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EU-APR Safety Features Reflecting Recent European Requirements

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CONTENTS

1 Introduction

1. Introduction

Background

- Differences between licensing approaches in Korea and Europe
- Customized engineering intended for European nuclear market

Project Overview

- Government R&D project for nuclear market diversification
- 102 Months / 48 Million Euro

Strategy

- 1st Phase (June 2009 – May 2011)
  - ✓Basic design of SSCs and safety assessment for EU-APR
- 2nd Phase (June 2011 – November 2017)
  - ✓Design updates for EUR Rev. D and certification

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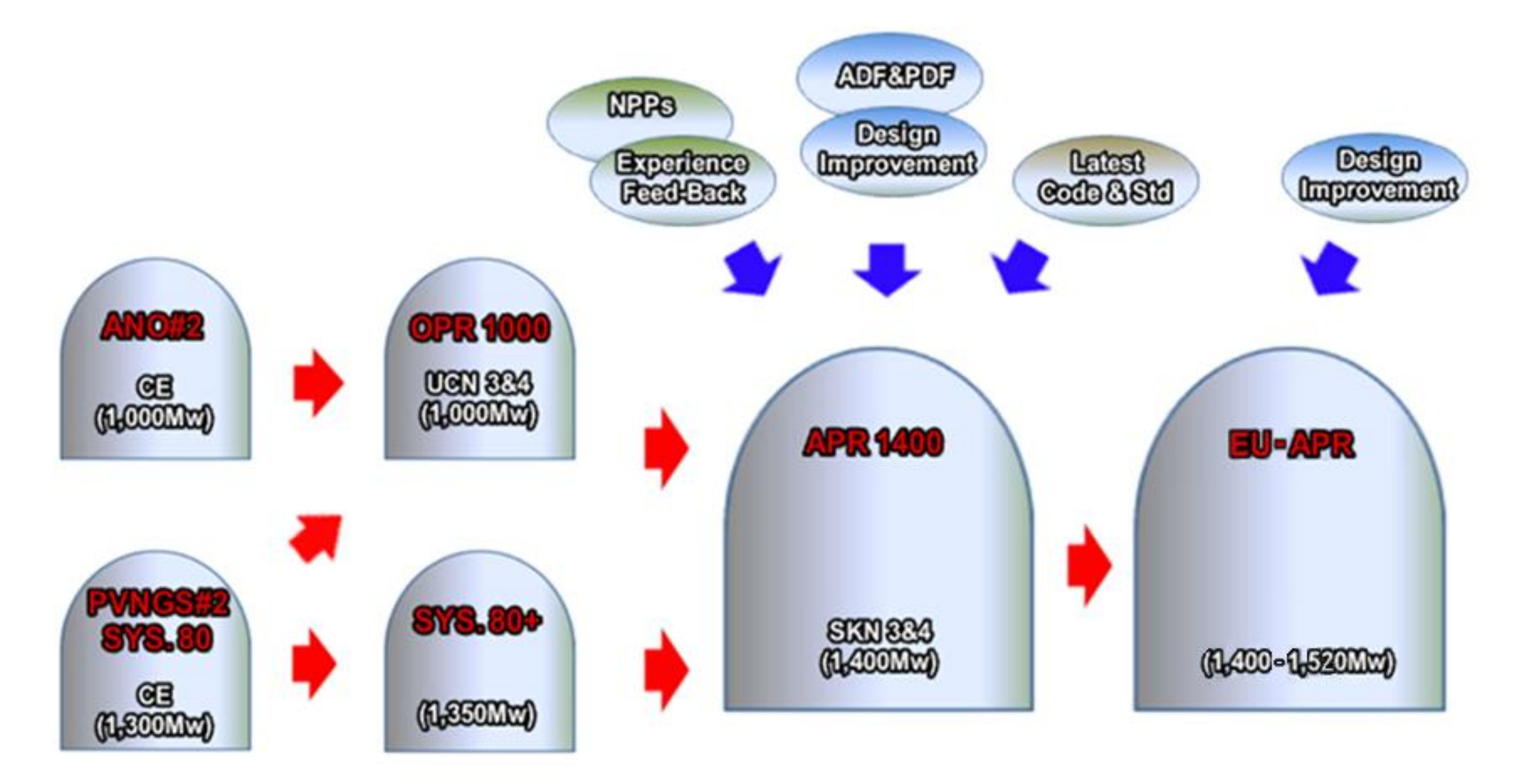
1. Introduction

EU-APR Standard Design

- Evolutionary 1400-1520 MW_e Gen III+ PWR with 60-year design life time
- Safety improvements in accordance with European requirements



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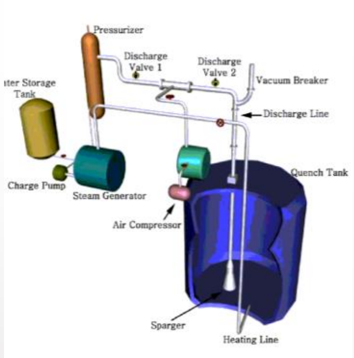
Key Requirements for EU-APR

2. Design Basis

Use of proven Design Features of APR1400

- Pilot-Operated Safety Relief Valve (POSRV)
- Direct Vessel Injection (DVI)
  - ✓ Eliminating the safety Injection water spillage during LB LOCA in cold leg
- Safety Injection Tank (SIT) with Fluidic Device (FD)
  - ✓ No need of LPSI pumps by regulating the SIT flow passively
- In-Containment Refueling Water Storage Tank (IRWST)
- Fully Digital Human-Machine Interface (HMI)



2. Design Criteria (1/3)

Licensing Basis in Europe

- IAEA SSR 2/1, EUR Rev. D, Finnish regulatory guide (YVL), WENRA requirements, etc.

Categorization of Plant States

Design Category		Plant State	Frequency of Initiating event (per year)
Design Basis Condition	DBC 1	Normal Operation	
	DBC 2	Anticipated Operational Occurrence	$10^{-2} < f$
	DBC 3	Postulated Accident Class 1	$10^{-3} < f < 10^{-2}$
	DBC 4	Postulated Accident Class 2	$f < 10^{-3}$
Design Extension Condition	DEC A	Category A : (DBC 2 or DBC 3) + CCF	$10^{-7} < f < 10^{-4}$
	DEC B	Category B : multiple failure event	
	DEC C	Category C : very rare external event	
Severe Accident Condition		Severe Accident	$f < 10^{-5}$

cf. EUR Rev. D: DBC 3 ($10^{-4} < f < 10^{-2}$) and DBC 4 ($10^{-6} < f < 10^{-4}$)

2. Design Criteria (2/3)

Acceptance Criteria

	Unit Parameters	Radioactive Doses and Releases
DBC1	Process Parameters within normal operation range	Liquid: 10 GBq (except Tritium) Gaseous: 50 TBq (Noble), 1 GBq (Halogen & aerosol)
DBC2	No DNB on any fuel 1st and 2nd Pressure < P_{Design}	
DBC3	< 1% of the fuel rods experiencing DNB Max. fuel cladding Temp. < 650°C 1st and 2nd Pressure < 110% of P_{design}	No action beyond 800m: 1 mSv Limited economic impact: 160 TBq (I-131) 20 TBq (Cs-137)
DBC4	< 10% of the fuel rods experiencing DNB Core coolable geometry retained Peak clading Temp < 1204°C Local cladding exidation < 17% Radial average peak enthalpy < 837 kJ/kg 1st and 2nd Pressure < 110% of P_{design}	No action beyond 800m: 5 mSv Limited economic impact: 160 TBq (I-131) 20 TBq (Cs-137)
DEC	Core coolable geometry retained Peak clading Temp < 1204°C Local cladding exidation < 17% Radial average peak enthalpy < 837 kJ/kg 1st and 2nd Pressure < 120% of P_{design}	No emergency protection action beyond 800m: 50 mSv No delayed action beyond 3km (first 4 days): 30 mSv No long-term actions beyond 800m: 100 mSv Limited economic impact: 4000 TBq (I-131) 30 TBq (Cs-137) 400 TBq (Sr-90)
SA	No HPME and no DCH No MCCI and no hydrogen detonation No recriticality	

2. Design Criteria (3/3)

Safety Target

- Core Damage cumulative frequency < 10^{-5}/RY
- Cumulative frequency of exceeding the Criteria for Limited Impact < 10^{-6}/RY

Main Items for Implementation of Safety Features

	European Requirements
Redundancy of Safety System	For important safety systems, single failure criterion and 1 train out of operation due to maintenance shall be assumed to achieve their functions during postulated accidents.
Diversity of Safety Function	In ensuring the most important safety functions, systems based on diverse principles of operation shall be used to the extent possible.
Severe Accident Mitigation	To ensure containment integrity in severe accidents, SSCs shall be designed independent of systems designed for plant operational conditions and postulated accidents.
Protection against Extreme External Hazards	The protection design against a large commercial aircraft crash shall be incorporated as a man-made hazard. Loss of the primary ultimate heat sink should be considered in the design.

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3 Major Characteristics

3. Key Parameters

Comparison between APR1400 and EU-APR

Parameters	APR1400	EU-APR
Design Criteria Base	10CFR, NRC RG	IAEA, EUR, WENRA
Metrication	British	SI
Seismic Design	0.3g (fixed base)	0.25g (10 soil-properties)
Electrical Frequency	60 Hz	50 Hz
RCS	Two Loop 1 RV, 2 S/Gs, 4 RCPs	Two Loop 1 RV, 2 S/Gs, 4 RCPs
Turbine/Generator	1,800 rpm	1,500 rpm
Redundancy of ESF	Mech. 4-Train Elec. 2-Division	Mech. 4-Train Elec. 4-Division
Containment	Single	Double
Corium Cooling	Cavity Flooding System (+ IVR Strategy)	Core Catcher
I&C Design	2-platform	3-platform

3. Design Philosophy

Refined Defense-in-Depth (DiD) Concept

- Functional: 5 levels of protection approach

Level of DiD	Objective	Essential means
Level 1	Prevention of abnormal operation and failures	Conservative design and high quality
Level 2	Detection of failures and control of abnormal operation	Control, limiting and protection systems and surveillance
Level 3	*Level 3a:* Control of Accidents *Level 3b:* Control of Design Extension Conditions	Engineered Safety Features Diverse (Additional) Safety Features
Level 4	Mitigation of Severe Accidents	Dedicated (Complementary) Safety Features
Level 5	Emergency preparedness	Off-site emergency response

- Physical: Independent 3 barriers (Fuel, RCPB and Containment)

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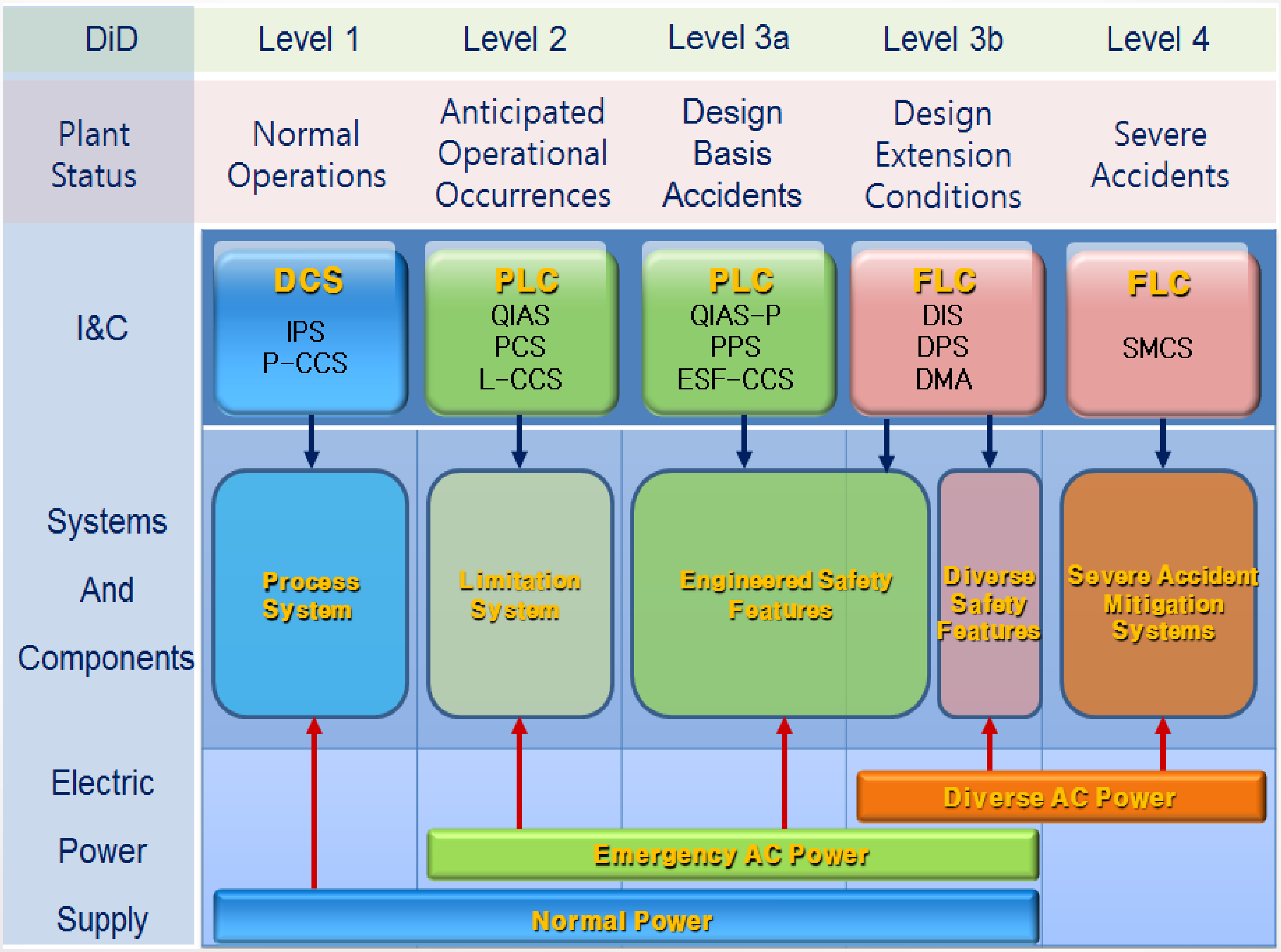
3. Safety Architecture

- **SSC and associated I&C and Electrical Systems to satisfy WENRA**



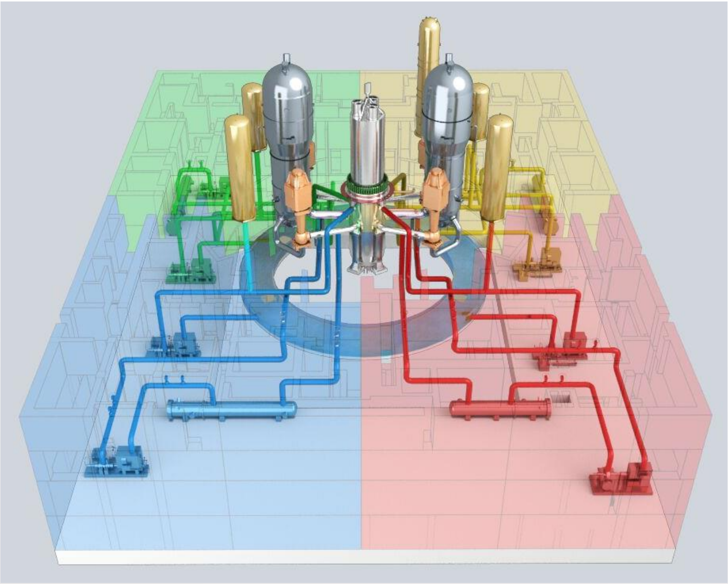
3. Safety System Design Principles

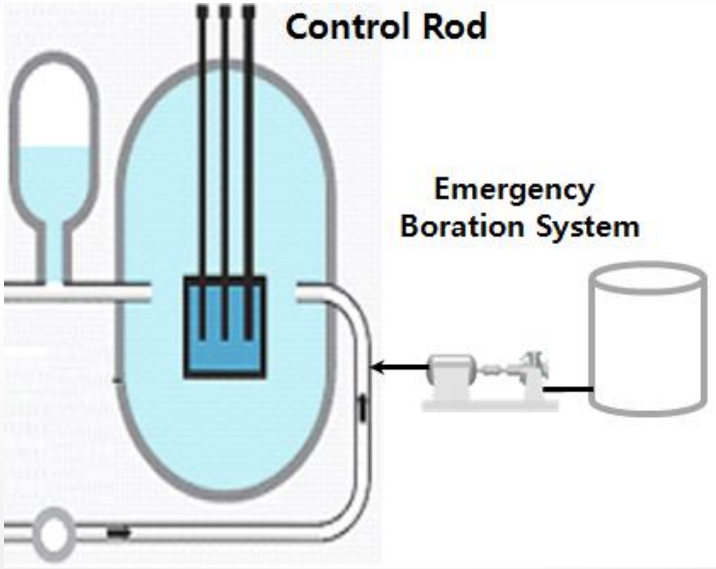
Failure Criteria by Finnish YVL

- N+2 Design : Safety systems to mitigate DBC 3 & 4 accidents
- N+1 Design : Safety systems to mitigate DBC 2, DEC and Severe Accidents

Protection against Common Cause Failure to meet IAEA SSR-2/1

- Equipping with system or component level alternative measures against CCFs of systems performing safety functions in the event of DBC 2 & 3





3. Engineered Safety Features

Function of ESF

- Protection in an accidental release of radioactive fission products from the RCS against DBC 3-4 and Complex sequences
  - ✓Safety Depressurization and Vent System (SDVS) with POSRVs
  - ✓In-containment refueling Water Storage System (IWSS)
  - ✓SIS including FD in connection with DVI and Emergency Core Barrel Duct
  - ✓Shutdown Cooling/Containment Spray System (SC/CSS)*

    ** Decay heat removal chain: CCW and ESW*
  - ✓Auxiliary Feedwater System (AFWS)
  - ✓Associated Containment Isolation System (CIS)
- Associated Supporting Systems
  - ✓AC power supplied by Emergency Diesel Generators (EDGs)
  - ✓Safety-related I&C system for plant protection

3. Diverse Safety Features

Function of DSF

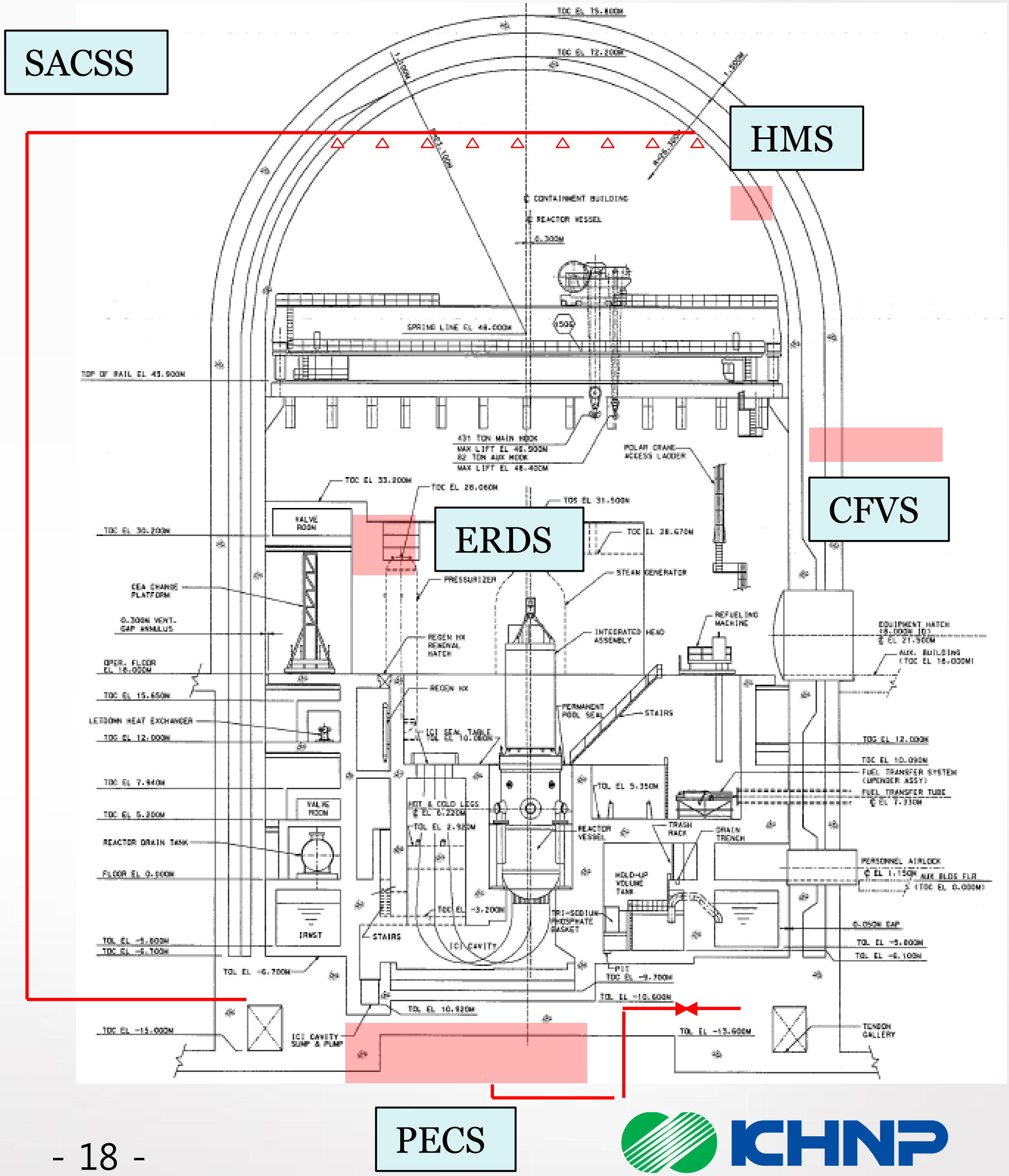
- Accident mitigation functions in the event of postulated Complex sequences
  - ✓Emergency Boration System (EBS)
  - ✓Decay heat removal from reactor core

Front System	Alternative Measures
SIS	Primary depressurization using secondary MSADVs + SIT Injection + IRWST water injection by Shutdown Cooling Pumps
AFWS	Primary feed and bleed operation using POSRVs and Safety Injection

  - ✓SFP decay heat removal by make-up
- Associated Supporting Systems
  - ✓AC power supplied by Emergency Diesel Generators (EDGs) or Alternate AC Diesel Generators (AAC DGs)
  - ✓Safety-relate I&C system with diverse platform

3. Severe Accident Mitigation (1/2)

- **Dedicated Defense Line to meet EUR and WENRA**
  - Independent from systems for AOO and DBA
  - Practical elimination of early or large releases in case of core melt accidents
    - ✓ Direct Containment Heating
    - ✓ Steam explosion
    - ✓ Hydrogen detonation
    - ✓ Basemat melt-through
    - ✓ Containment over-pressurization



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3. Severe Accident Mitigation (2/2)

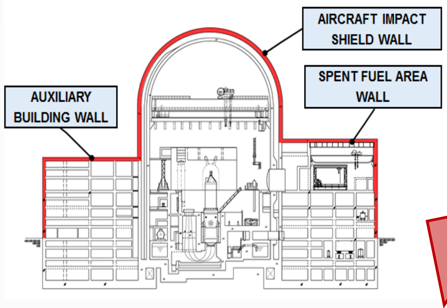
Function of Severe Accident Mitigation Features

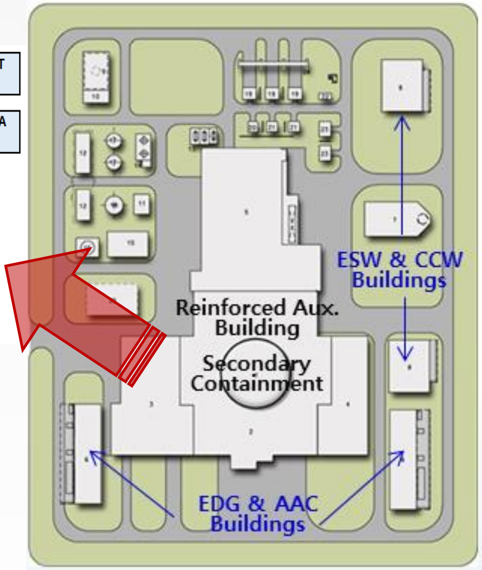
- Limitation of off-site releases after the core melt accidents
  - ✓Emergency Reactor Depressurization System (ERDS)
  - ✓Passive Ex-vessel corium retaining and Cooling System (PECS)
  - ✓SA dedicated Containment Spray System (SACSS)**

    *** Decay heat removal chain: SA dedicated CCW and ESW*
  - ✓Hydrogen Mitigation System (HMS)
  - ✓Containment Filtered Vent System (CFVS)
- Associated Supporting Systems
  - ✓AC power supplied by Alternate AC Diesel Generators (AAC DGs)
  - ✓Safety-related I&C system with dedicated platform

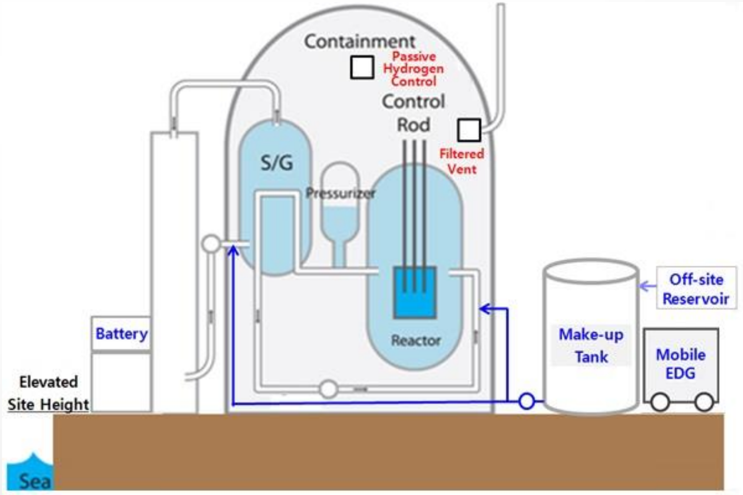
3. Rare External Hazards Protection

- **Man-made Hazard**
  - Structures against intentional aircraft crash & external explosions
    - ✓Secondary containment
    - ✓Reinforced or physically separated arrangement of safety buildings





- **Natural Hazard**
  - Protection designs against loss of electrical power & ultimate heat sink
    - ✓External injection paths for emergency cooling of RCS, SG and SFP
    - ✓Mobile generator, capacity-reinforced and flood-protected batteries



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4 Closing Remarks

4. Summary and Conclusions

- The basic design of the EU-APR, the customized APR1400 for European market, was successfully developed by KHNP consortium with the support of Korean Government.
- The latest European nuclear requirements, including IAEA SSR-2/1, EUR Rev. D, YVL, and WENRA, have driven the specific design features for safety improvement.
- The EUR assessment were valuable elements for sustaining a long-term positive view of nuclear power contribution to Europe.
- With a high level of compliance with the European requirement, the plant could be build in any of the European countries.

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THANK YOU

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