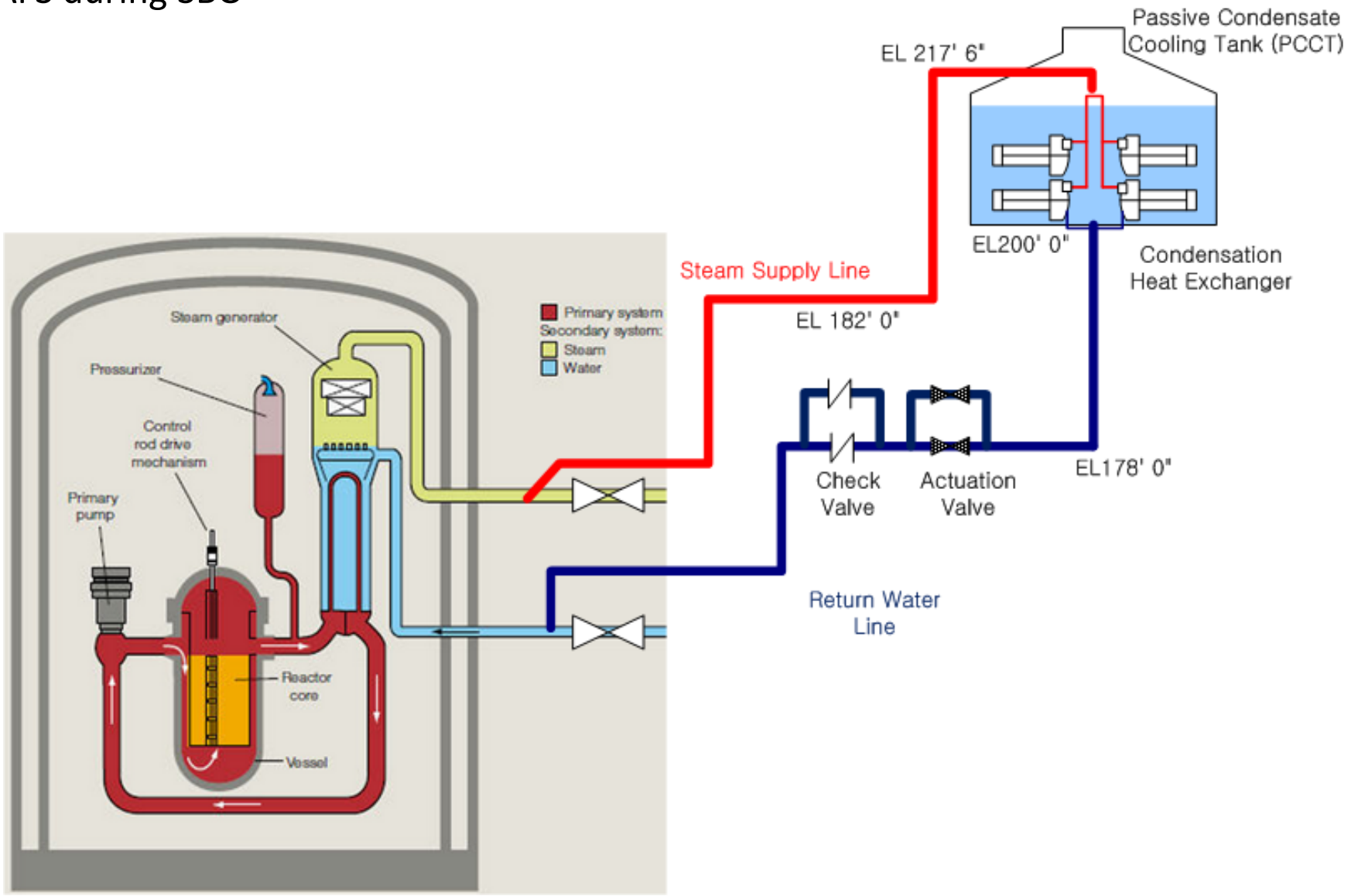
    - Driving force: gravity, free convection, condensation
    - Over 8 hours operation capability during SBO
    - 100% volume heat exchanger per SG





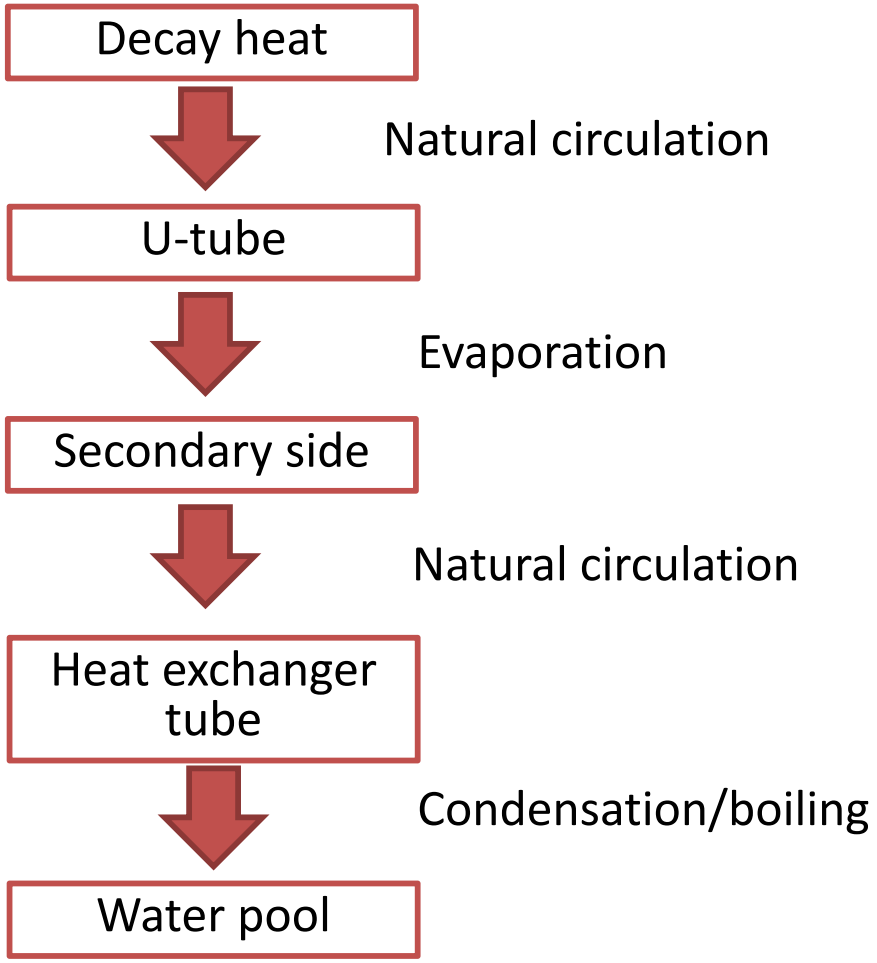
APR+ Safety Features

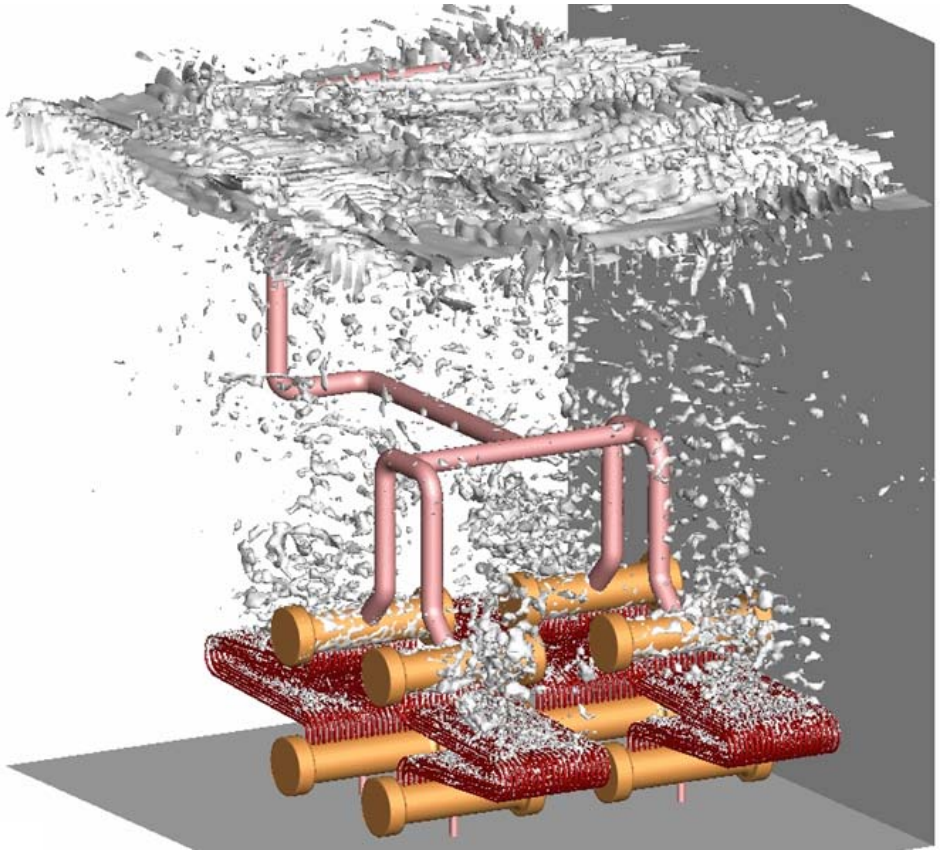
- New Safety Features
  - PAFS during SBO



APR+ Safety Features

- New Safety Features
  - During SBO

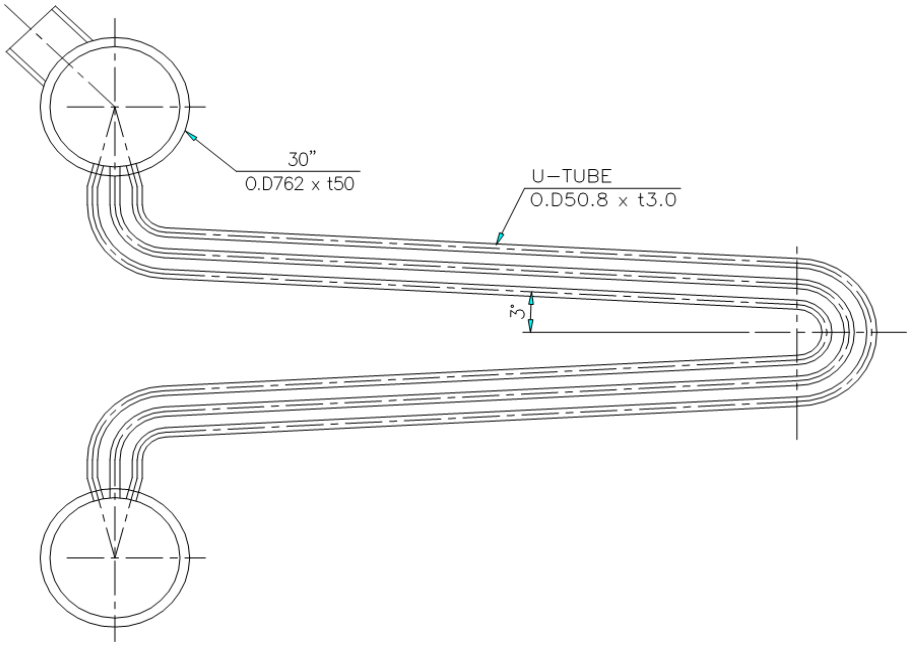




APR+ Safety Features

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

Water Hammer (differential shock)



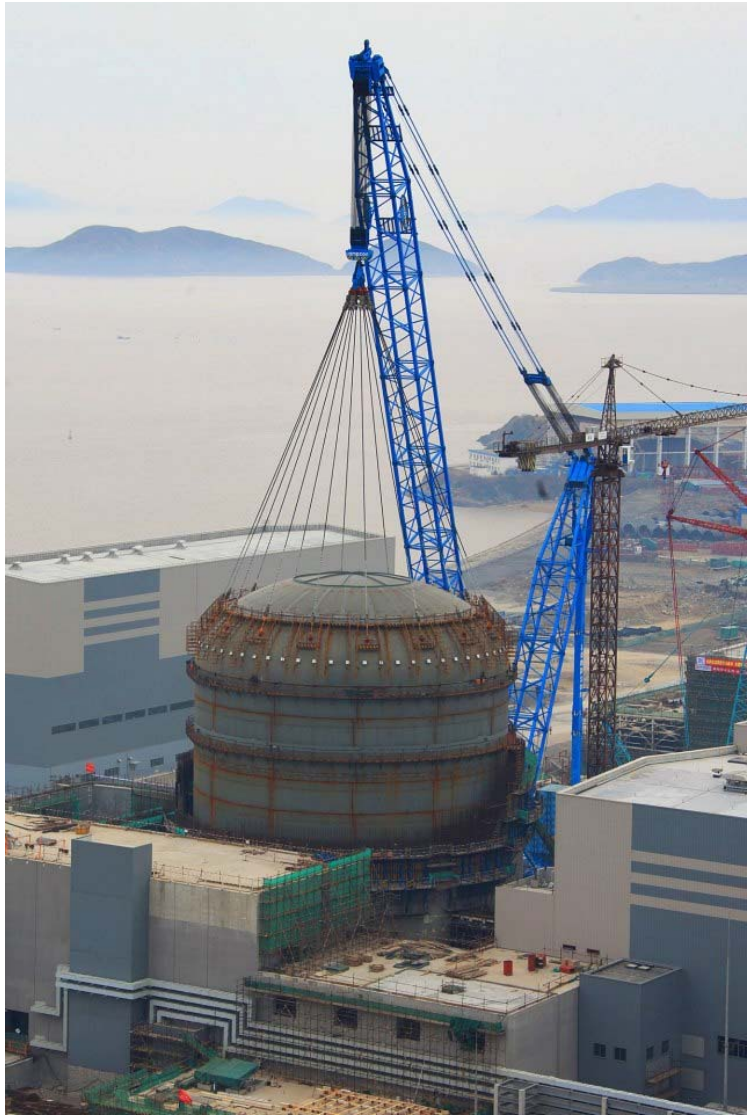
- Velocity of Steam is 10-100 times greater than the velocity of liquid
- Steam moving over the condensate will start manufacturing waves
- Waves will grow until they block the pipe completely forming a “Slug”
- Stopping only when suddenly impacted by equipment, tee, elbow, valve, or any bend in the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

APR+ Safety Features

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

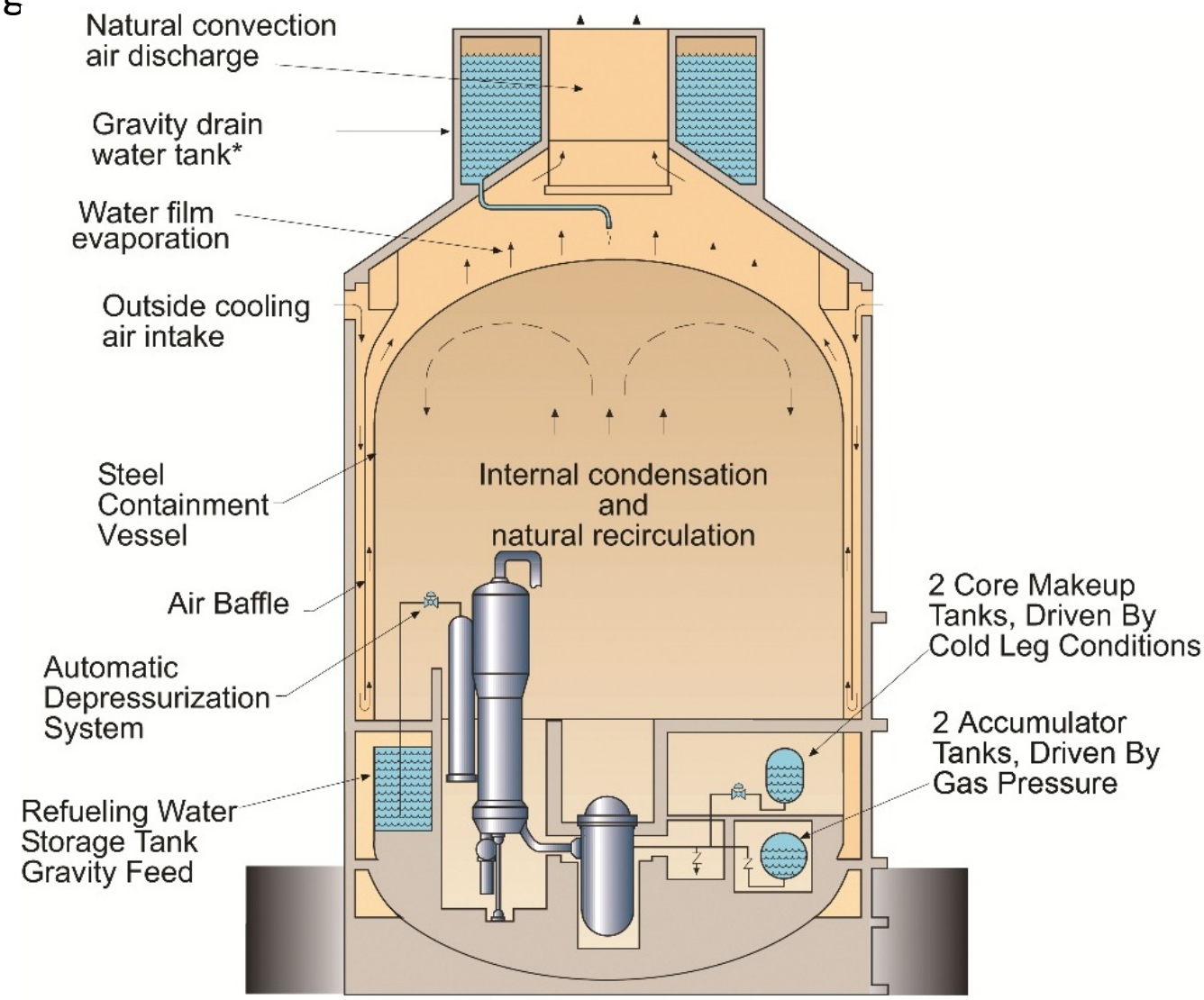
AP1000 Safety Features

- 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



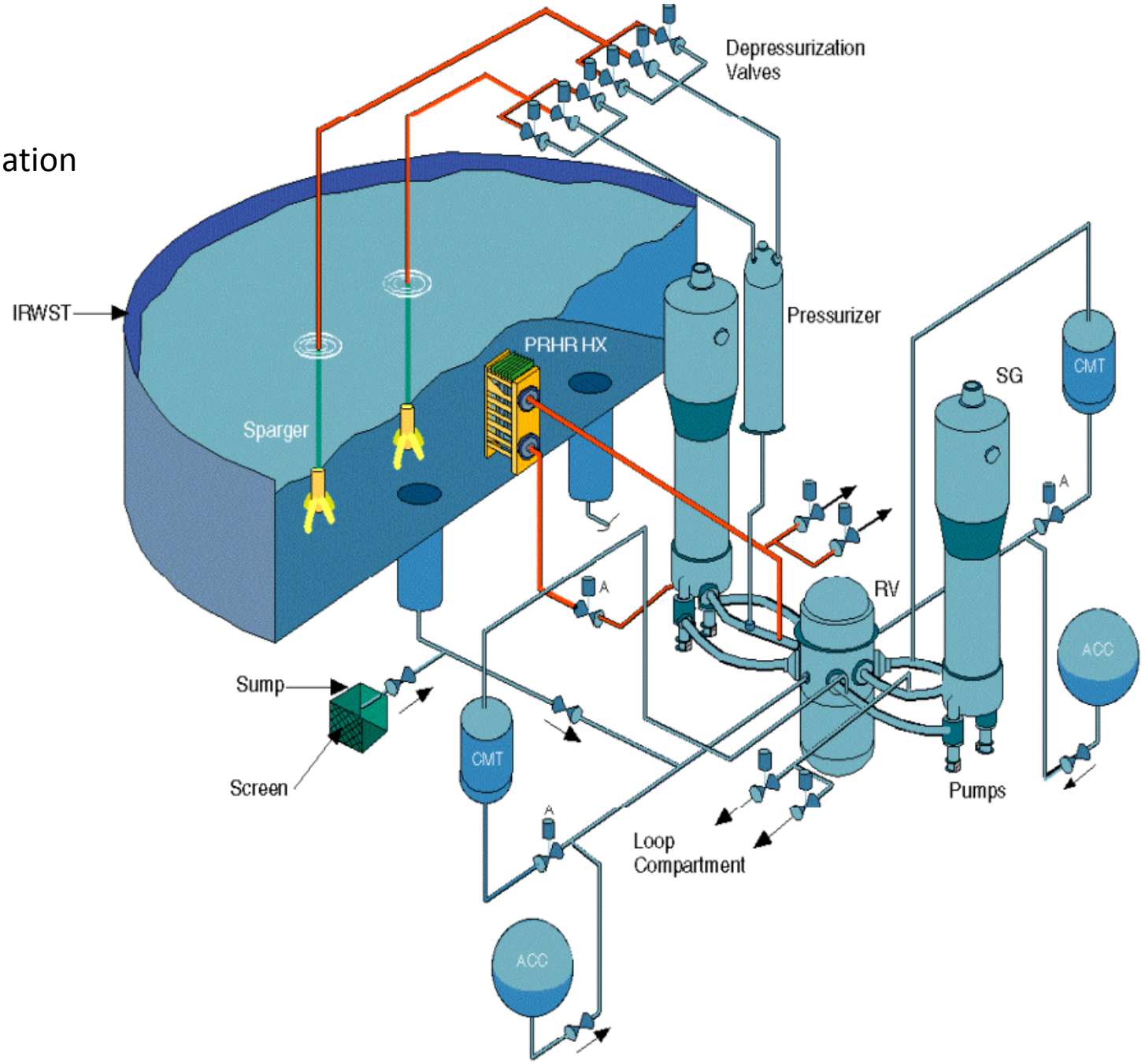
AP1000 Safety Features

- 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



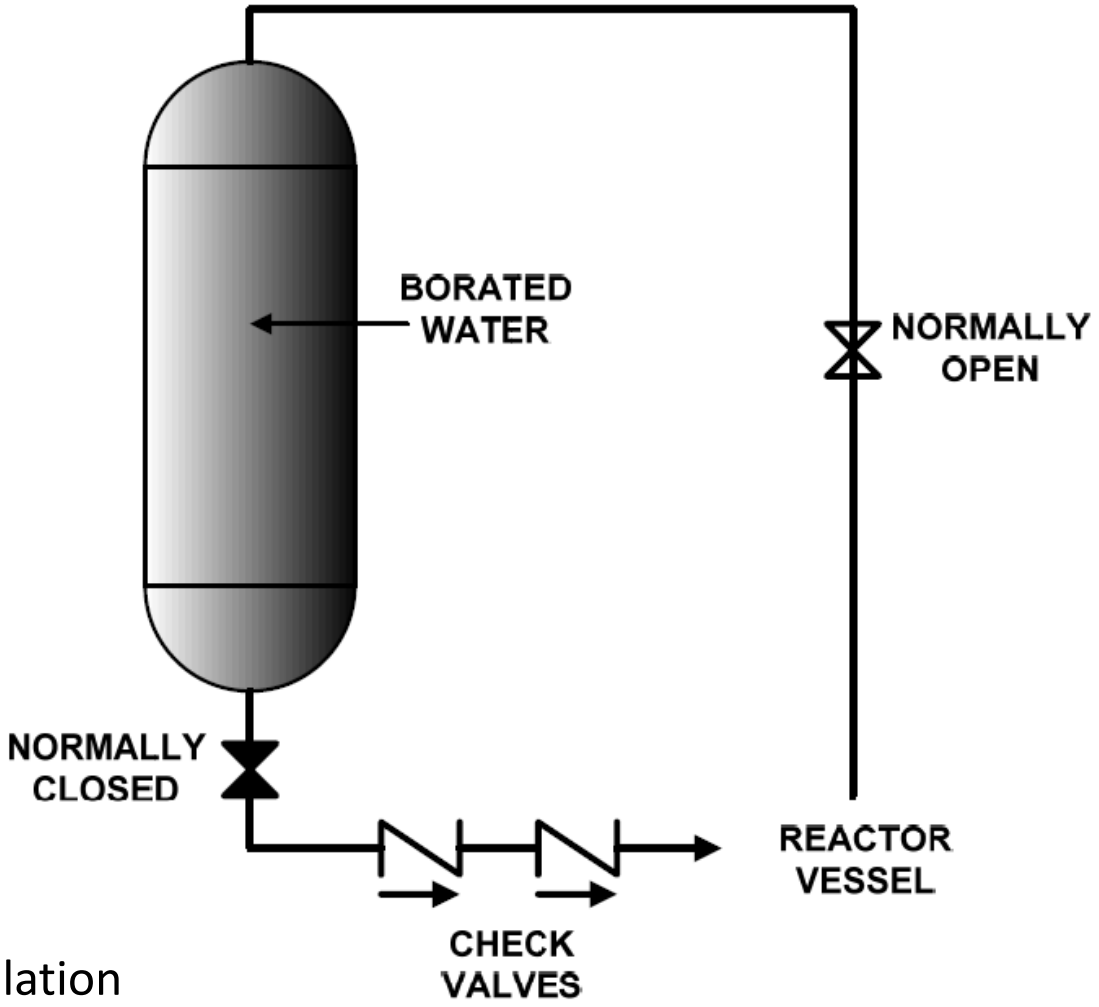
AP1000 Safety Features

- 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

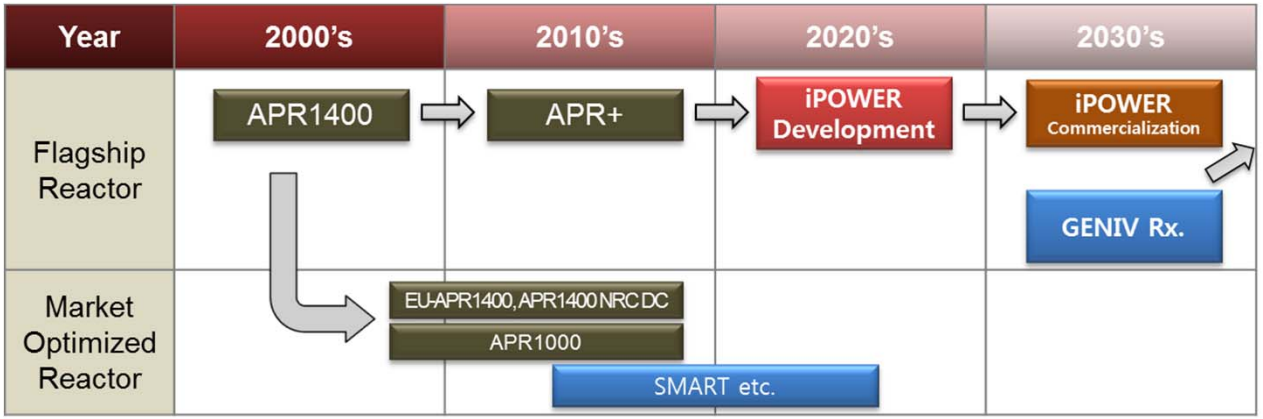
AP1000 Safety Features

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

❖ iPOWER (Innovative Passive Optimized Worldwide Economical Reactor)

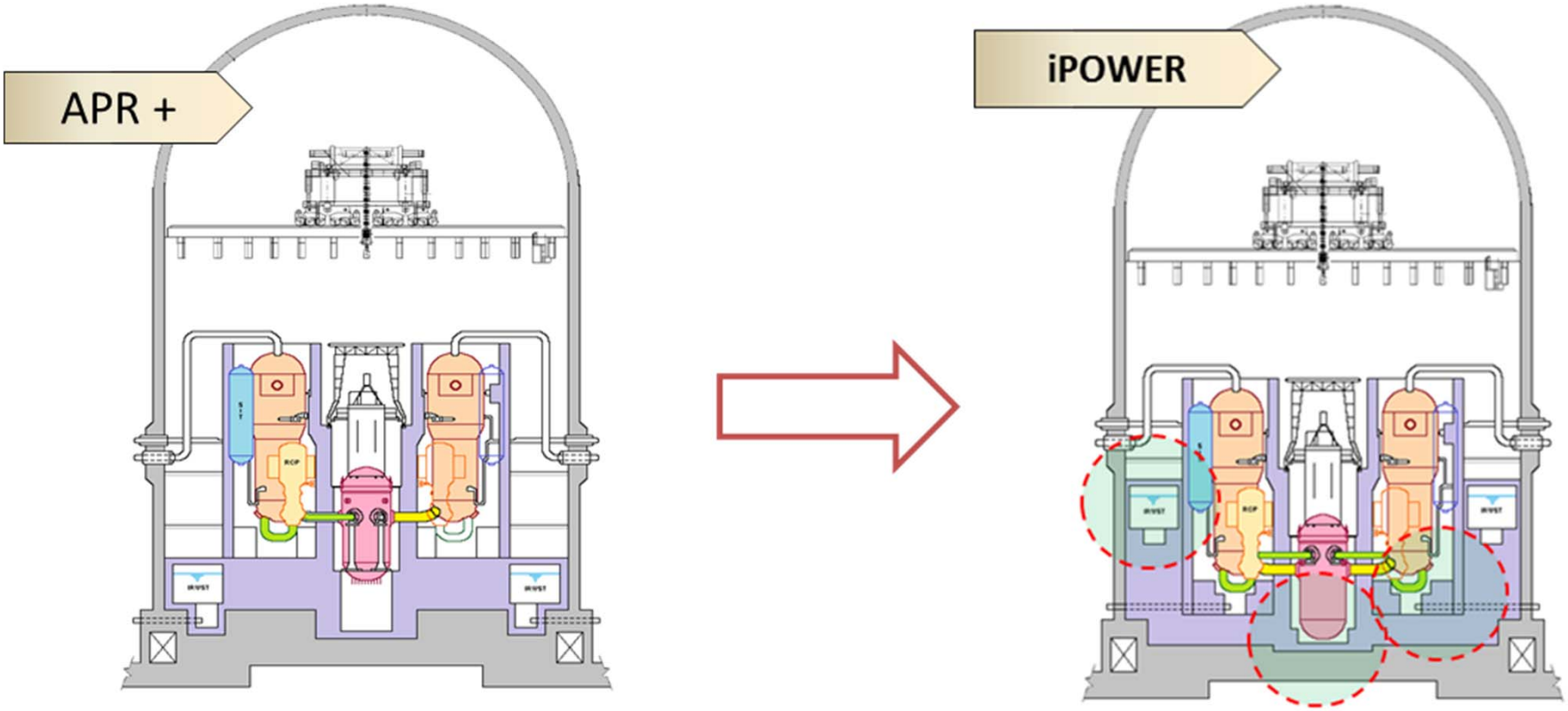
● Background

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



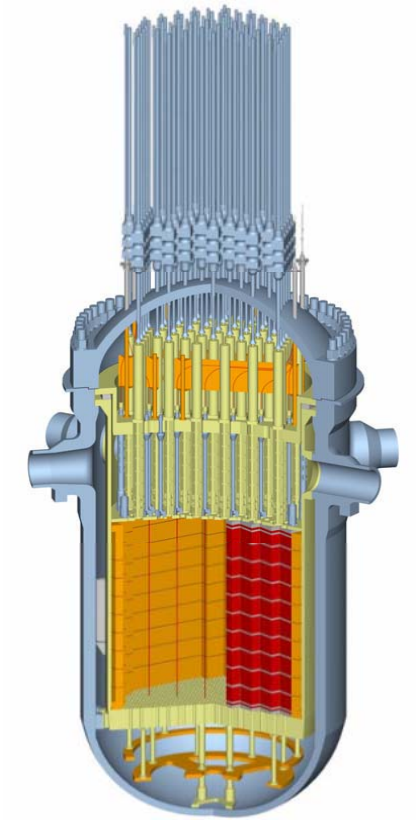
Category	Development Strategy
Design life	Longer than 80 years
Power output	1200~1500MWe (1250MWe)
CDF	< 1 X 10^{-7} /RY (5 X 10^{-8} /RY)
Containment Failure Frequency	~ 0 (<1 X 10^{-9} /RY 이하)
Operator's grace time	> 72 hours (1 week)
Safety System	Fully passive

- 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**

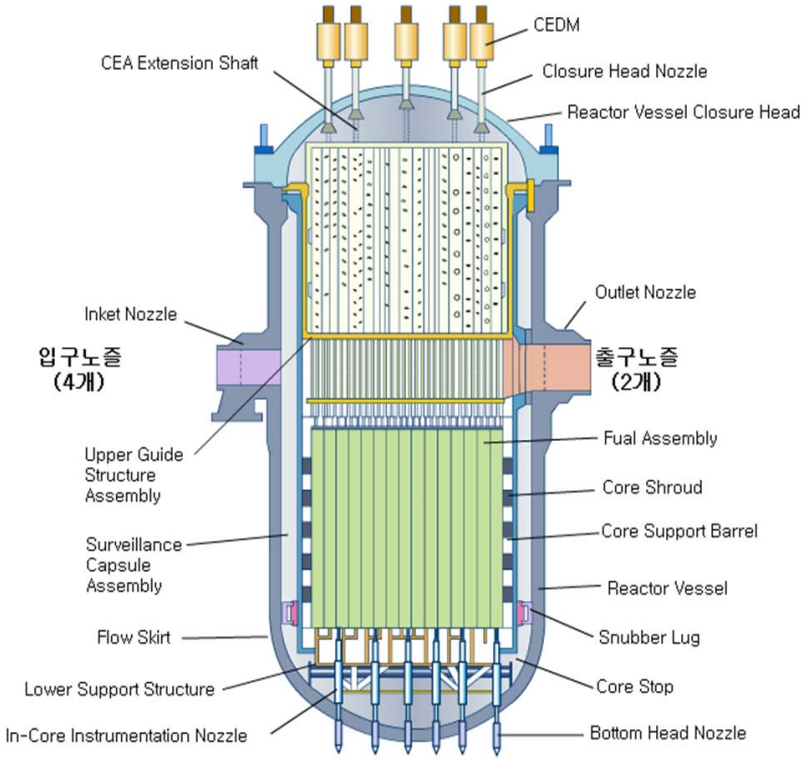


❖ iPOWER (Innovative Passive Optimized Worldwide Economical Reactor)

- **Top-mounted ICI**



Top Mounted ICI
(AP1000, EPR, APWR)

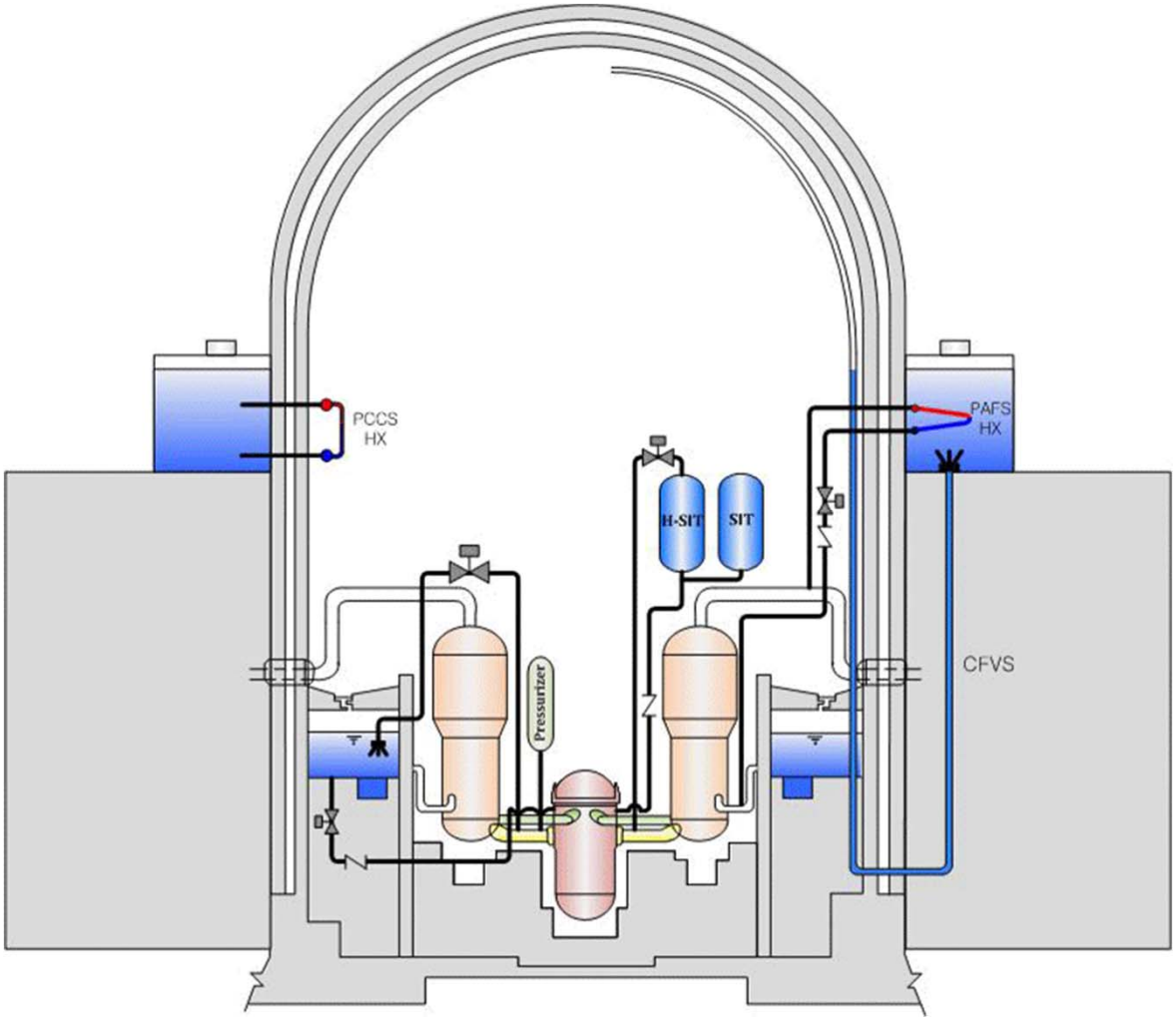


Bottom Mounted ICI
(APR1400, APR+)

❖ iPOWER (Innovative Passive Optimized Worldwide Economical Reactor)

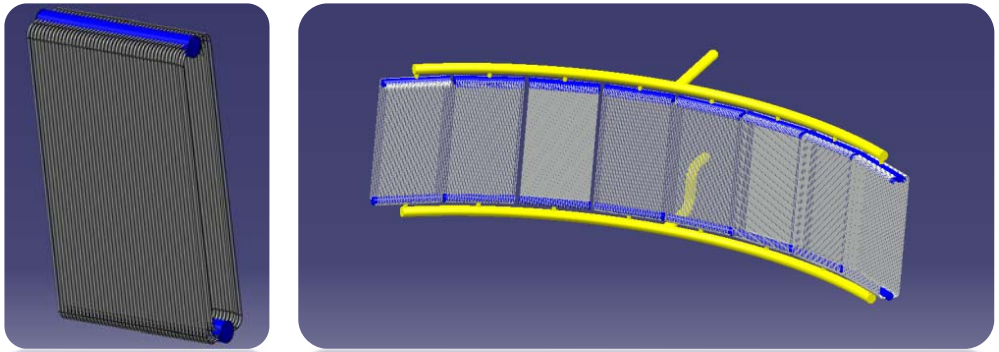
- Passive safety features
  - Passive containment cooling
  - Passive safety injection system
  - Passive residual heat removal system
  - Passive filtered ventilation system
  - Passive spent fuel pool cooling

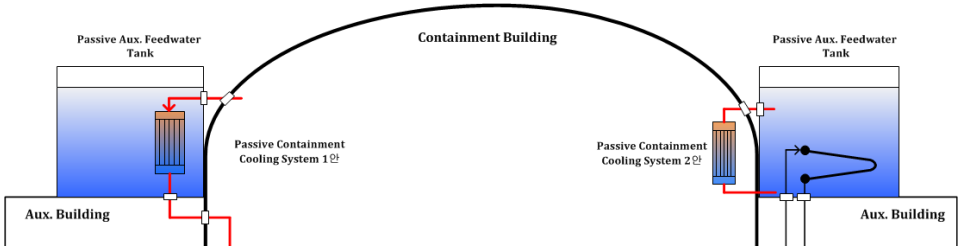
- **No Pump**
- **No Electricity**
- **No Operator Action**
- **No Failure**

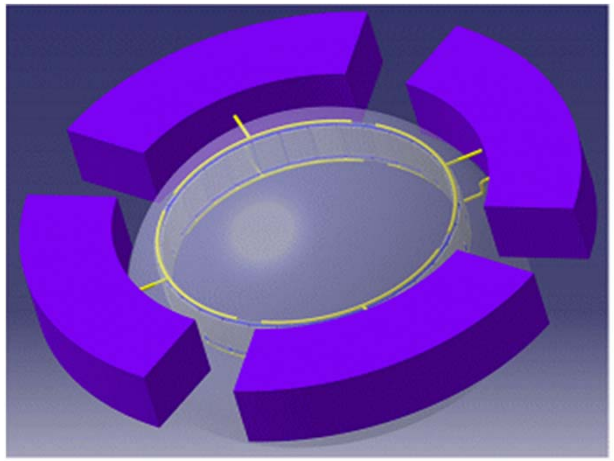


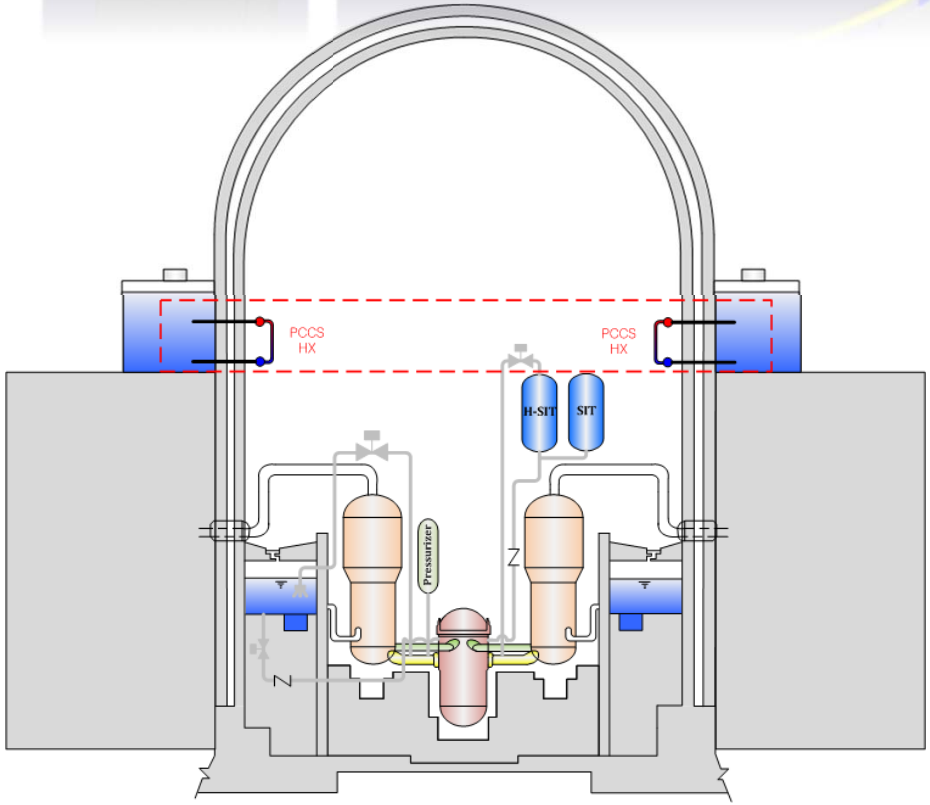
❖ iPOWER (Innovative Passive Optimized Worldwide Economical Reactor)

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



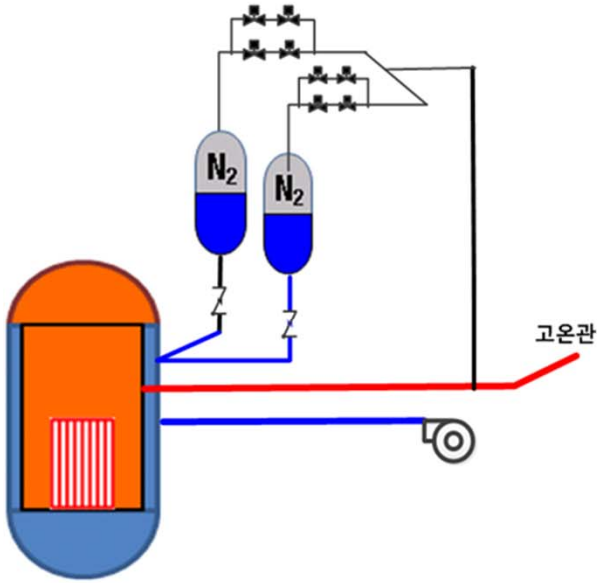


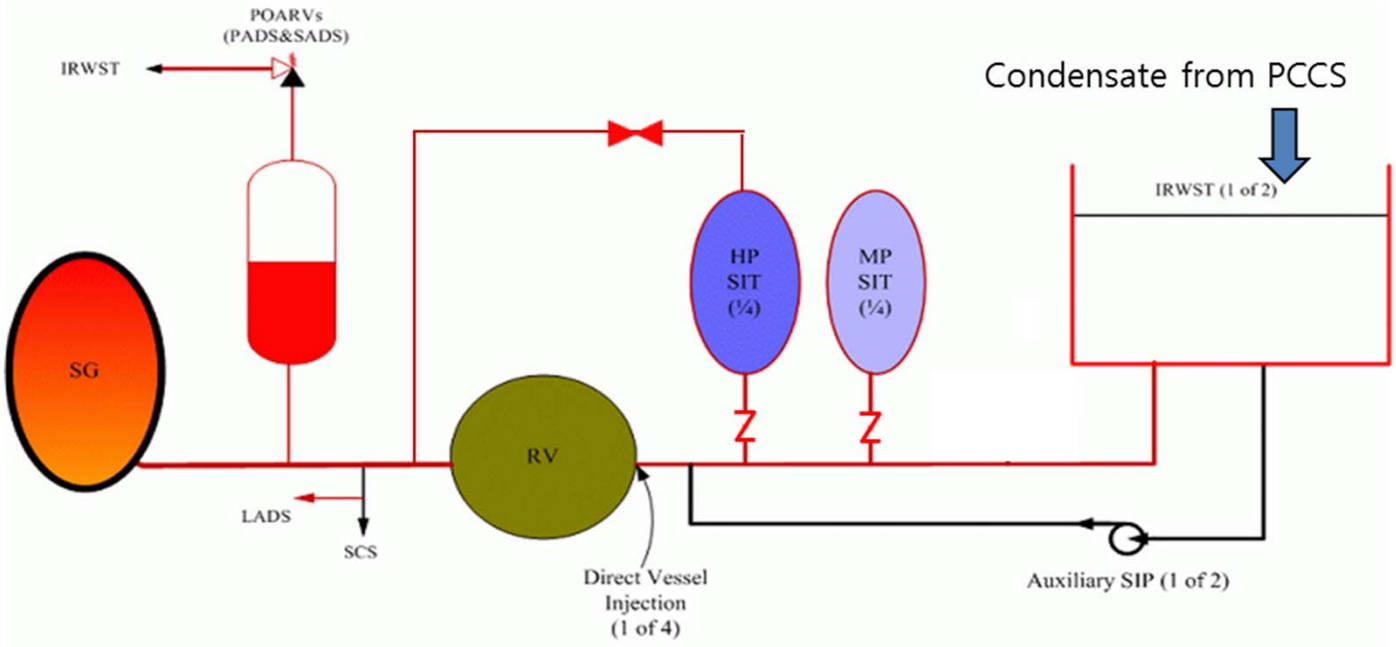




❖ iPOWER (Innovative Passive Optimized Worldwide Economical Reactor)

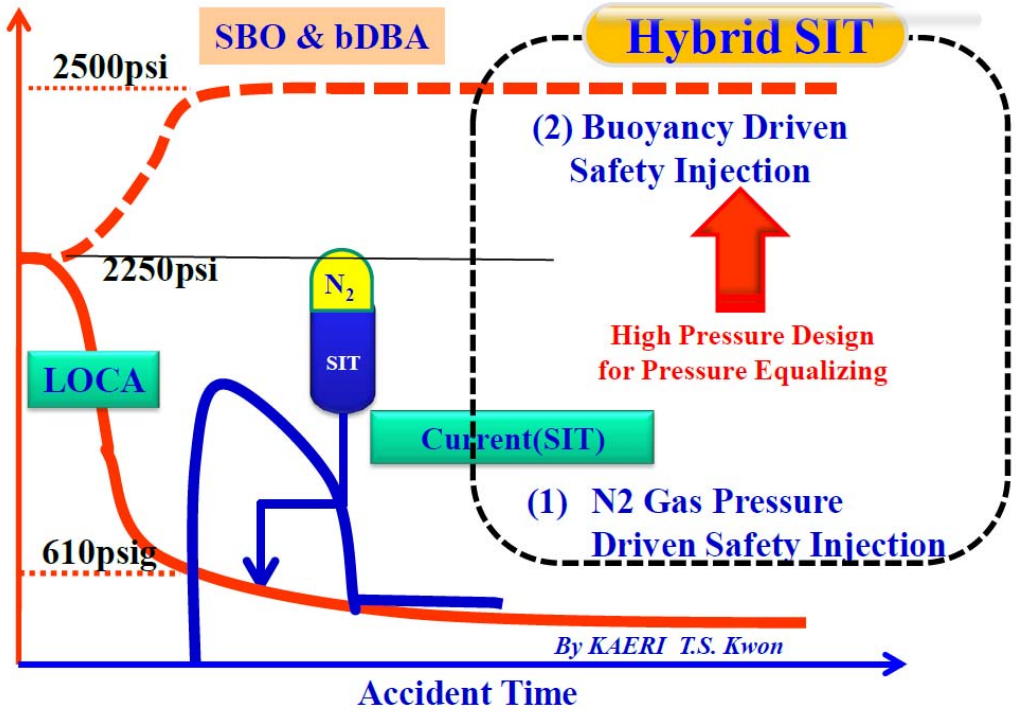
- Passive safety features
  - Passive safety injection system (PECCS: Passive Emergency core cooling system)
    - Hybrid SIT
      - ➢ Depressurization event (LOCA): conventional SIT
      - ➢ High pressure event (SBO): pressure equalization between RCS and SIT
        - Gravity feed of safety injection water
    - Elevated IRWST
      - ➢ Gravity driven low pressure safety injection

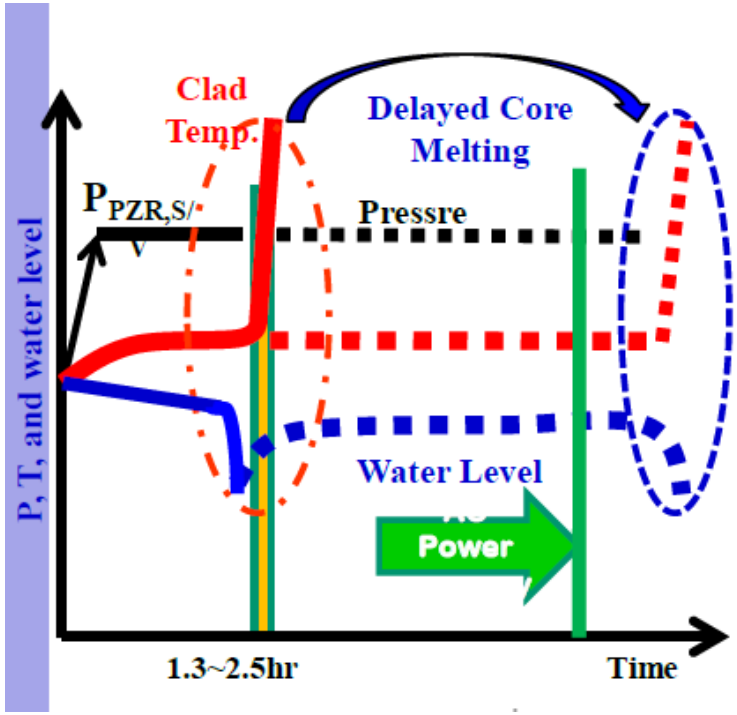




iPOWER (Innovative Passive Optimized Worldwide Economical Reactor)

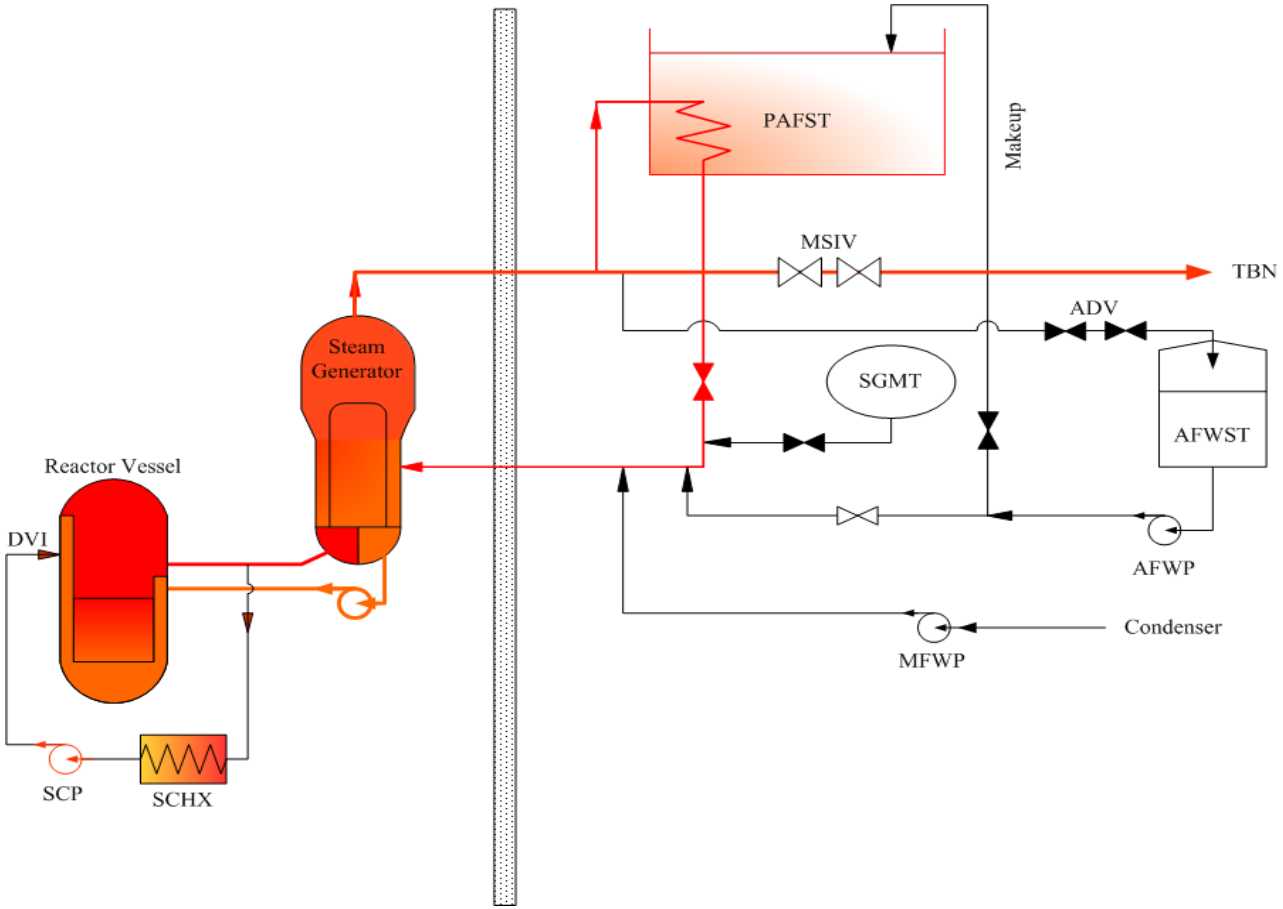
- Passive safety features
  - Passive safety injection system (PECCS: Passive Emergency core cooling system)
    - Hybrid SIT





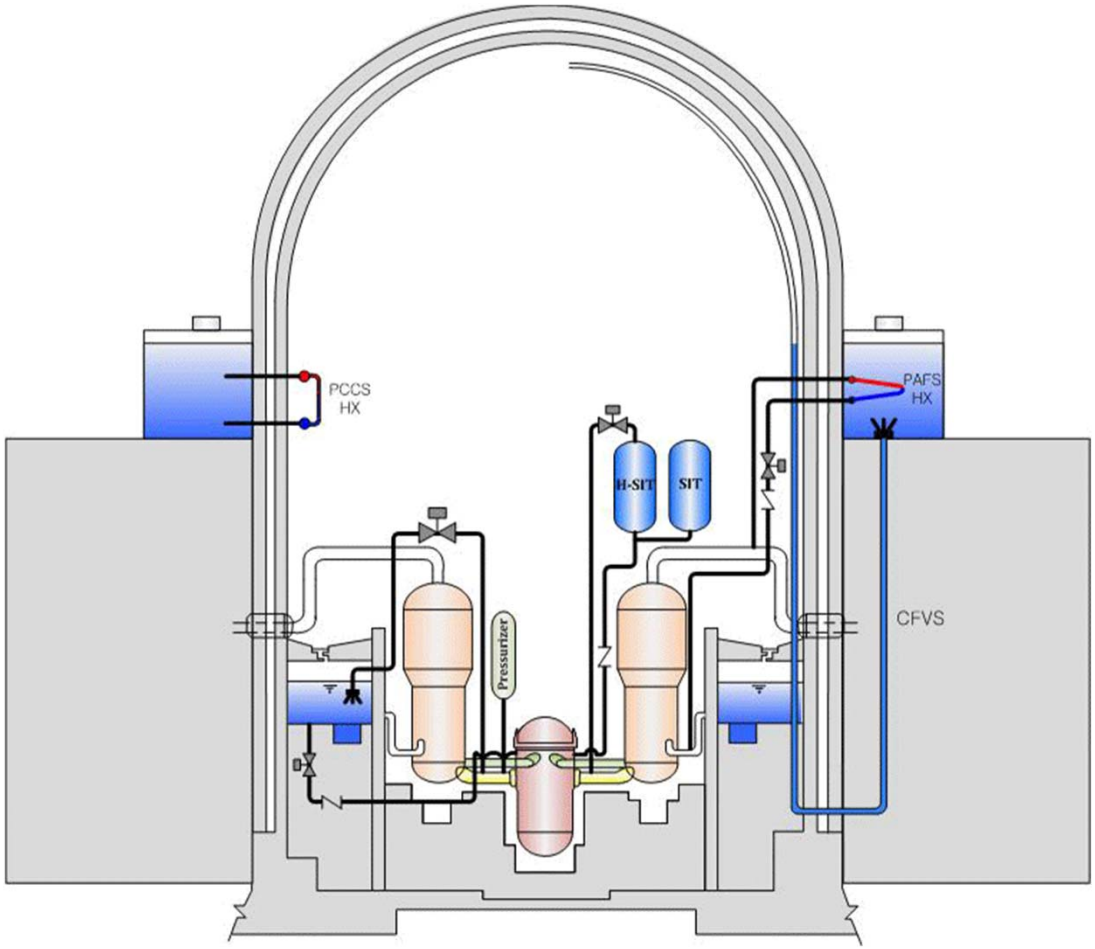
iPOWER (Innovative Passive Optimized Worldwide Economical Reactor)

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



iPOWER (Innovative Passive Optimized Worldwide Economical Reactor)

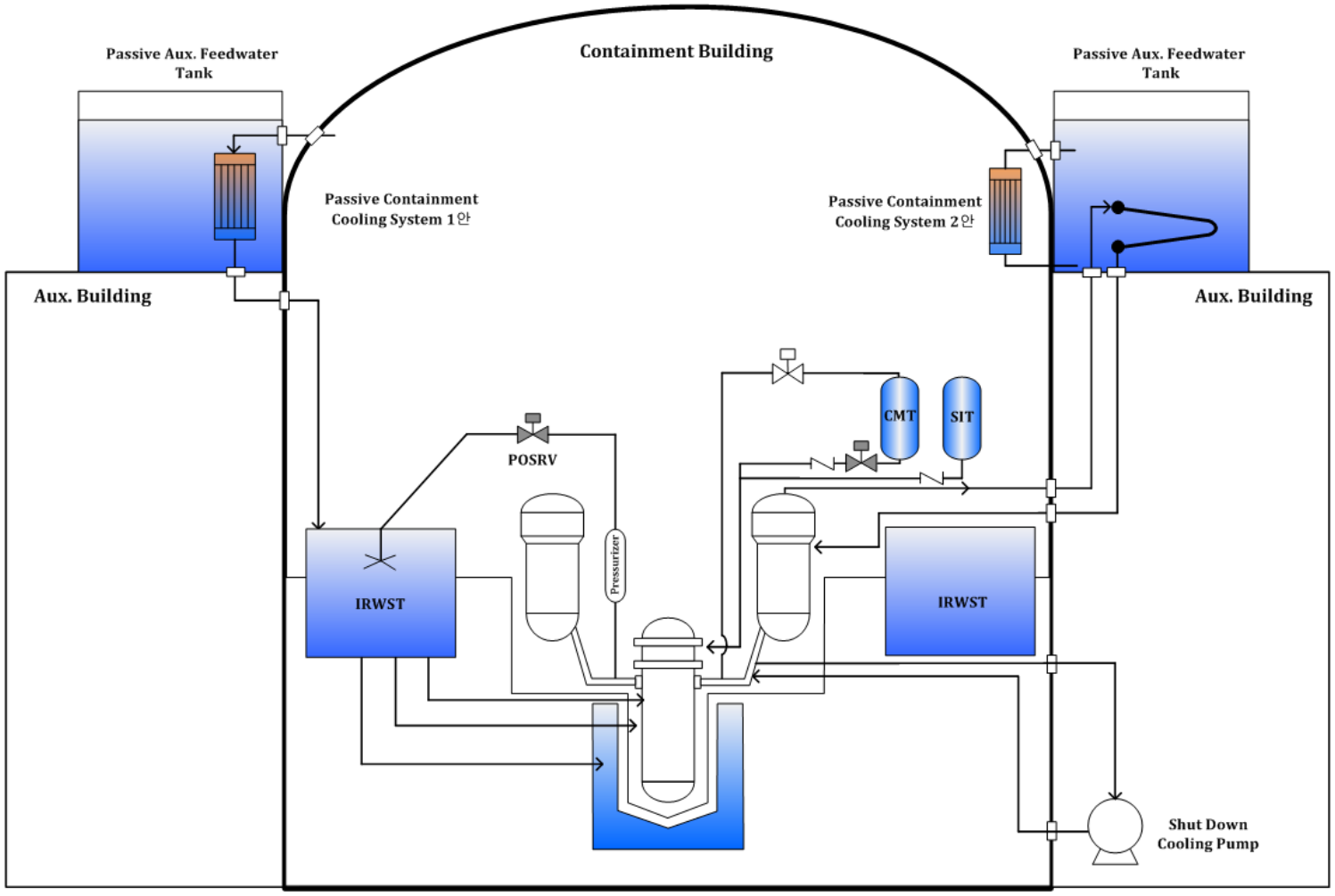
- Passive safety features
  - Passive filtered ventilation system
    - Containment filtered ventilation system
    - Water valve: zero failure probability
  - Passive spent fuel pool cooling
    - Water supply using PAFS water tank



iPOWER (Innovative Passive Optimized Worldwide Economical Reactor)

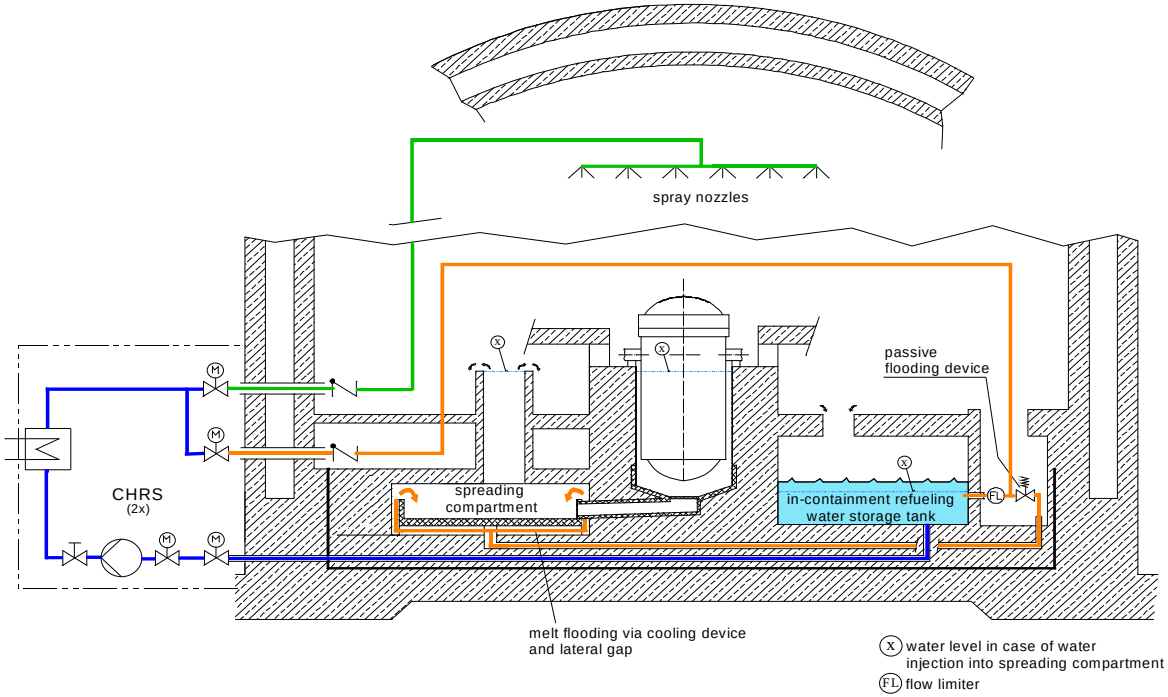
Passive safety features

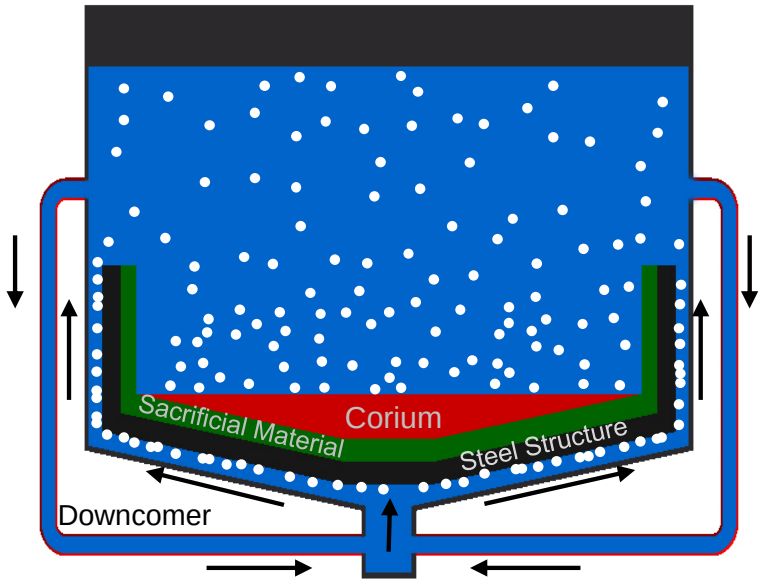
Passive IVR/ERVC



iPOWER (Innovative Passive Optimized Worldwide Economical Reactor)

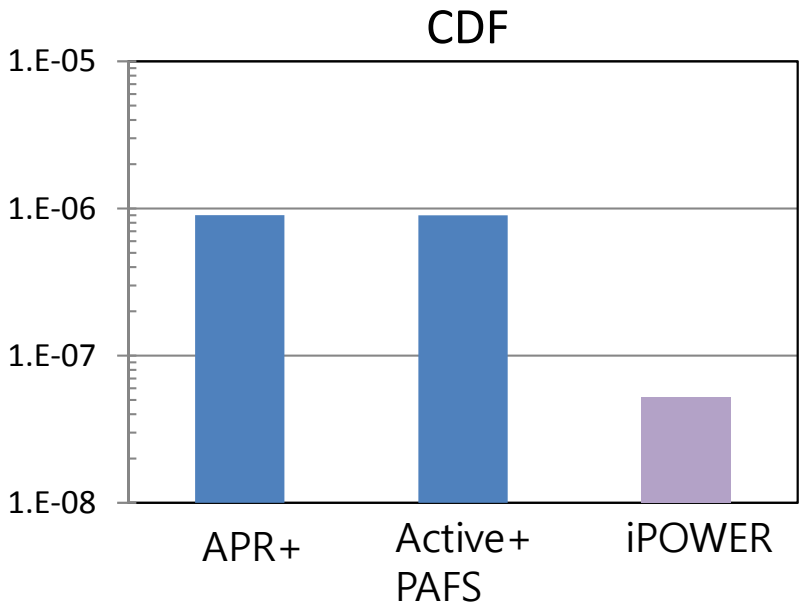
- Passive safety features
  - Core catcher
    - A core catcher is a device provided to catch the molten core material (Corium) of a nuclear reactor in case of a nuclear meltdown and prevent it from escaping the containment building.
    - Passive water supply using IRWST





❖ 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



From KHNP presentation material

추진 전략

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