Nuclear Physics Seminar at University of Warsaw

Introduction to SMART

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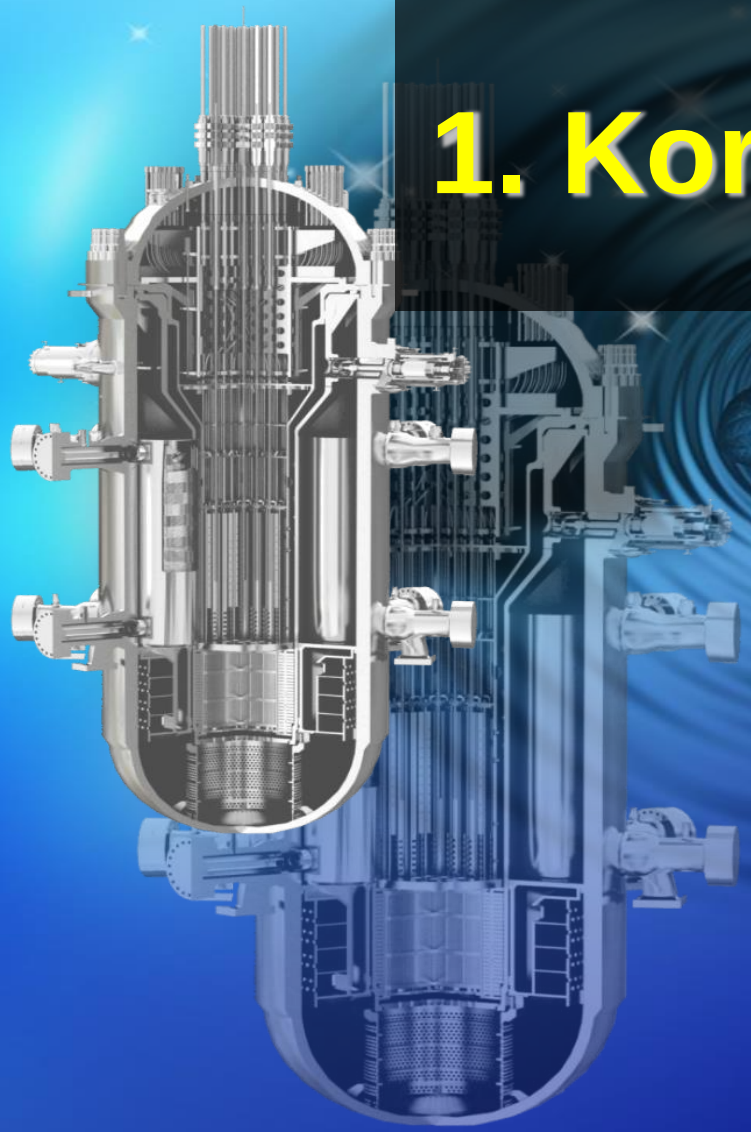
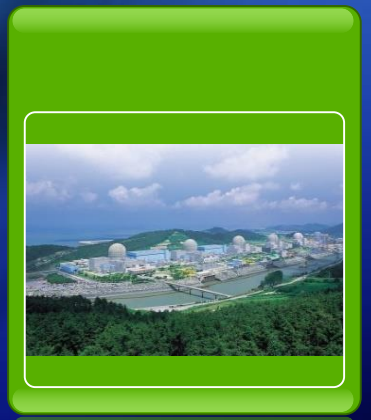
KEPCO INTERNATIONAL NUCLEAR GRADUATE SCHOOL

Outline

1. Korean Nuclear Power Plant
2. SMR Characteristics
3. SMART Development
4. Summary

1. Korean Nuclear Power Plant

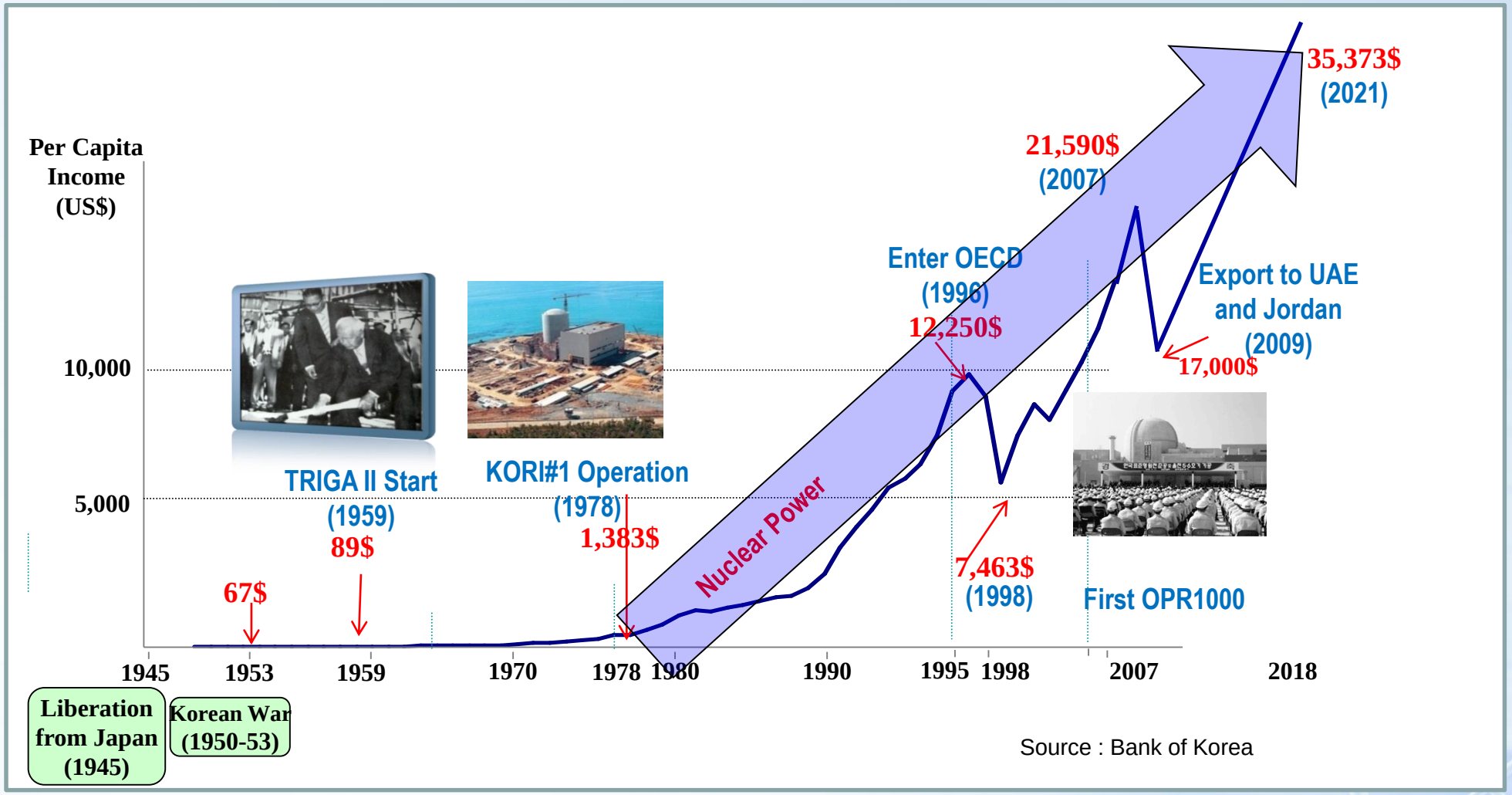




Korea at a Glance

- Difficult Environment
  - Small Land, High Population, Rare Natural Resource, Divided Country
    - Land size 99,000 km^2 (108th)
    - 50Mth Baby Girl born on June 23, 2012
    - Energy Consumption 9th, Oil Consumption 7th, Oil Import 4th
    - Highest Soldier Density.
- Fastest Developed Country
  - Good Quality of Human Resource, High Level of Technology, Diversified Industry
    - Trade : 1,415B$ (2022)
    - Per Capita Income: 35,373$ (2021)
    - Enter 30-50 Club(2017) (US, Japan, German, France, UK, Italy, Korea)

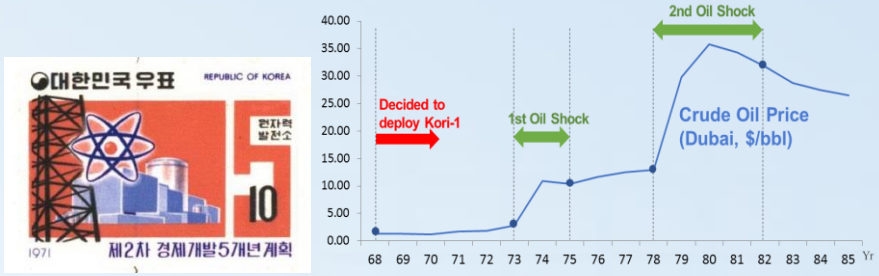
Korean Economy and Nuclear



Nuclear Energy → Locomotive to Korean Economy

The Least Country, but Bold Investments

Korean War (1950~1953):
Total devastation



Decision to Construct Kori-1(1968)
based on the 2nd Five-year Economic Development Plan

TRIGA-Mark II
Ground-breaking Ceremony
(1959)

1958: Started the first nuclear research reactor project (Investment: $350,000, ~1.5% of total government budget*)

Construction of Kori-1(587MWe)**
(1971~1978)

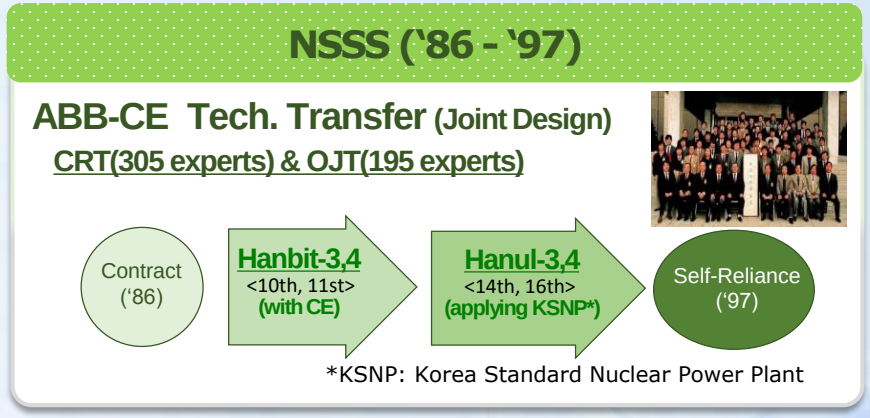
1971: Started the first NPP construction (Total Construction Cost: $493 million, ~25% of the total government budget)

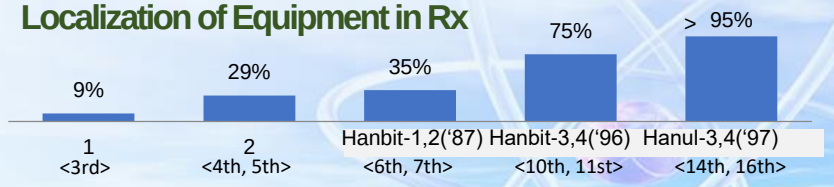
* $23 million, Half of revenue from foreign aid

** 23% of total generating capacity(2.5GWe) in 1971

ROK Nuclear Tech. Self-Reliance

- 0th Stage: Buy and Run
  - Buy from Westinghouse, Framatome, AECL
  - Turn-key and Local Participation as Subcontractors
- 1st Stage: Build with Technology
  - Technical Transfer Agreement with CE for Hanbit 3&4 Construction
  - Class Room Training (CRT), On Job Training (OJT), Joint System Design (JSD)
    - ~200 Men for ~2 Years in CE (Mostly Fresh Graduated and Recruited)
- 2nd Stage: Lead Project with Partner's Help
  - Through Hanul 3&4 Construction
  - Project Management , Design and Engineering led by Korea
    - CE helped as Technical Review and Consulting
- 3rd Stage: Build Own NPP
  - From Hanbit 5&6 Construction
- 4th Stage: Develop Own System
  - SMART, APR1400, APR+, SFR, VHTR



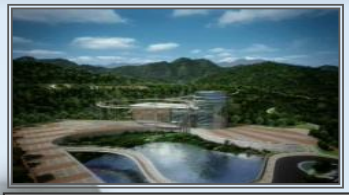


Accomplishments in 60 years

"From Import to Export"

Korean Nuclear Power Plants

- In operation (25 units / 24,650 MW)
- Under construction (3 units / 4,200 MW)
- Permanent Shutdown (2 unit / 1,266 MW)



Radioactive Waste Disposal Facility

Seoul

Hanul Plant

Hanul 1, 2, 3, 4, 5, 6

Shin Hanul 1, 2

Wolsong Plant

Wolsong 1, 2, 3, 4

Shin Wolsong 1, 2

Saeul Plant

Shin Kori 3, 4, 5, 6

Kori Plant

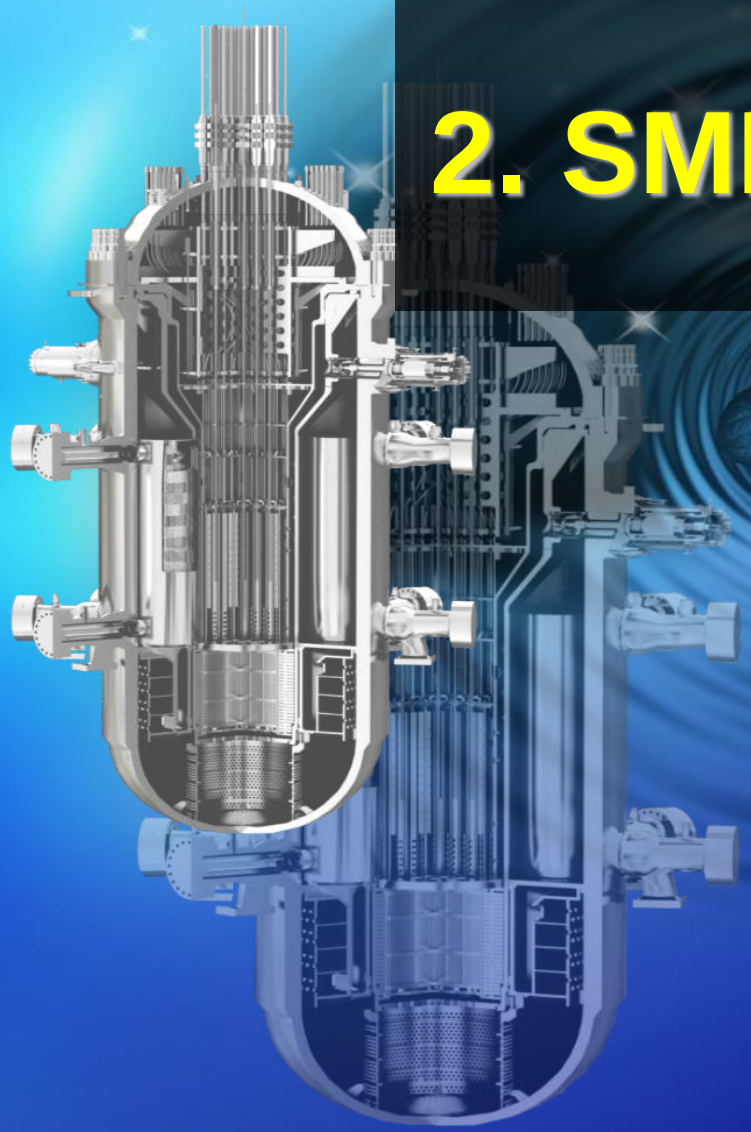
Kori 1, 2, 3, 4

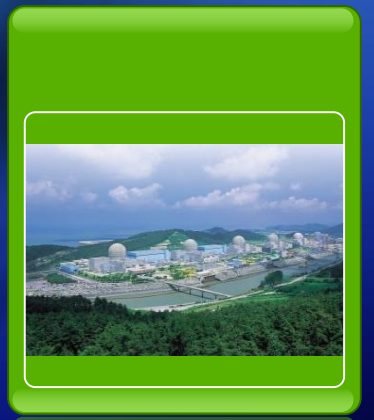
Shin Kori 1, 2,

Hanbit Plant

Hanbit 1, 2, 3, 4, 5, 6

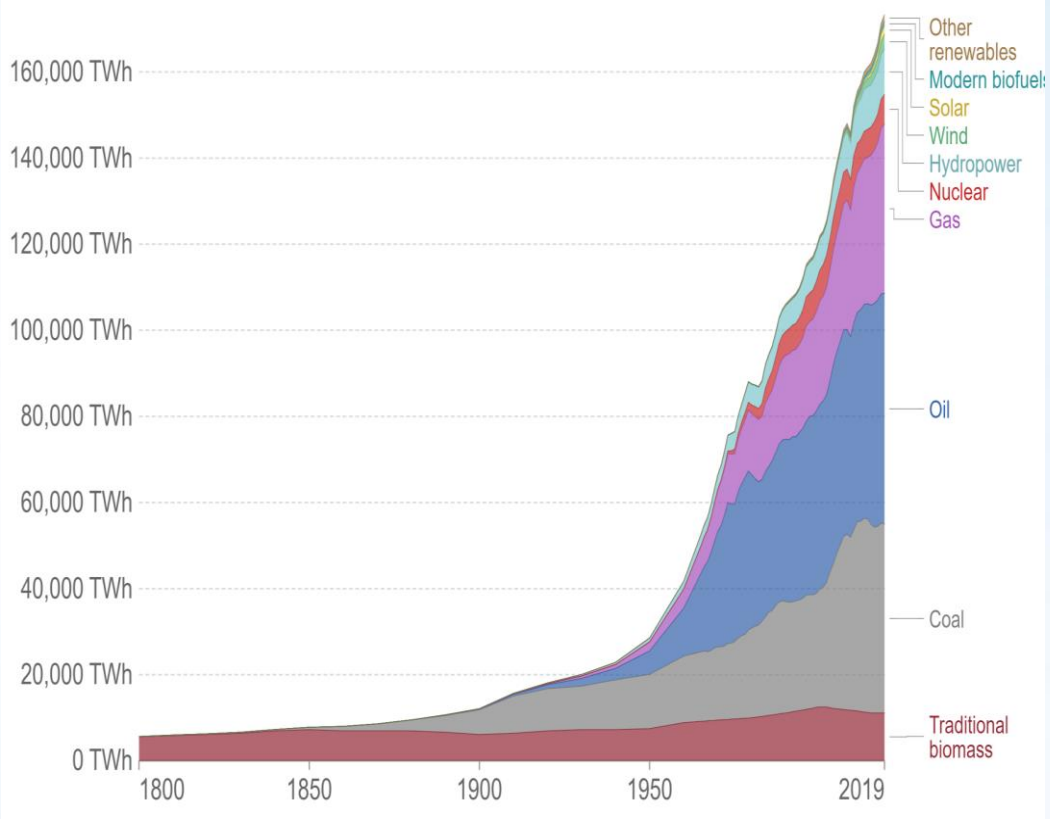
2. SMR Characteristics





Energy Consumption and Energy Source

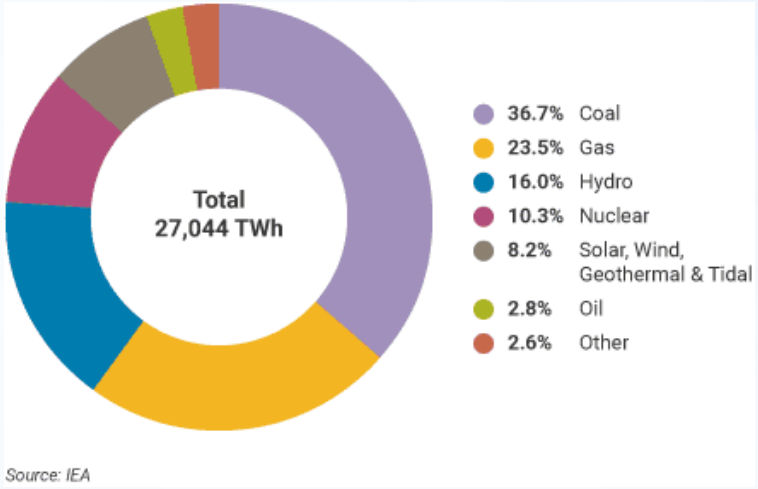
❑ Energy Consumption

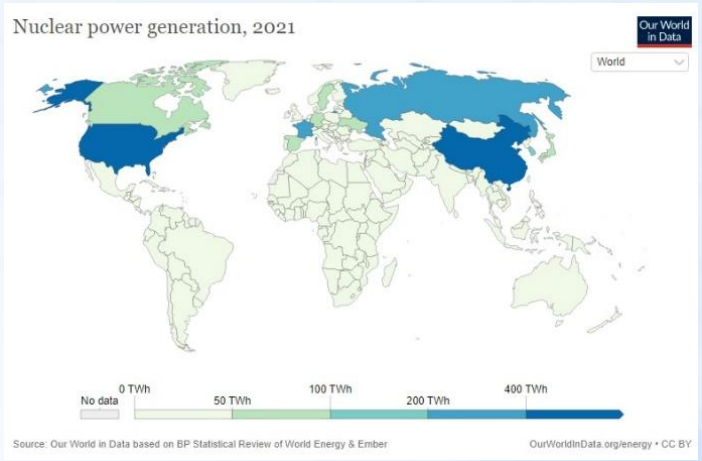


- Energy Sources
  - Fossil Fuel
    - Oil, Coal, Gas
  - Renewables
    - Hydro, Solar, Wind, Geothermal, Wave
  - Nuclear Energy
- For the long-term ambitions of net-zero energy policy, Nuclear energy is key energy with renewables.

Nuclear Energy

- Nuclear Power Plant
  - 438 NPPs are in Operation in 30 Countries(2022)
  - 57 NPPS are under Construction
- Nuclear Energy is contributing to world energy supplies on a large scale
  - 10.3% of Global Electricity Supply (2021)





Issues on Nuclear Energy

- Economics: Suffers from Shale Gas (in USA)
  - Gas Power Plant has Competitive Economics over Coal and NPPs
- Public Opposition
  - on Economics, Safety, Waste Disposal and Proliferation
  - Declining Industry in Some Western Countries(USA and UK)
- NE has the Potential to be Expanded if the Challenges are Addressed
  - Challenges on safety, non-proliferation, waste management, public opinion, social license challenges, and economic competitiveness
- Limitation of Large NPP
  - Large Scale Initial Investment
  - Long Construction Time
  - Good for Large Size Grid

SMR Definition

❑Definition

- Small and Medium size Reactor by IAEA (Late 1990)
  - Small size Reactor : up to 300MWe
  - Medium size Reactor: from 300MWe to 700 Mwe
  - Large size Reactor: Larger than 700MWe
- Small Modular Reactor by USA DOE (Late 2000)

❑ANS Position Statement

- SMR are considered to be nuclear reactors with power levels less than or equal to 300MWe.
  Some of these reactors are designed to stand alone and some can be deployed as modules

Drivers of SMR Deployment

Safety

- Passive Safety System Inherent Safety Features
- Innovative Technologies

Public Accepted Safety

Economics

- Standardization
- Modularization and Manufacturing Innovation

Cost Reduction and Accelerating Deployment

Flexibility

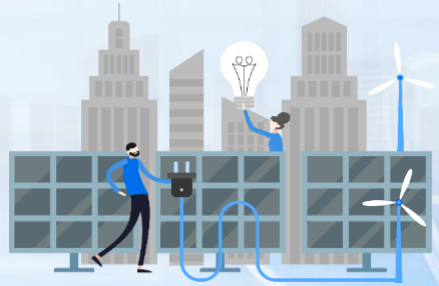
- Wide Operating Temp. Range
- Flexibility of Load-following

Various Application & Compensate Intermittent Renewable Energy

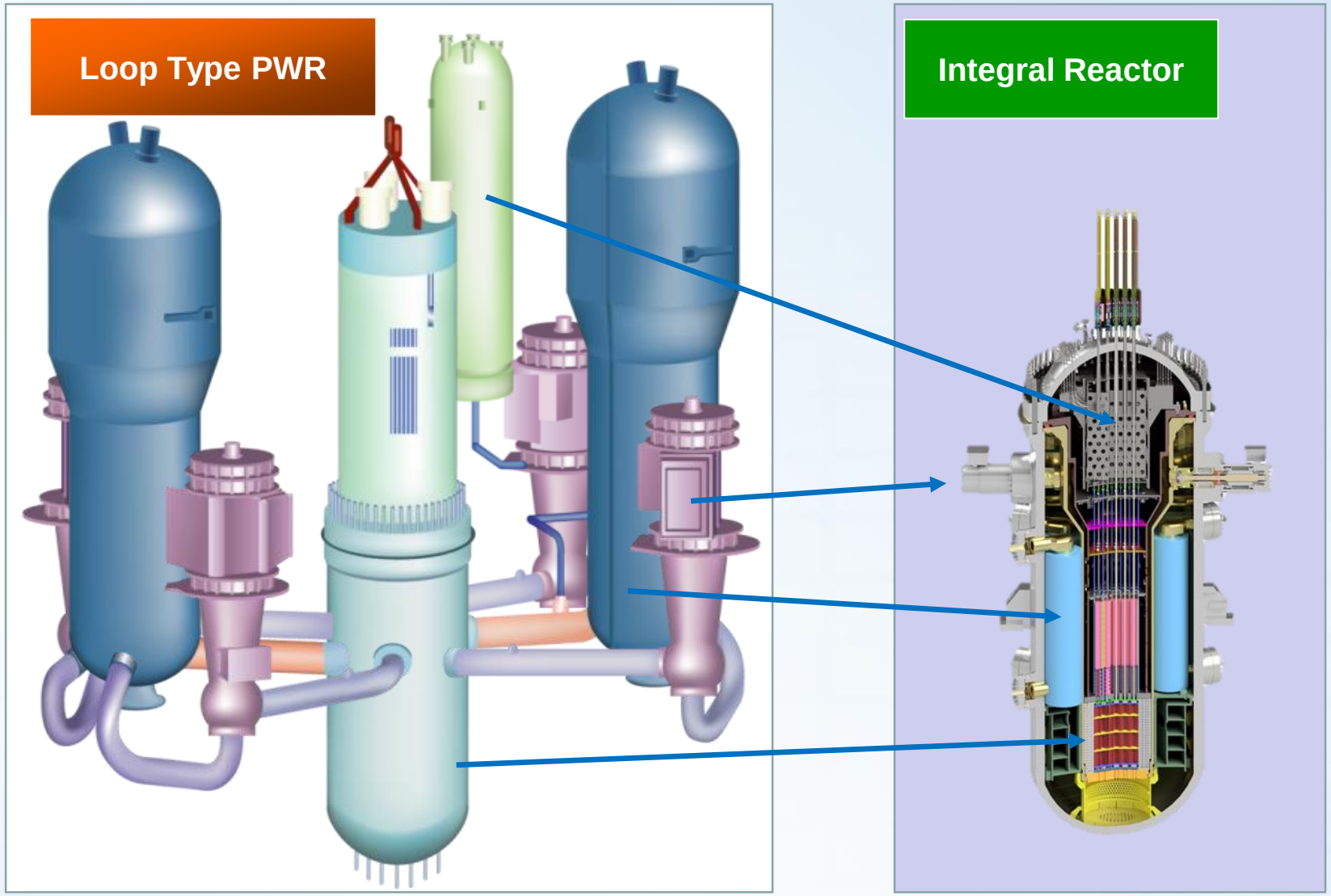
Clean Energy

- Environmental Friendly and Low Carbon Energy

Carbon Free Energy



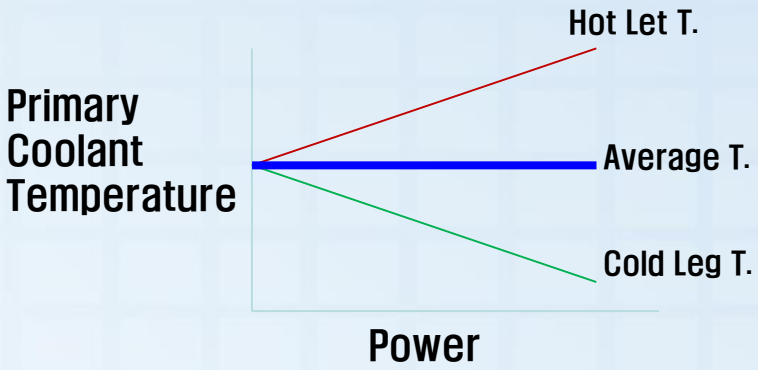
Integral Reactor



- ❑ Advantage
  - Eliminates Loop Piping and External Components, thus making Safety Systems more Simple and and Compact
  - Eliminates the possibility of Large Break LOCA
- ❑ Disadvantage
  - Large reactor pressure vessels will be needed
  - Difficulty of Maintenance

Load Following Operation of SMR

- SMR has Superior Capability of Load Follow Operation due to Design Characteristics
  - Short Active Core Height
    - Xenon Oscillation due to Power Fluctuation does not occur
  - OTSG(Once Through Steam Generator)
    - Constant Primary Coolant Temperature Program over Whole Power Range
    - Reduce the Burden of Coolant Volume Control and Reactivity Control due to Power Change
  - Easy Power Control
    - To control feed water flowrate will lead the reactor Power Control



- Easy Integration of SMR and Renewable Energy
  - Compensate for intermittency of renewable energy

Prospects of SMR Market

SMR market of 65~85 GW capacity expected until 2035

- Distributed grid, alternatives of old coal plants, seawater desalination, process heat supply, etc.
- 96.5% of existing power plants is small (<300MW).

Developed countries

- Clean and zero-emission alternatives of old coal-fired plants
- Stable backup of variable renewable energy system

Newcomer countries

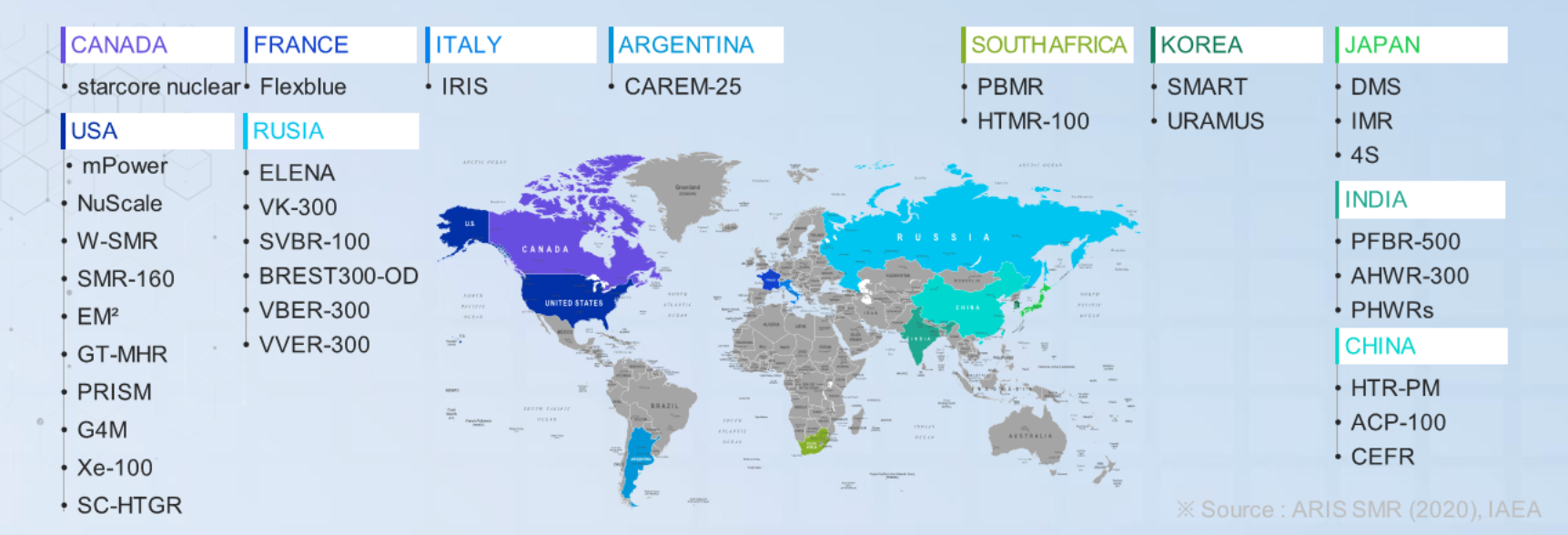
- Cheap and stable electricity supply
- Maintaining existing transmission line

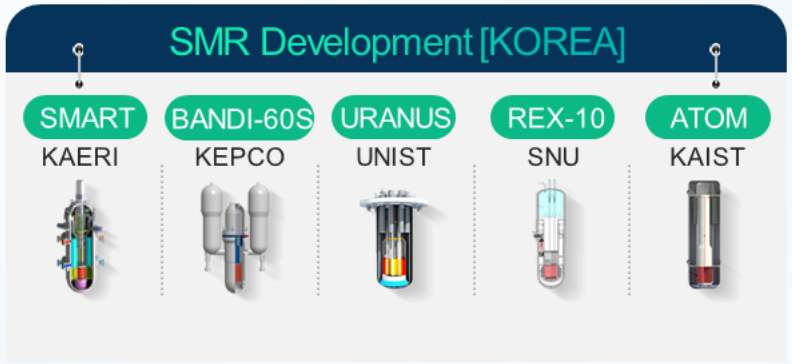
Ref : Markets and Markets (Sep. 2021)

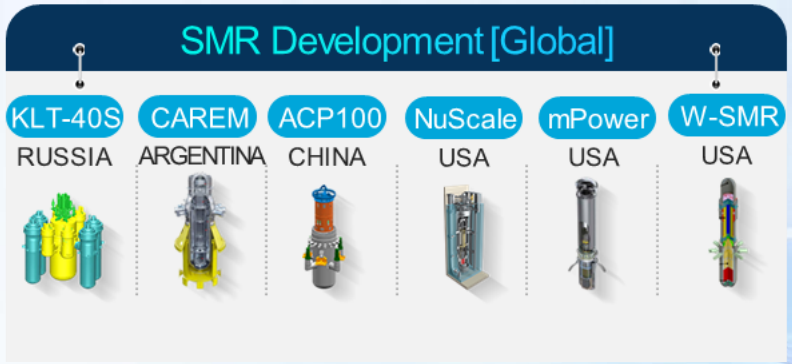
※ Source : Small Modular Reactors – once in a lifetime opportunity for the UK (2017)

Global SMR Development

- More than 70 SMR designs are under developed globally for different application.(IAEA ARIS)

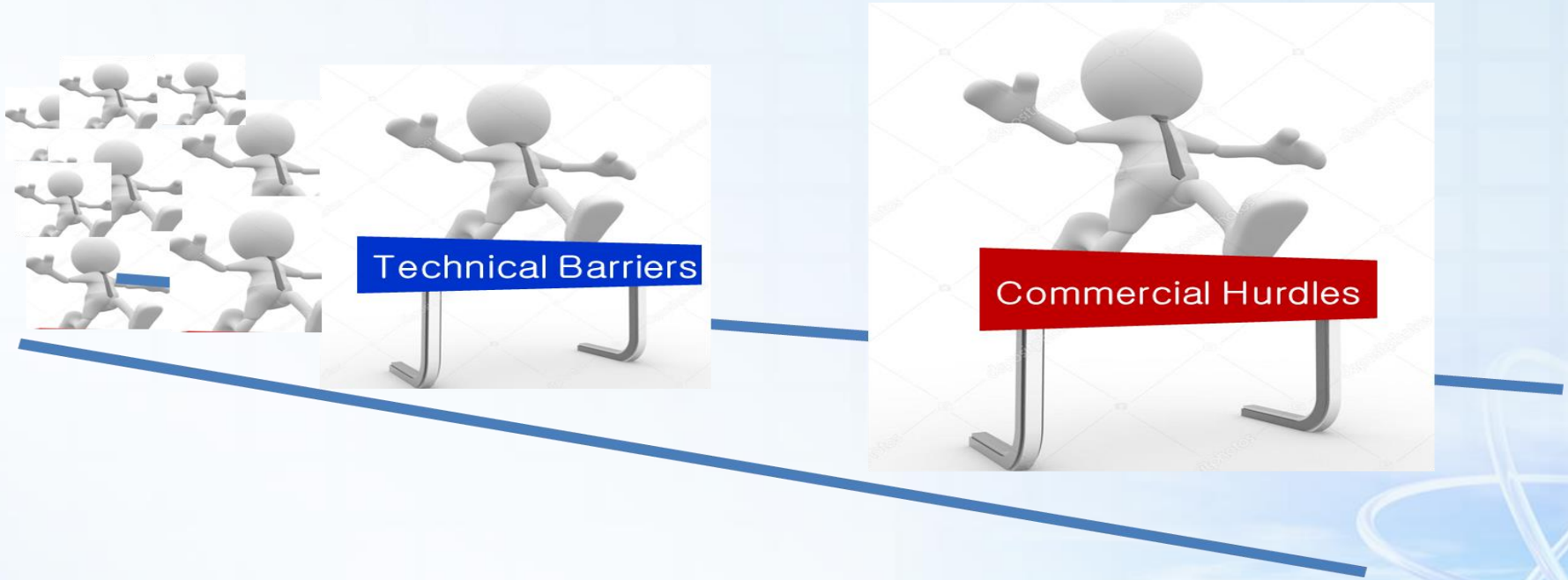




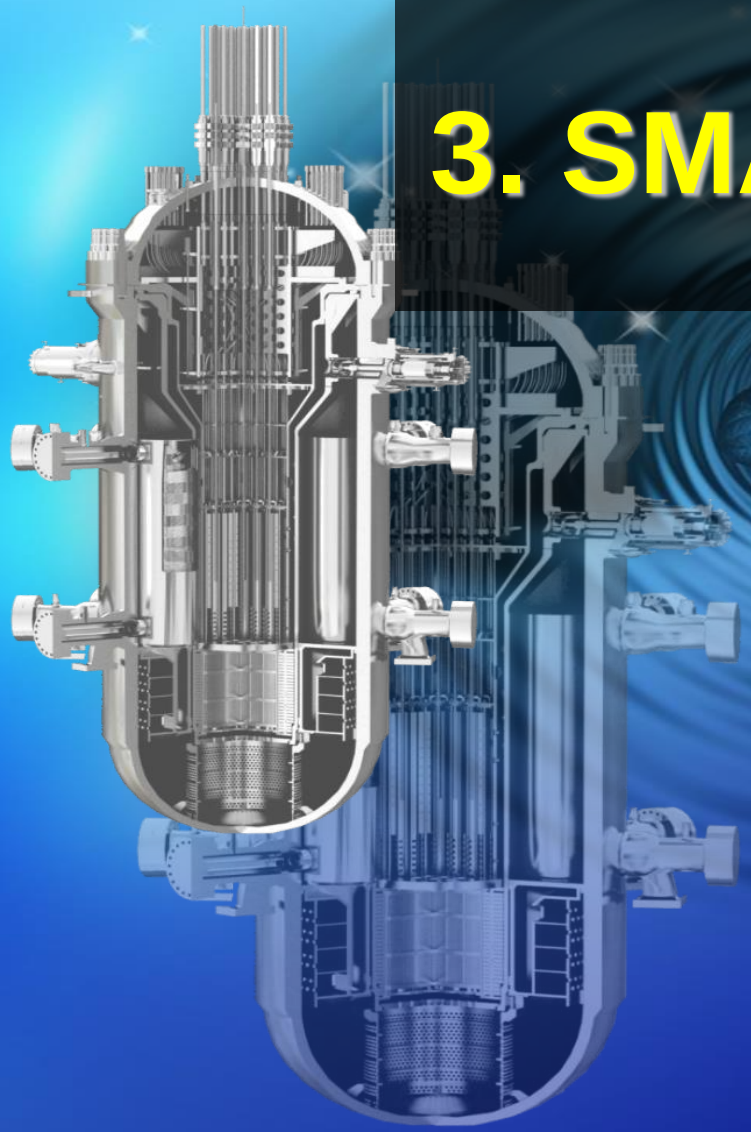


Challenges to Deploy SMR

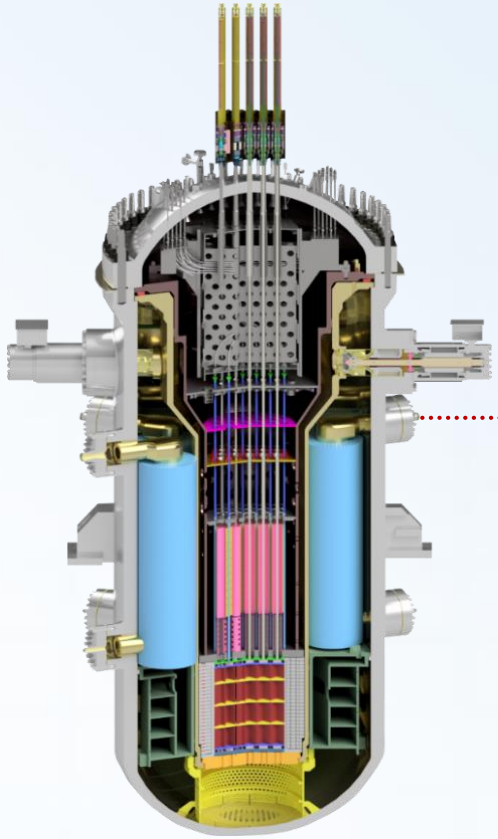
- Technical Barriers
  - Technology Validation through Experience, Test and Experiments
- Commercial Hurdle
  - Economic Justification Compared with Other Energy Sources and Demonstrate NPP Operation and Maintenance



3. SMART Developmnet



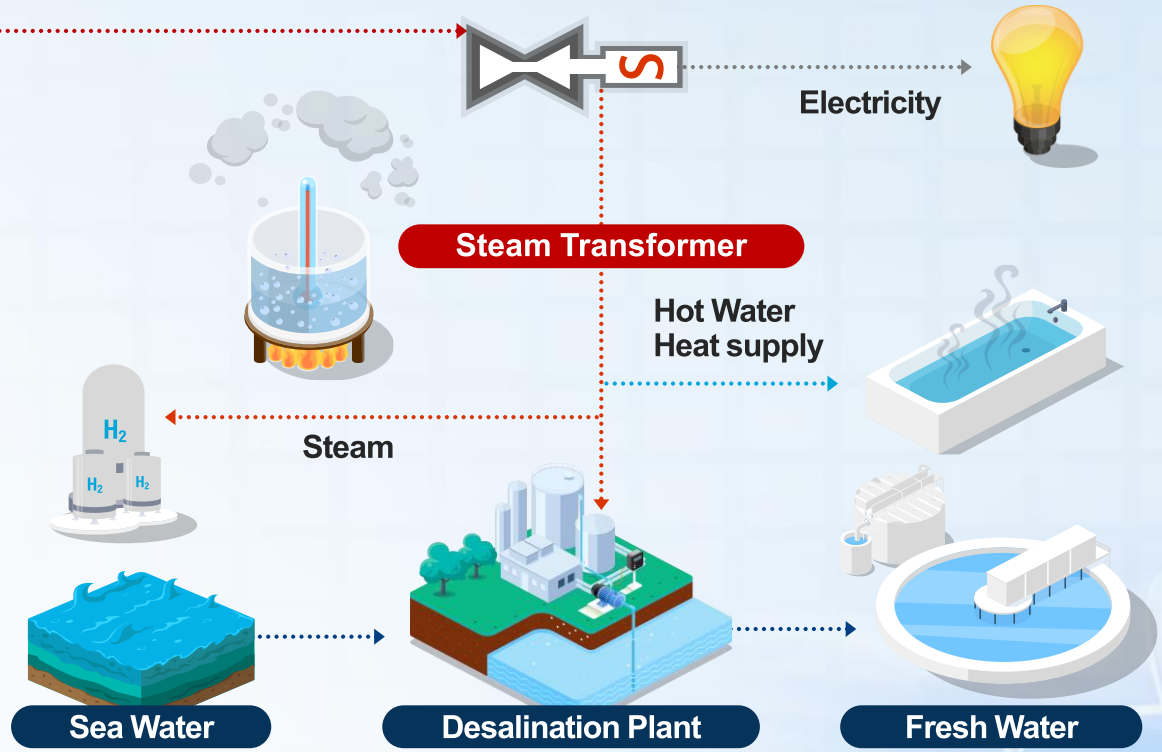
SMART



System-integrated Modular Advanced ReacTor

Advanced Integral PWR

for Electricity Generation and Seawater Desalination or District Heating



Thermal : 365 MWt

- 110 MWe
- 100MWe & 40,000 t water/day
- 86Mwe & 150 GCal/h

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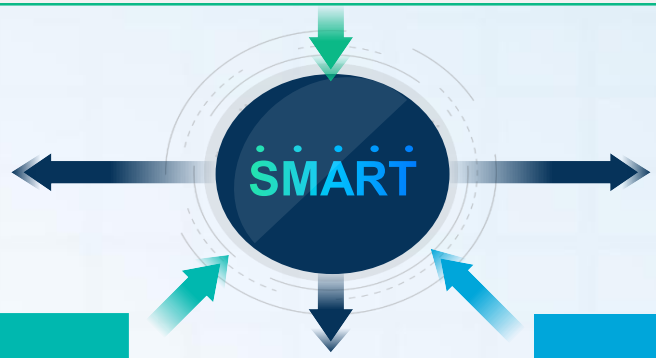
SMART Design Goals and Means

DESIGN INNOVATION

- Integral Arrangement of Primary Components
- Passive Safety System
- Inherent Safety Features

ENHANCED SAFETY



IMPROVED ECONOMICS

MODULARIZATION & SIMPLIFICATION

- Modularized Components
- Scalability with Multiple Units in one Site
- System Simplification

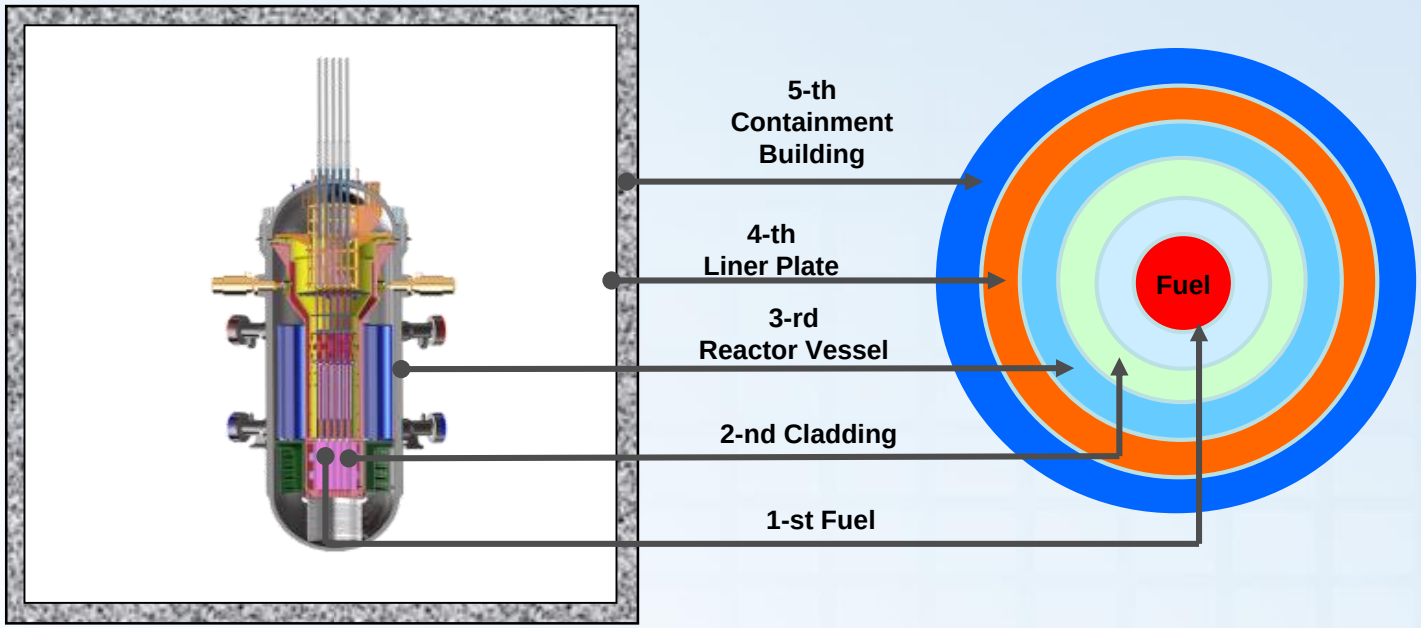
UPGRADED OPERABILITY

PERFORMANCE UPGRADE

- Advanced Man Machine Interface System
- Digital Core Protection/Monitoring System
- Wild Operation Range

SMART Safety

❑ Multiple Physical Barriers: Defense in Depth (DID)



❑ Step-by-step Design Approach for Safety Enhancement

- Minimize Accident Occurrence Possibilities
- Decrease the Possibilities of Fuel Failure Occurrences
- Lessen Consequences of Accidents and Radiation Release Paths

SMART Technology

❑ Harmonizing Innovative Concept and Proven Technology

Innovative Concept

- All Major Components in Rx Vessel
- Modularization for Field Installation and Maintenance
- Passive Safety System
- Fully Digitized Control System

Proven Technologies

- 17 x 17 UO_2 Proven Fuel Technology
- Control Rod Drive Mechanism
- Reactivity Control Concepts Using BP and Soluble Boron

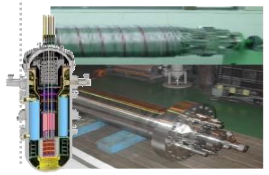
Comprehensive Technology Validation

Systems, Component, and Design Tools have been fully Developed and Licensed

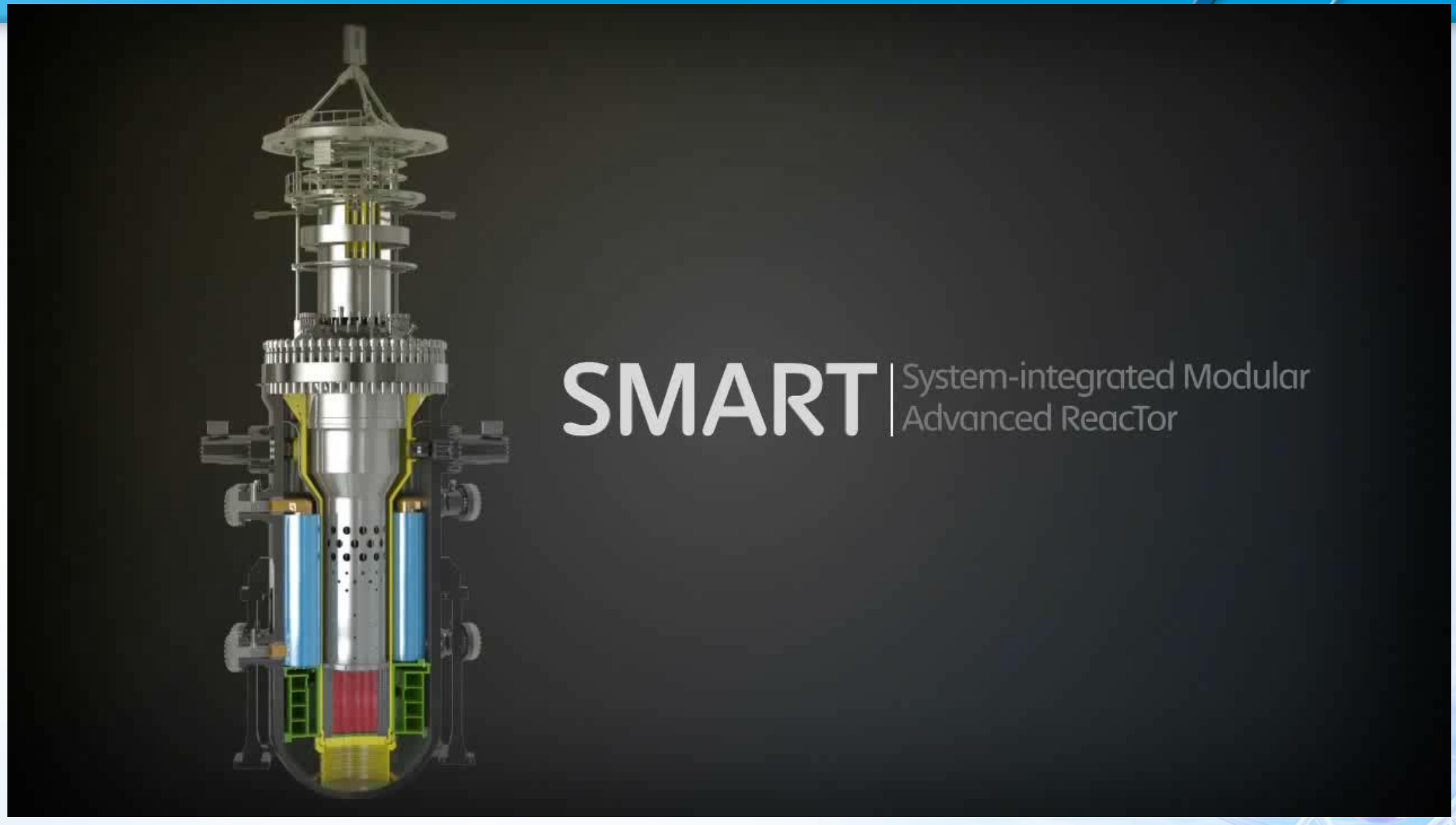
Separate Effect Tests

Integral Effect Tests

Component Development



SMART RVA (Animation Movie)



Technology Validation Experiments

Fuel TH Tests

- Fuel Performance Tests


TEST Fuel


Vibaration TEST


Measurements


TEST Section

- CHF Measurement Test


Spacer Grid


TEST Section

Mechanics and Components

- RPV Dynamics Test, RCP Mockup Test and Helical ISI Test


Dynamic Test


RCP TEST Loop


Low Friction Cable

- SG Tube Material (A690) Irradiation Test


Test Facility

Thermal - Hydraulics Experiment


PRHRS Heat Ex.

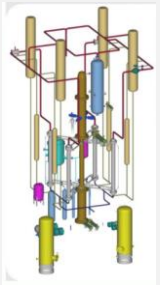

Safety Ingection


Pressurizer


VISTA Integral Test Facility

SMART - ITL

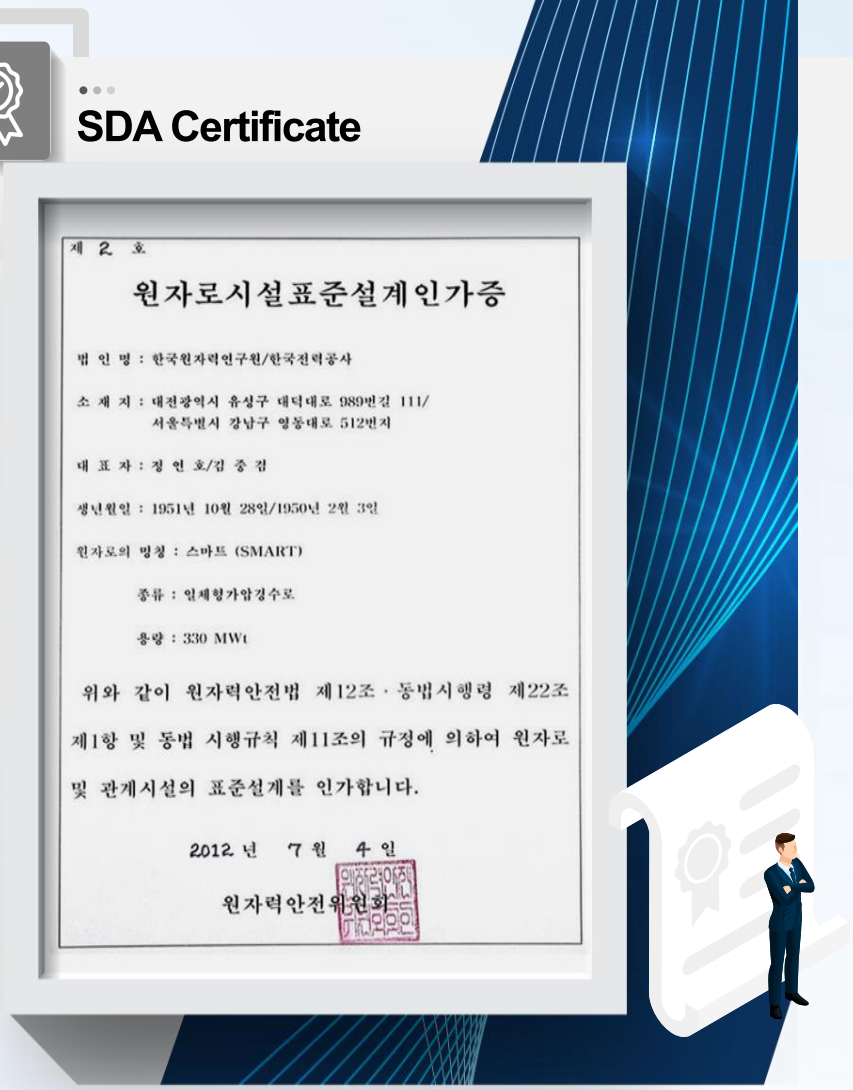
- World's Unique and Largest Full Scope Accident Simulation
  - 1:1 Height, 1/49 Volume



SMART - MCR Simulator

Standard Design Approval

SDA Certificate



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 인 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 300M$ 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

SMART Partnership with KSA

SMART = سمارت

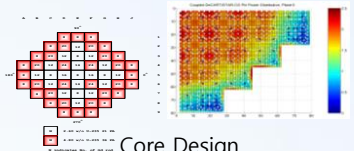
Joint Feasibility Study

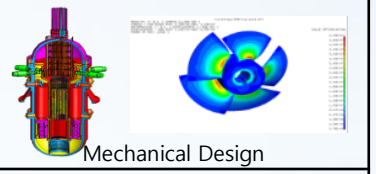
Partnership Cooperation

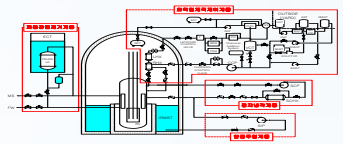
- ❑ SMART Partnership for Joint Commercialization
  - Joint Development and Shared IP Ownership
  - Joint Commercialization
  - Joint Marketing

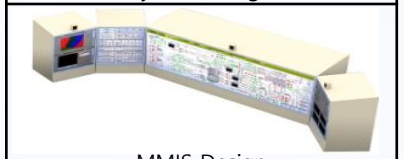
SMART FOAKE Design

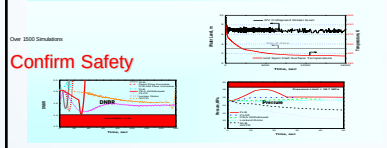
NSSS Design


Core Design


Mechanical Design

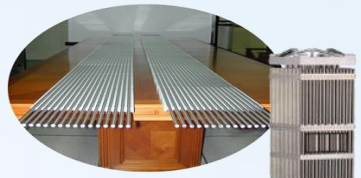

System Design

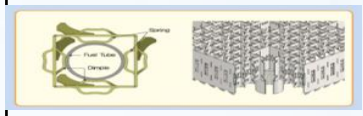

MMIS Design

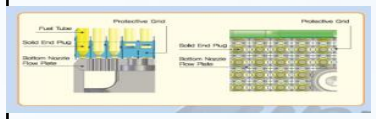


Safety Analysis

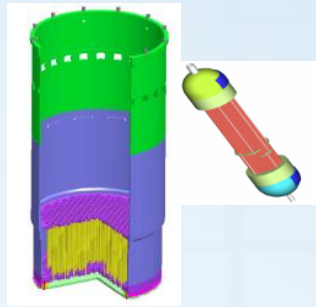
Fuel Design

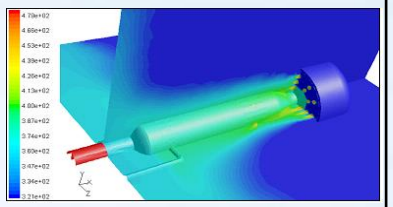

Fuel Design




Fuel Assembly Design

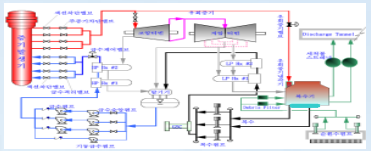
Component Design


Component Design

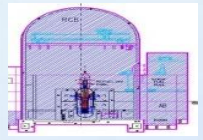

Component Design Analysis


Equipment Vendor Survey

BOP/AE Design

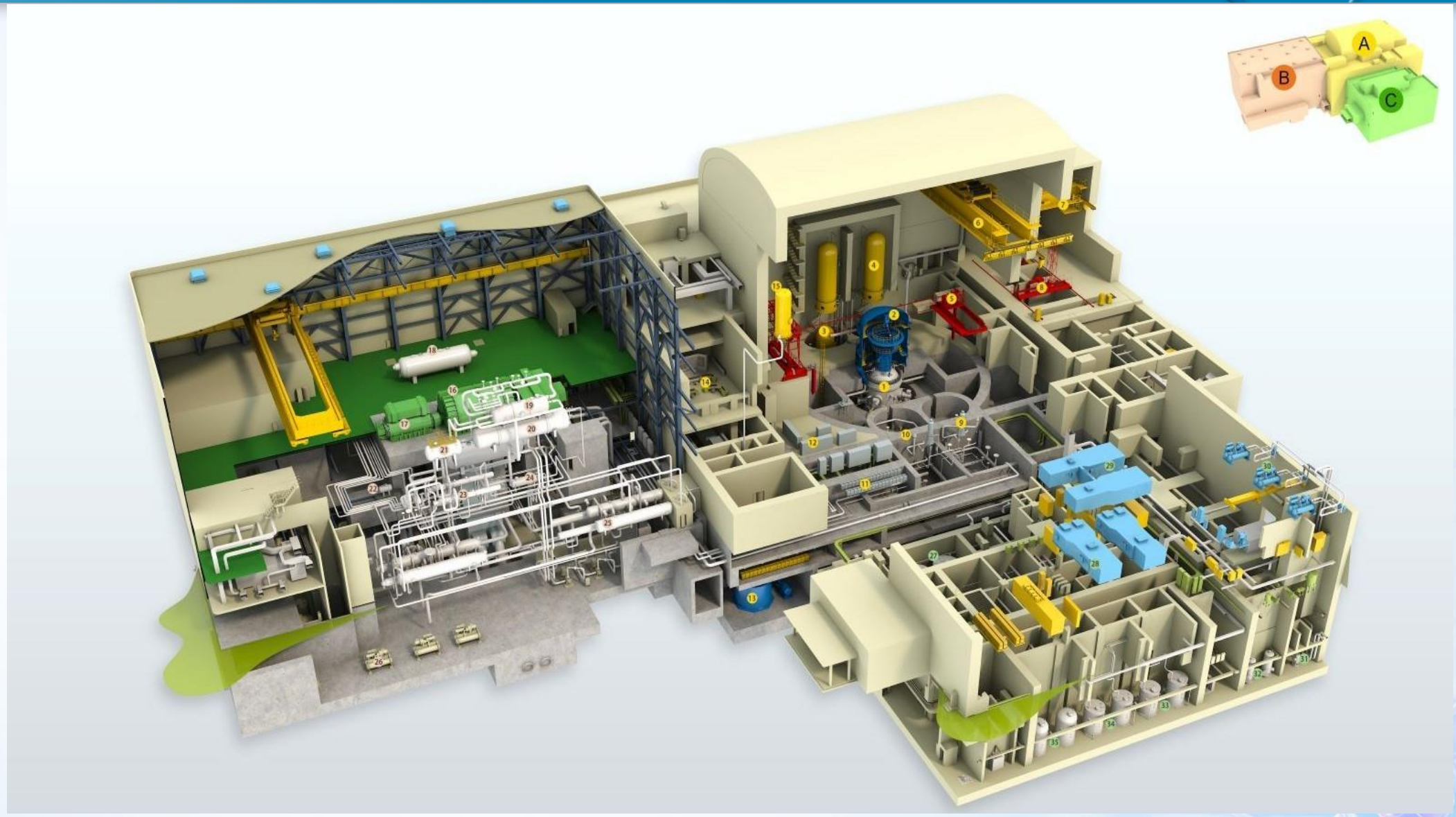

Main Feedwater and Main Steam


General Arrangement

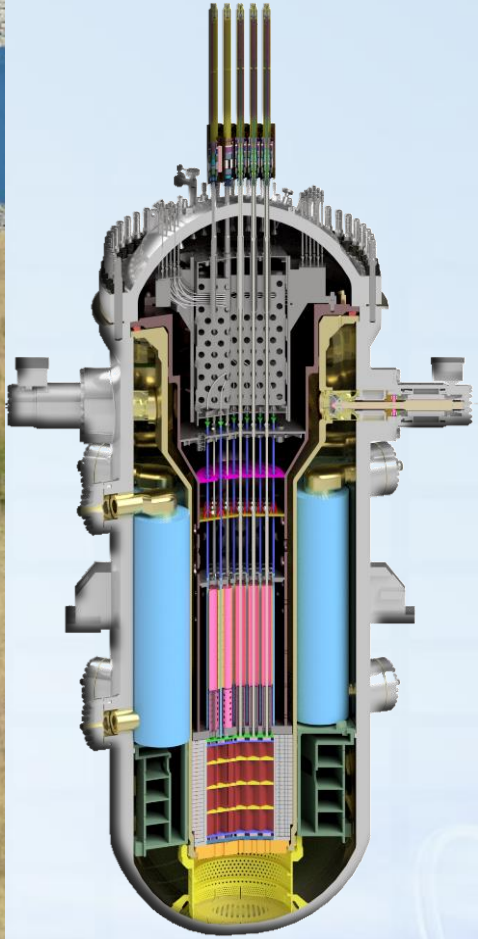

Containment Building


Aux. system Design

SMART Plant Layout



Bird’s eye View of SMART Plant

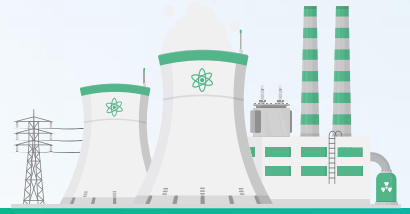


SMART Plant (Movie)

Advantages of SMART

Safe Nuclear Power Plant

- ~100 times Safer than Current Nuclear Power Plant
- Safe against Natural Hazards and Terror
  - Earthquake and Tsunami
  - Aircraft Crash

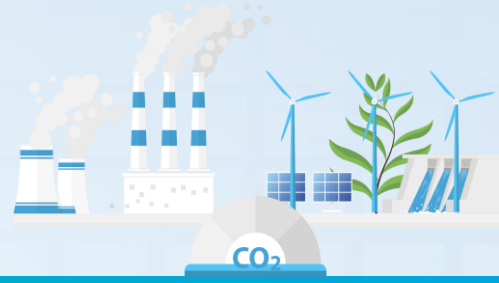


Licensed and Validated Technology

- Standard Design Approval in 2012
- Meet the Most Country's Licensing Requirements

Competitive Economics

- Competing with Renewable Energy with ESS or Gas Power Plant with Carbon Capture



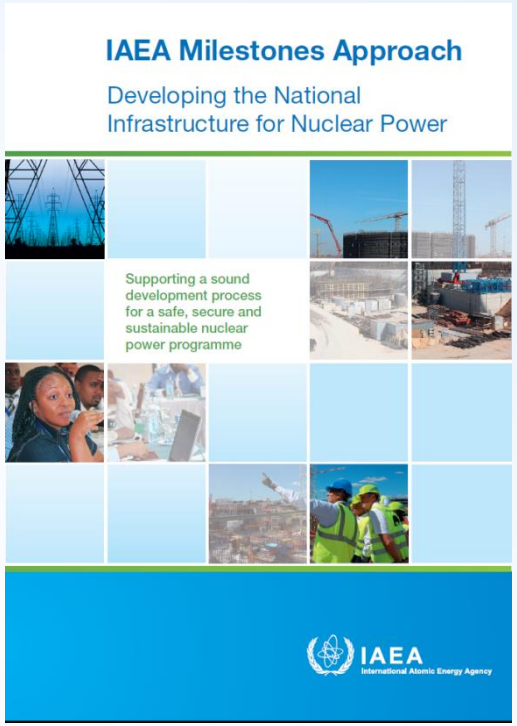
Minimize the Unexpected Operating and Maintenance Issues

- Similar Operating Condition of Current Nuclear Power Plant

Reliable Equipment Suppliers

- Ready to Deploy in Anywhere

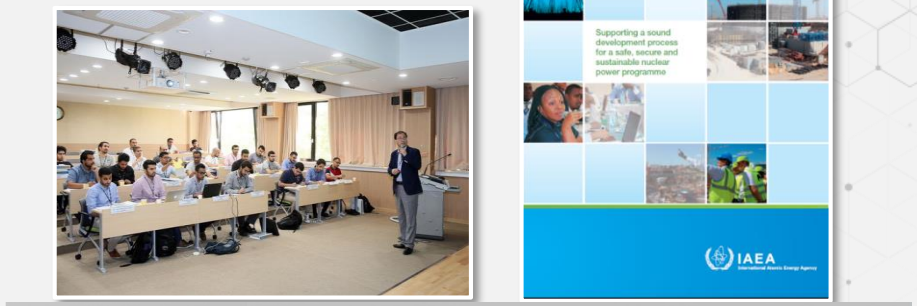
Infrastructures for NPP



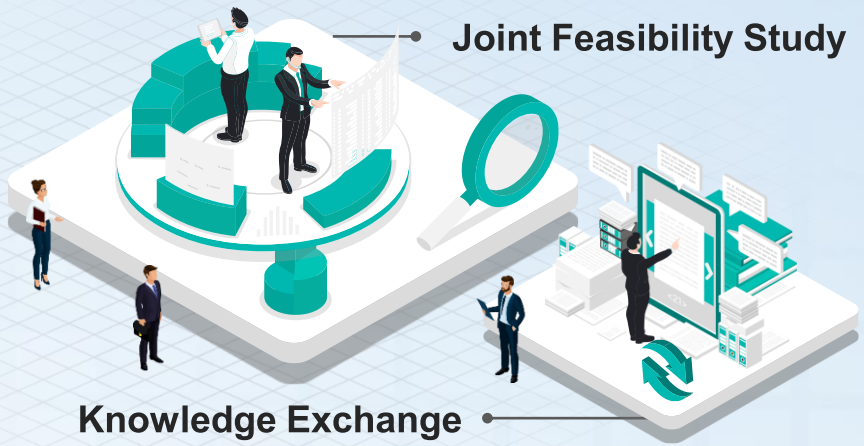
- The Milestones Approach is holistic and considers 19 specific infrastructure issues (IAEA)

Multilateral Collaboration Model

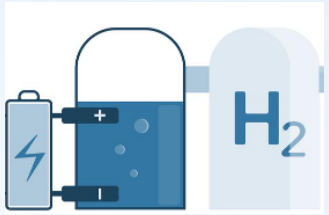
Shared Core Service



Country-wise Solution

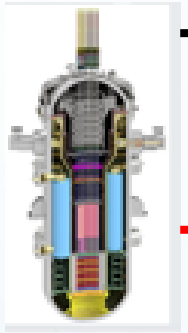


SMART's Flexible Application



Nuclear Hydrogen

Mobility



SMR

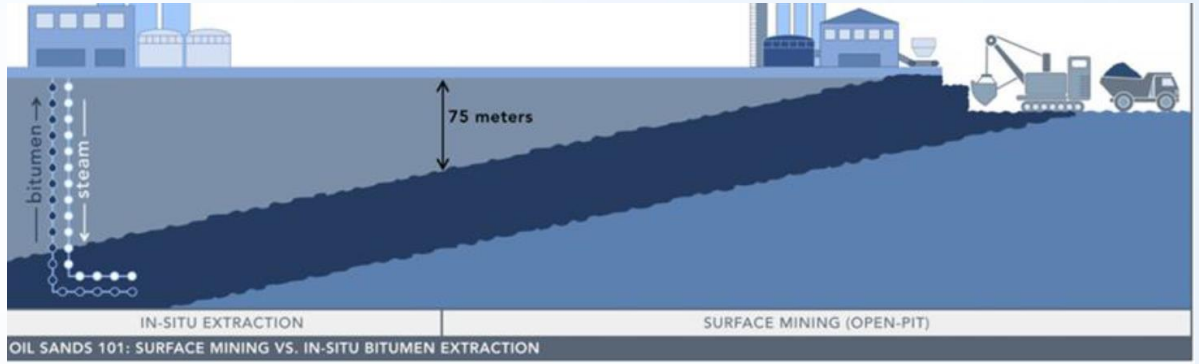
Replace
Co-generation
Power Plant

District Heating

House, Factory, Building

Heat Supply for Oil Sand

- Canada Oil Sand : ~ 3.5 Mbbl/day
  - Mining and SAGD
  - Need High Temperature Steam



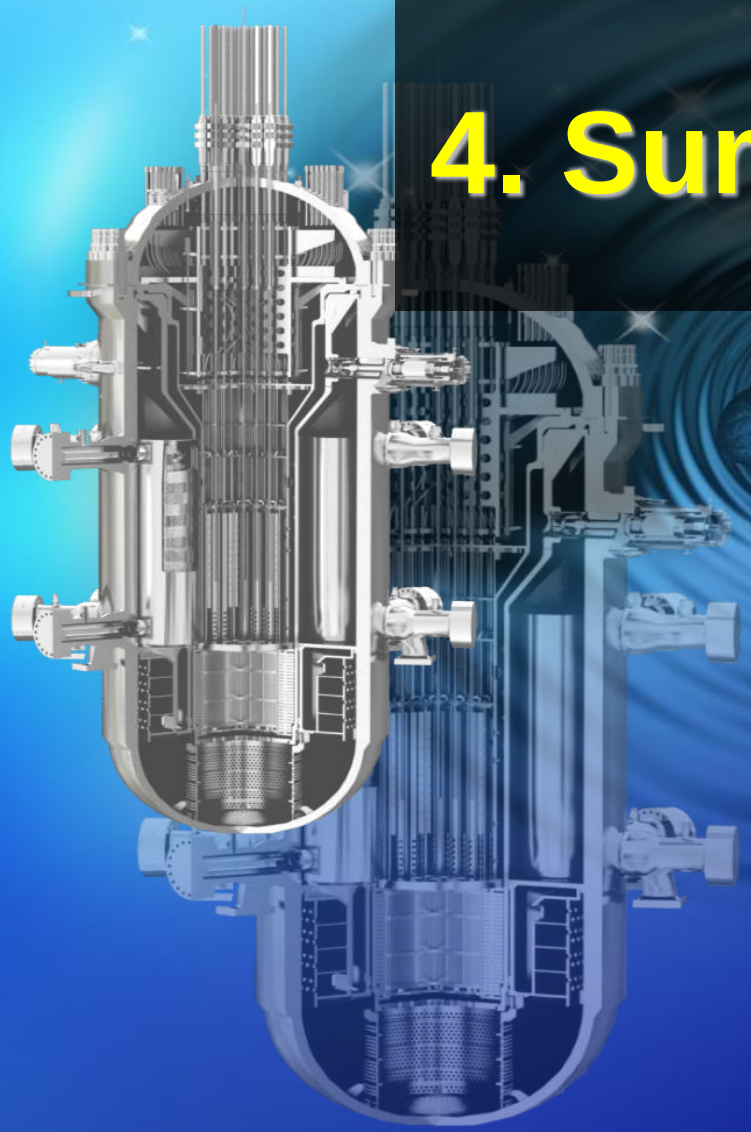
Oil Sand

Bitumen

Crude Oil

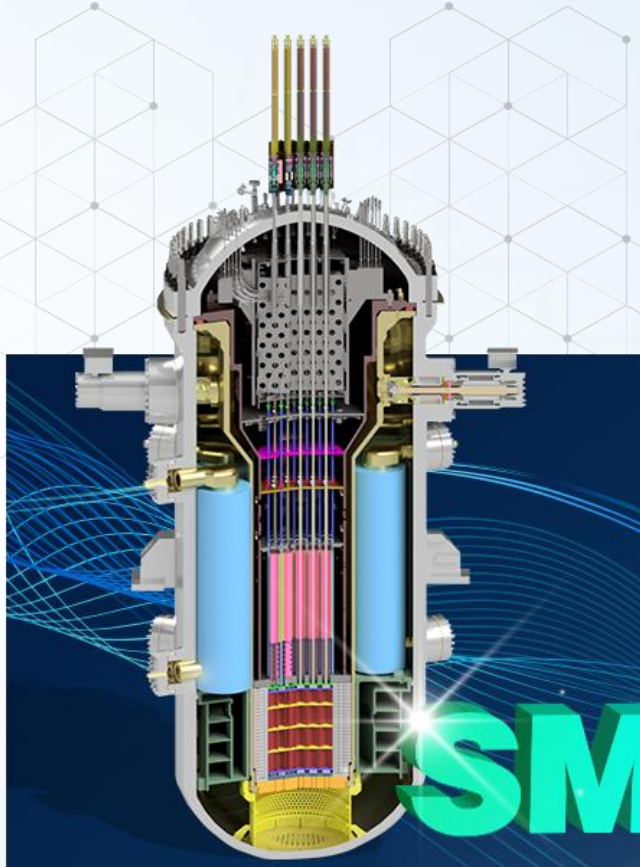
  - SMART for Hot Water Supply
    - No Electricity Conversion System(Turbine and Generator System)

4. Summary



Summary

SMART is ready for immediate deployment with established supply chain.

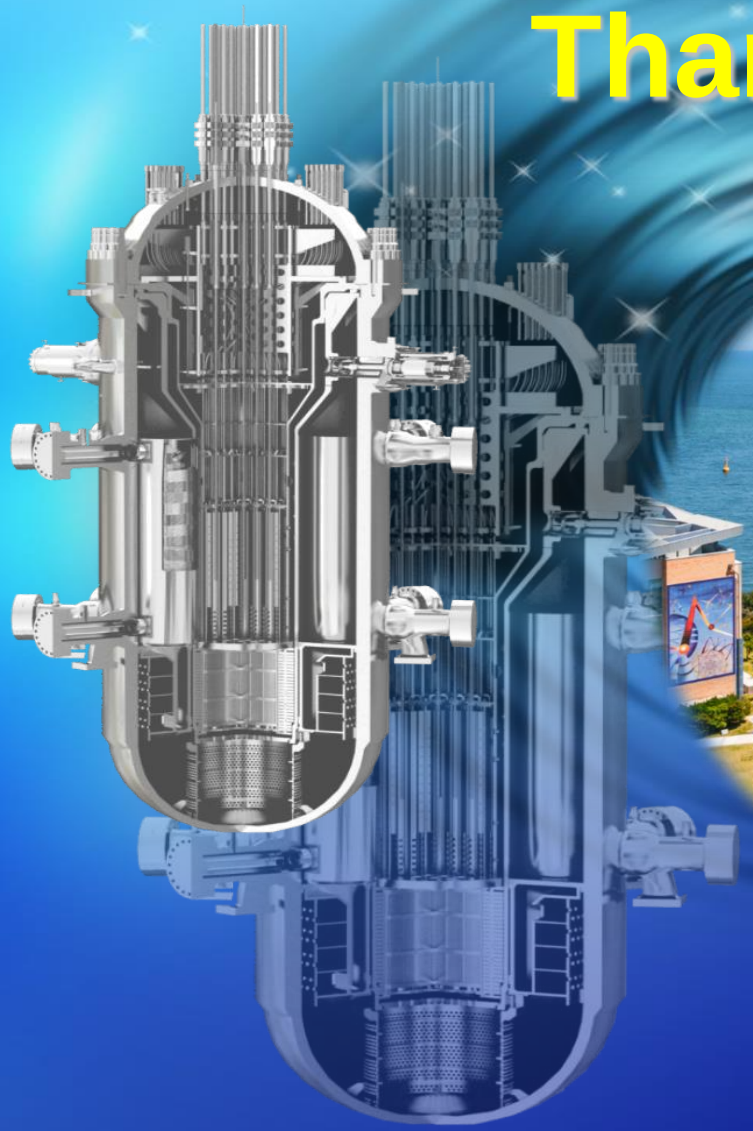


- Technologies proven through comprehensive technology validation program
- Meet All Licensing and Regulatory Frameworks of Most Countries

SMART

Good Solution
for Electricity and Fresh Water
without Carbon Emission

Thank You for Your Attention!



KINGS
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KEPCO INTERNATIONAL NUCLEAR GRADUATE SCHOOL