SMART100 Mechanical Design

Codes and Standards, Design Engineering and Manufacturing of Components

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Korea Atomic Energy Research Institute

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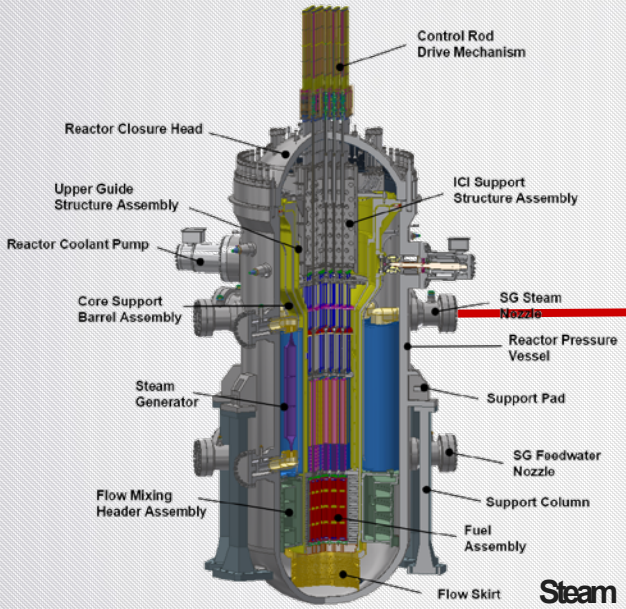
01 Introduction

01 Speaker

- Kwanghyun Ahn
- BS/MS/Ph.D. in Mechanical Engineering (~2012)
  - Solid mechanics
  - Plasticity
  - Dynamic analysis of structure
- SMART project in KAERI (2016~)
  - Structural design of reactor internals
  - Seismic analysis of reactor vessel assembly
  - Structural analysis of SSC in SMART
- Leader of SMR mechanical design group (2021~)
  - Standard design approval of SMART mechanical design
  - Research for mechanical design of SMR

02 SMART100

System-integrated Modular Advanced ReacTor

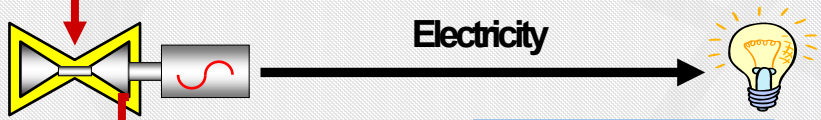


Advanced Integral PWR

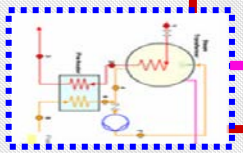
for Electricity Generation and District Heating or Desalination

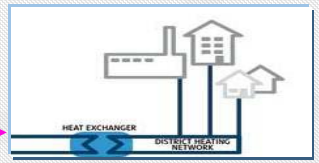
Thermal : 365 MWt

- Electricity : 110 MWe
- Fresh Water : 40,000 t/day



Steam Transformer



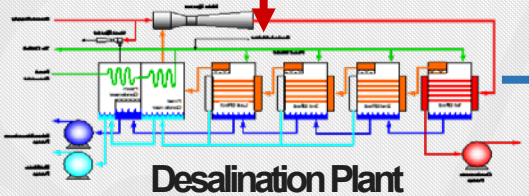


Hot Water

Heat supply

Steam

Sea Water



Fresh Water

❑ Electricity and Water for a City of 100,000 ~ 500,000 Population

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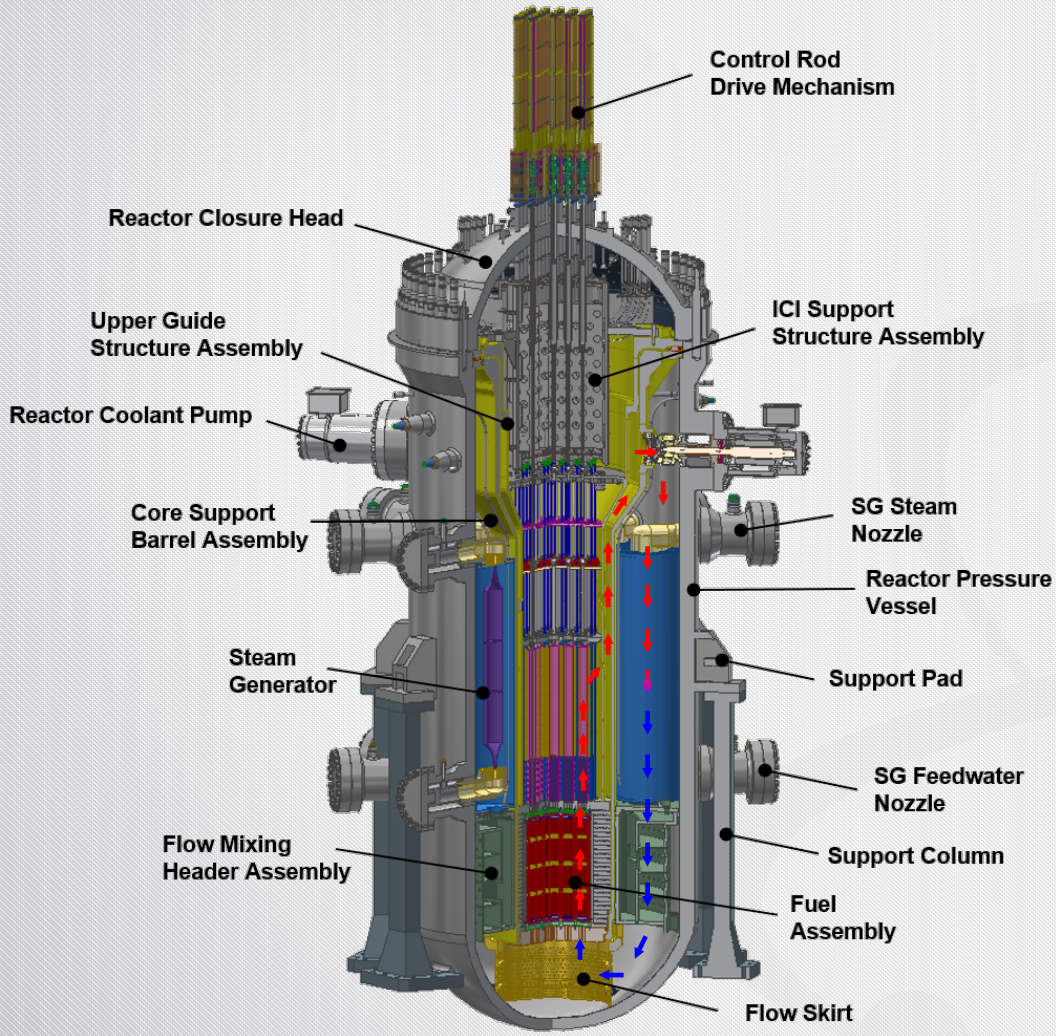
03 SMART100 Reactor Vessel Assembly



- **No large RPV penetration**
  - Less than 2 inch penetrations
  - Penetrations above the top of SG
- **In-Vessel Steam Pressurizer**
- **4 Reactor Coolant Pumps**
  - Canned motor type
  - Horizontally mounting
- **8 Helical Steam Generators**
  - Once through SG
  - Produce superheated steam
  - Inlet orifices (DWO)
- **Flow Mixing Header Assembly**
- **57 Fuel Assemblies**
  - Standard 17x17 UO2 (< 5 w/o U235) w/ reduced height (2 m)
  - Performance proved at operating PWRs

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04 Site Plot for 2 SMART100 Units

05 Current Status

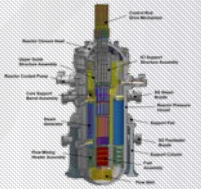
Development Chronicle

’97~’99	’99~’02	’02~’06	’09~’12	’12~’15	’16~’18	’19~
Conceptual design	Basic design	Prototype	Standard design approval	Safety enhancement	Pre-project engineering	Standard design change approval (on going)



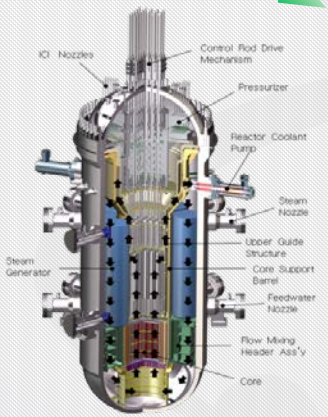




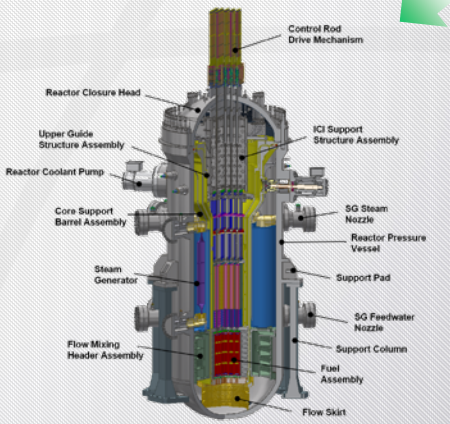


1997 1999 2002 2006 2012 2016 2018

330 MWt (100 MWe)



365 MWt (110 MWe)



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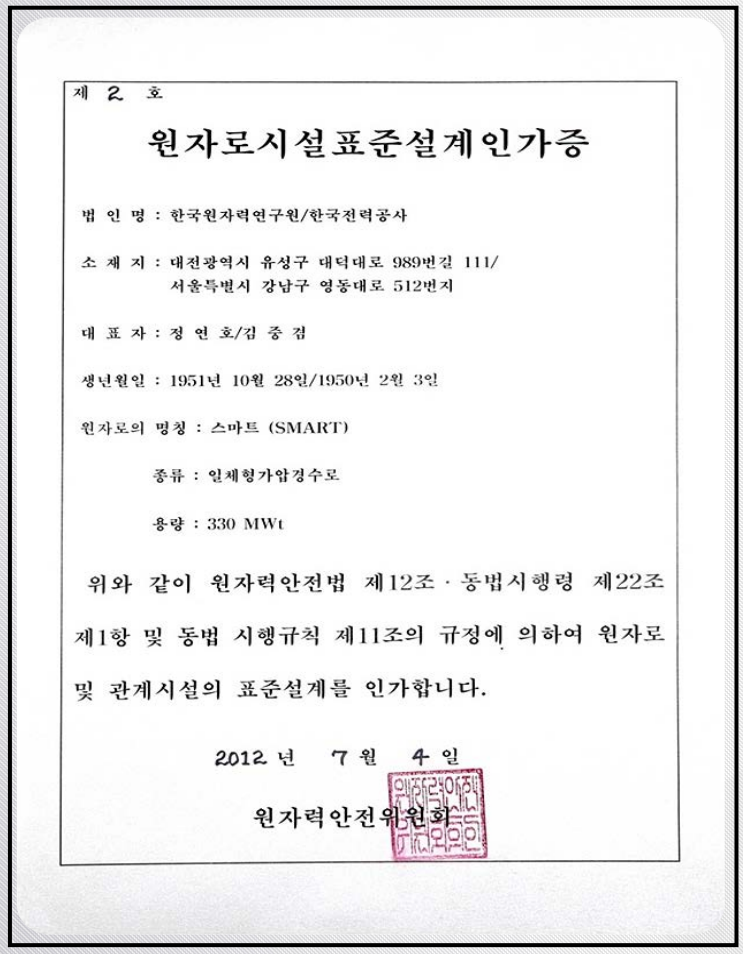
06 Standard Design Approval (2012)



제 2 호

원자로시설표준설계인가증

법 인 명 : 한국원자력연구원/한국전력공사

소 재 지 : 대전광역시 유성구 대덕대로 989번길 111/
서울특별시 강남구 영동대로 512번지

대 표 자 : 정 연 호/김 중 겸

생년월일 : 1951년 10월 28일/1950년 2월 3일

원자로의 명칭 : 스마트 (SMART)

종류 : 일체형가압경수로

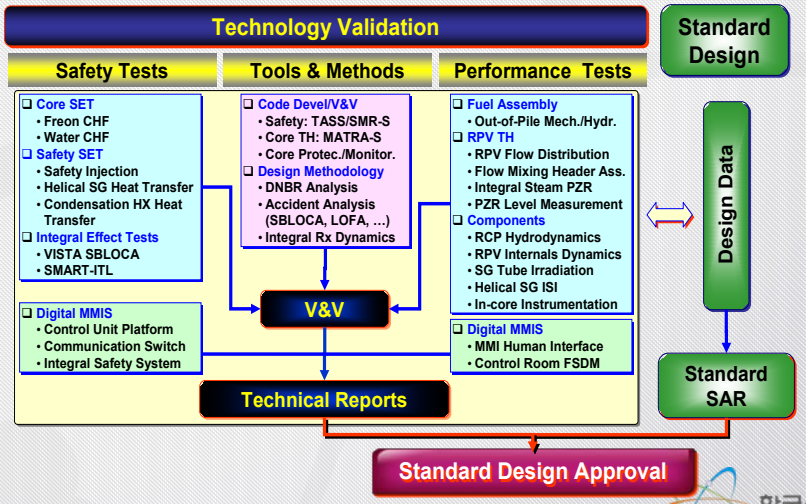
용량 : 330 MWt

위와 같이 원자력안전법 제12조 · 동법시행령 제22조 제1항 및 동법 시행규칙 제11조의 규정에 의하여 원자로 및 관계시설의 표준설계를 인가합니다.

2012 년 7 월 4 일

원자력안전위원회

- USD 300 M$ Budget
- 1,700 MY Manpower
- ~50 Experiments and Tests
- 1.5 Years for Licensing Review
- ~2,000 Technical Q&As & RAIs
- Satisfaction of Korean Regulatory Norm



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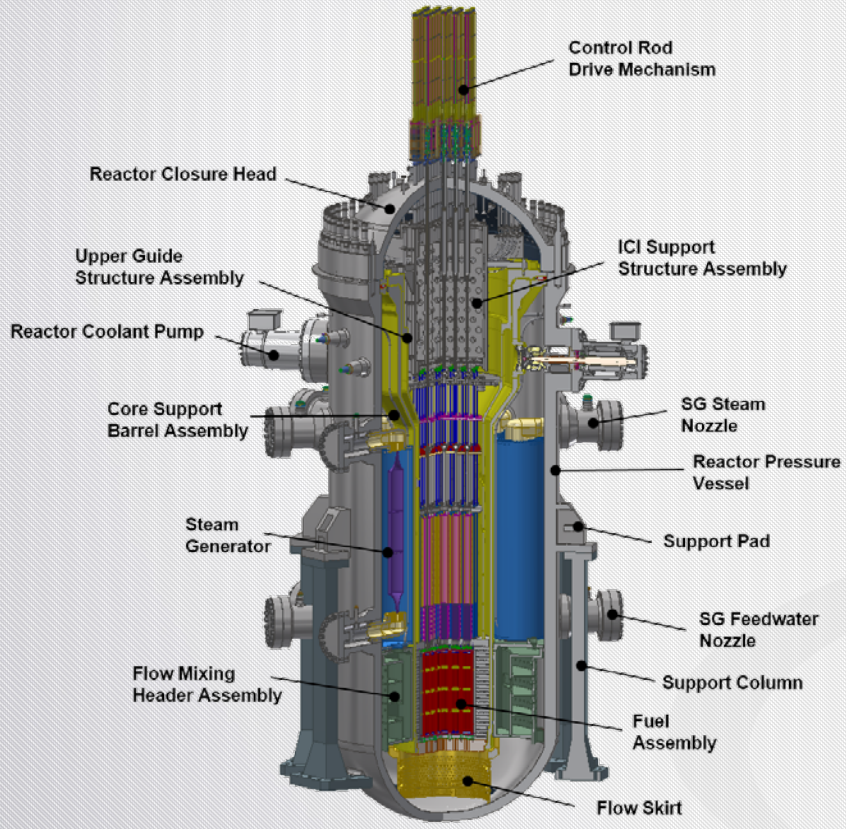
07 Standard Design Change Approval (on going)

Role of mechanical design group in SDA



- **Structural design**
  - Reactor pressure vessel, Reactor closure head
  - Reactor internals
- **Component design**
  - Reactor coolant pump
  - Steam generator
  - Control rod drive mechanism
- **CVAP**
- **Structural analysis**
  - Seismic analysis, BLPB analysis
  - Stress analysis

08 Codes and Standard

» SMART100 is designed in accordance with the requirements of KEPIC (Korea Electric Power Industry Code)

» Applicable codes and standard in SMART100 SDA

- ❑ American Society of Mechanical Engineers (ASME)
- ❑ American Nuclear Society (ANS)
- ❑ American Society of Testing and Materials (ASTM)
- ❑ American National Standard Institute (ANSI)
- ❑ Institute of Electrical and Electronics Engineers (IEEE)
- ❑ American Welding Society (AWS)

In viewpoint of mechanical design, conventional codes and standards for PWR are generally applicable for SSC design of SMR

But there are severe technical issues in several detailed points

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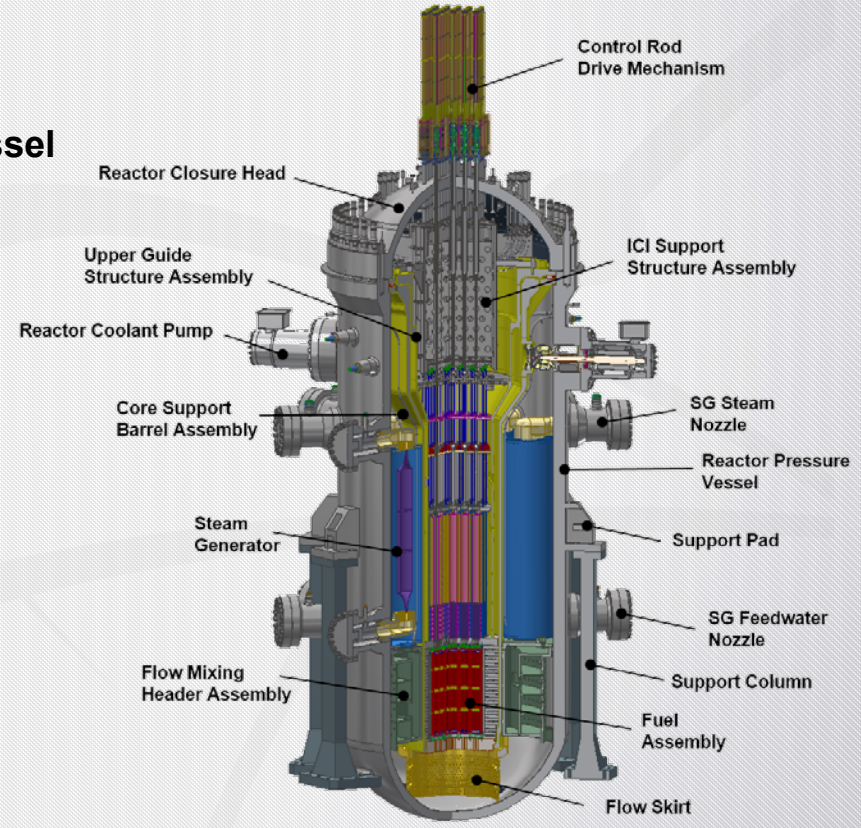
02 Technical Issues in SMART100 SDA

01 In-Service Inspection

ISI requirements (ex. ASME XI) are always challenging issue for SMR

- Inner surface of RPV
  - Complicate arrangement inside of vessel
  - Difficult to access weldments inside of vessel
  - All internals should be removed
- In-vessel steam generator
  - Steam generator installed inside of vessel
  - Low accessibility to SG tubes
- Reactor internals



Compactness

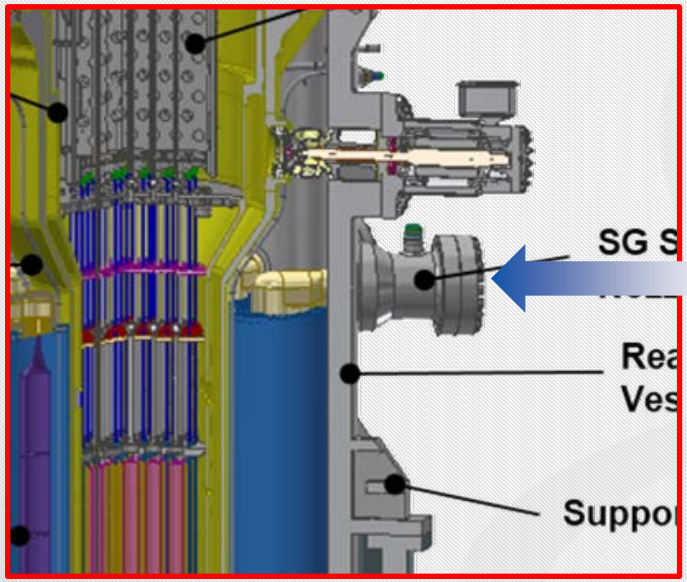
Target of SMR mechanical design

Difficulty increase in ISI

01 In-Service Inspection

Improvement of Design / Inspection Technology / Manufacture

- **Improvement of design**
  - **Structural design and arrangement considering accessibility**



Ex) Design of SG header

SG header and nozzle are designed

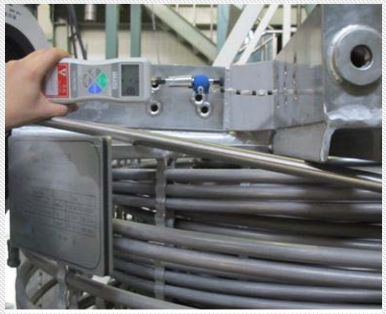
for all the tubes to be visible and accessible

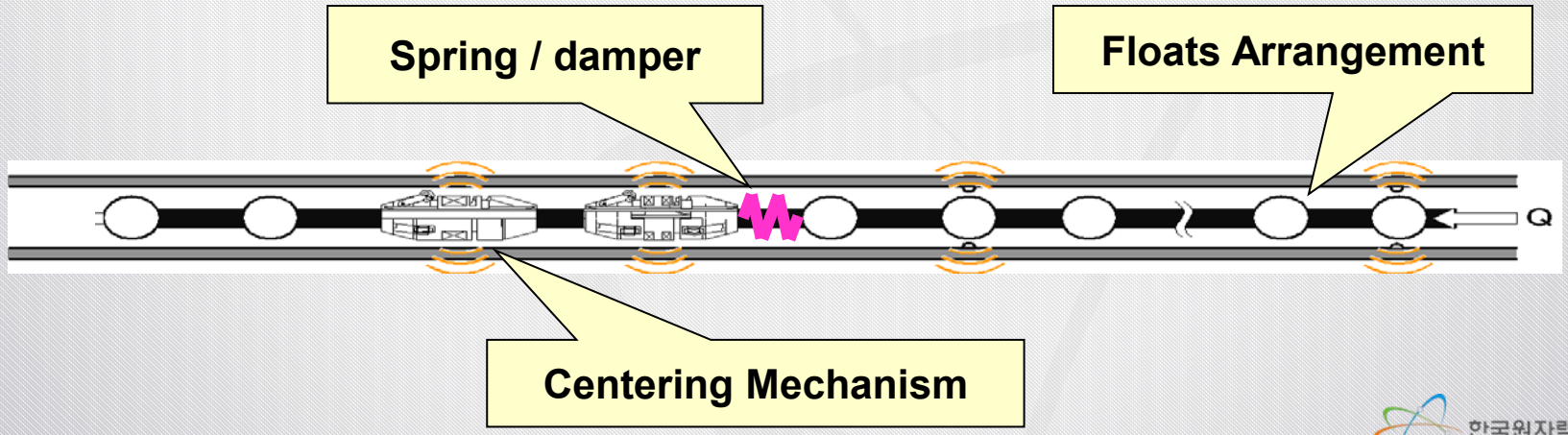
01 In-Service Inspection

Improvement of Design / Inspection Technology / Manufacture

- **Improvement of inspection technology**

Ex) Inspection of tube inside by using eddy current sensor w/ low frictional cable





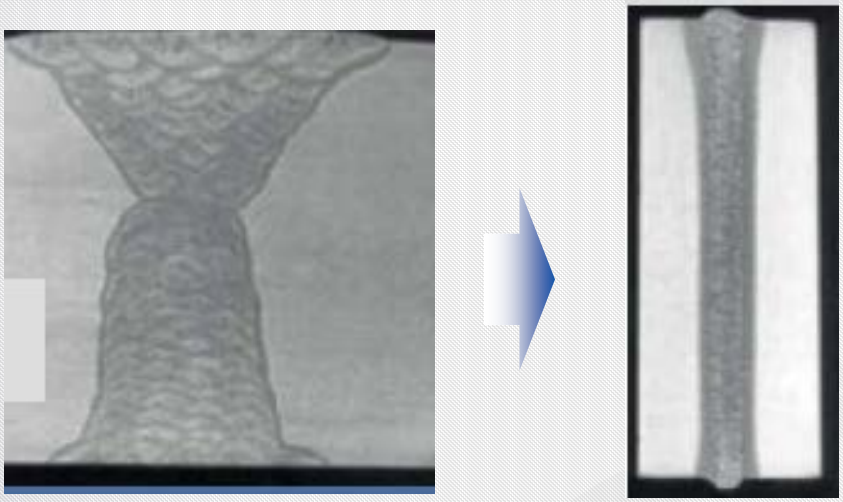
01 In-Service Inspection

Improvement of Design / Inspection Technology / Manufacture

- **Improvement of manufacturing technology**

1) Electron Beam Welding
2) Powder Metallurgy-Hot Isostatic Processing

Ex) Reduction of ISI area with elimination of weldment by applying innovative manufacturing (EBW[1], PM-HIP[2])



Elimination of Welds via Heat Treatment
-Resetting the Clock

Eliminate the Weld through re-austenitzation at high temperature. **How?**

- Perform chamber EB weld of sub-assemblies
- Solution HT, quench; normalize; temper
- Resulting microstructure is same as base metal
- Fracture toughness comparable to base material

* EPRI

For the design / manufacturing improvements, adequate code and standard are required

(Ex. manufacturing standard, material properties of base metal at higher temperature, and so on)

Difficulty in Comprehensive Vibration Assessment Program

- **Complicated reactor internals**

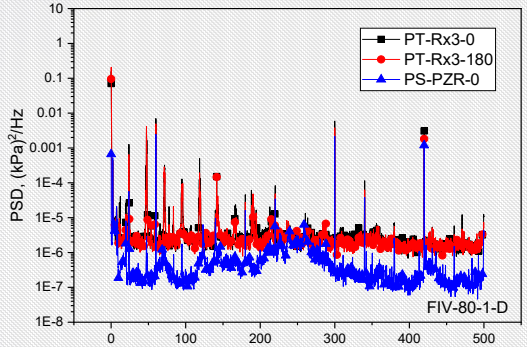


Fig. 3.1.2-16 PSD of RX3 & PZR

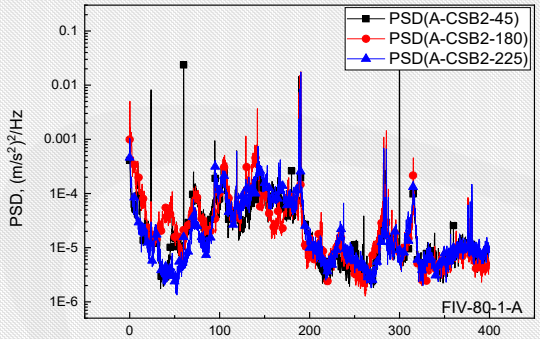


Fig. 3.1.3-8 PSD of CSB2

Example of measured signal from complicated structures

- **Excitation by multiple RCPs**
- **Space limitation in layout for sensor and their conduits**
- **Definition of reactor internals**
  - ✓ **Reactor internals in conventional PWR: CSB, UGS, and so on**
  - ✓ **Reactor internals in SMR: SG? RCP? CRDM?**

Our action and suggestion

- **Design simplification of scale model test**
  - ✓ **Simplification of measured signal with maintaining vibration characteristics of SMR**
- **Consider path of sensors and conduits at initial stage of reactor internals design**
  - ✓ **Sensors and their conduits should be removed after measurement**
- **Utilize inspection program with limited measurement**
  - ✓ **The inspection program with limited measurement can be replaced instead of extensive measurement requirements**

03 RV Surveillance Program

Requirements based on conventional PWR

- **Generally, SMR has lower thermal power**
  - ✓ **Shorter active core length**
  - ✓ **But, the same requirement for RV surveillance**

	USA Regulation	Korea Regulation	APR1400	SMART
Core Height (m)	-	-	3.81	2.00
Total No. of Specimens	52	69	108	
Total No. of Temp. Sensors	1 Set	Not Specified	1 Set	
Total No. of Neutron Sensors	3 Set	Not Specified	3 Set	

- **Reduction of mandatory total number of specimen?**

  Mitigate temperature requirement?

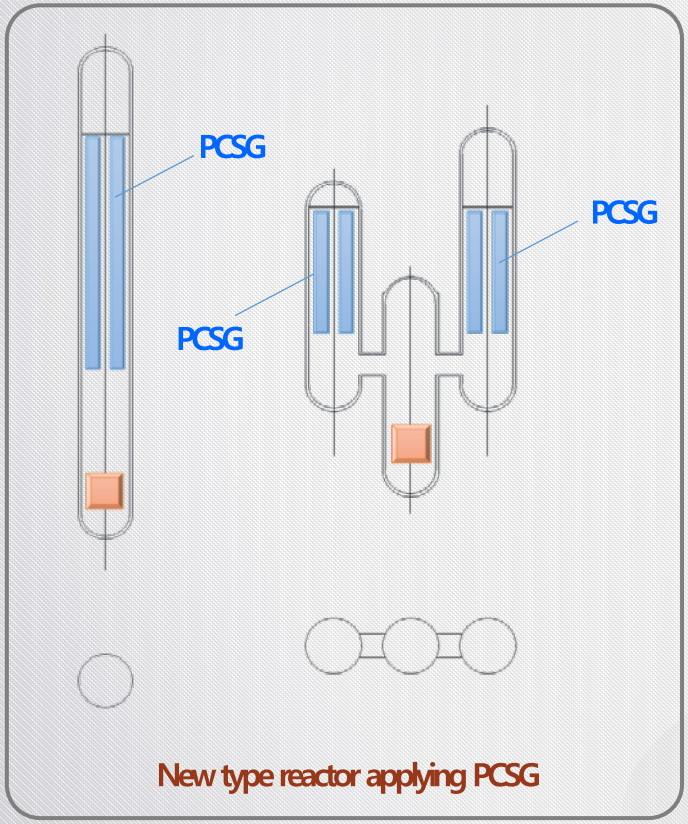
  Allow use of small sized specimen?

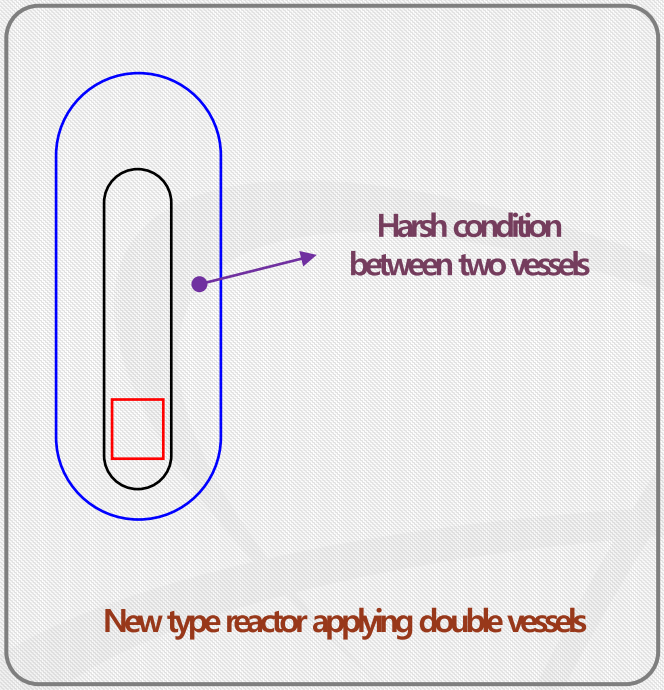
  Allow another surveillance mechanism?

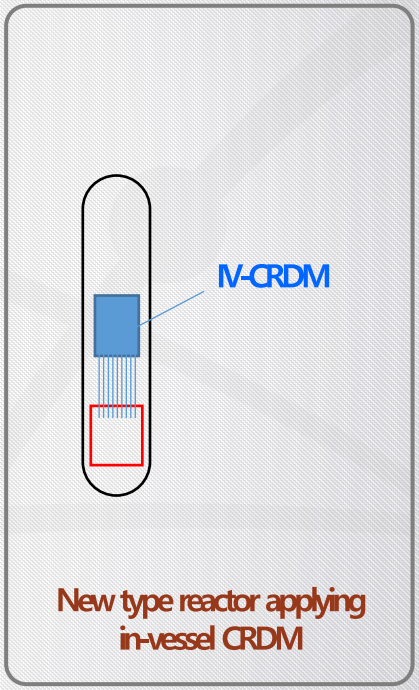
Minor example that can shows gap between SMR design and code & standard

03
Technical Issues in Next SMART

Researches for innovative technology







Innovative technology can be developed, but hardly applied to innovative reactor without adequate code and standards

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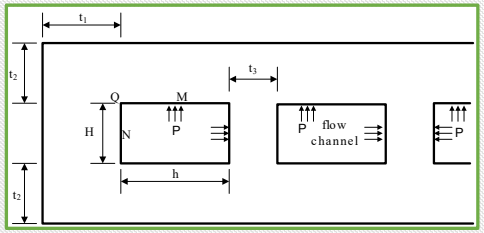
02 Printed Circuit-type Steam Generator

Compact SMR design adopting PCSG

- **No applicable code for structural design of PCSG**
  - ✓ **Regulation problem without applicable code**

- **Stress calculation**
  - ✓ **No applicable code in ASME Section III**
  - ✓ **Utilizing ASME Section VIII**

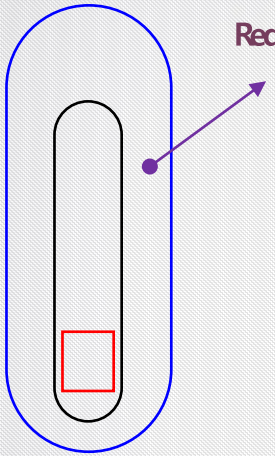


*ASME Sec. VIII Part 1. 13-9 (Rectangular shape flow area only)

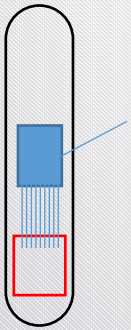
- **Manufacturing, test, and inspection**
  - ✓ **No applicable code in ASME Section III & VIII**

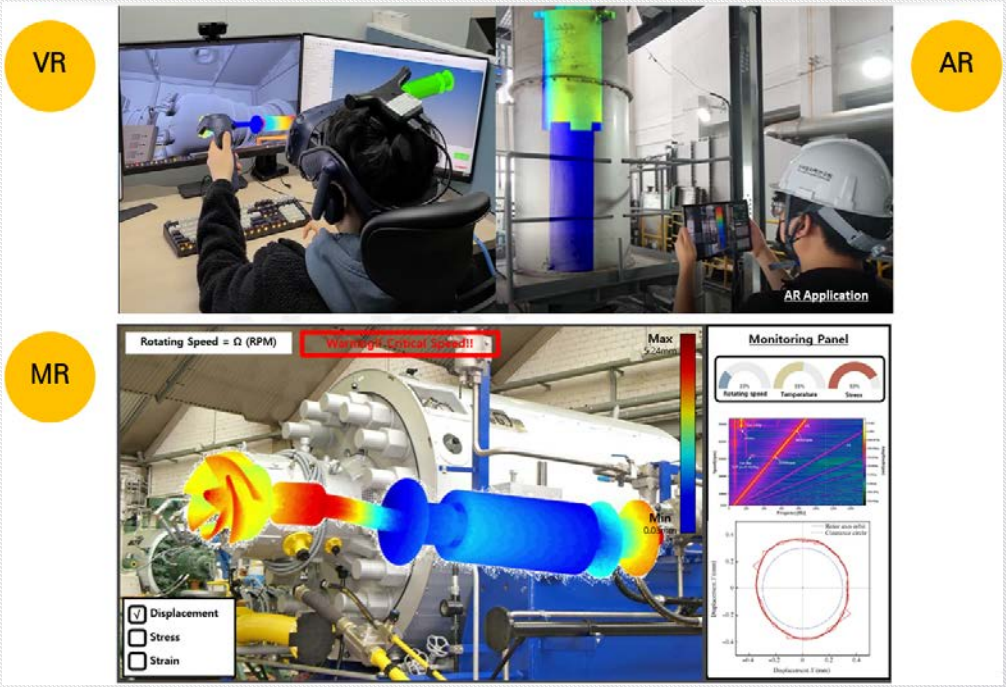
03 Measurement in Harsh Condition

Measurement technology using digital twin virtual sensing for harsh and inaccessible area



Requirements of measurement in harsh and inaccessible region increase as the SMR becomes compact and complicated





*Digital twin virtual sensing technology based on real time simulation, KAERI

04
Concluding Remark

Concluding Remark

Technical issues in SMART100 SDA

- SMART100 is designed based on code and standards for conventional PWR
  - ✓ Generally, current code and standard are applicable for SSC design of SMR
  - ✓ But, there are severe gaps, mainly due to compactness, size, and complexity of SMR
- Gap between code/standard and SMR design is on going issues in SMART100 SDA

Technical issues in innovative technology

- Innovative technology should be developed and applied for innovative design of SMR
- Code and standard for innovative technology are key issues for regulation of new SMR

Innovative technology can be developed, but hardly applied to innovative reactor without adequate code and standards