Global Trends, Prospects and Challenges for Innovative SMRs Deployment

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Division of Nuclear Power, Department of Nuclear Energy

Presented to
NUCLEAR POWER ENGINEERING COMMITTEE
Outline

• What’s new in global SMR development?
• Roles of IAEA on SMR Technology Development
• Status of Countries on Nuclear Energy Initiatives
• Global Status of SMR Development and Deployment
• Options of SMR Design & Technology
• Siting Options for New Electrical Generation – Water Needs
• Perceived Advantages and Challenges
• Newcomer Countries’ Considerations
• Current Newcomer Countries’ Plan
• Issues from Fukushima Nuclear Accident
• Summary
## What’s New in Global SMR Development?

<table>
<thead>
<tr>
<th>Country</th>
<th>SMR Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Korea</td>
<td>SMART</td>
<td>On 4 July, the Korean Nuclear Safety and Security Commission issued the Standard Design Approval for the 100 MWe SMART – the first iPWR received certification.</td>
</tr>
<tr>
<td>United States</td>
<td>NuScale mPower W-SMR Hi-SMUR</td>
<td>US-DOE funding of 452M$/5 years for two (2) out of the four (4) US competing iPWR based SMRs. Some have utilities to adopt in specific sites</td>
</tr>
<tr>
<td>Russia</td>
<td>KLT-40s SVBR-100 SHELF</td>
<td>2 modules marine propulsion-based barge-mounted KLT-40s are in construction, 90%; The lead-bismuth eutectic cooled SVBR-100 deployed by 2018, SHELF seabed-based started conceptual PWR-SMR design</td>
</tr>
<tr>
<td>France</td>
<td>Flexblue</td>
<td>DCNS originated Flexblue capsule, 50-250 MWe, 60-100m below water, 5-15 km from the coast, off-shore and local control rooms</td>
</tr>
<tr>
<td>Argentina</td>
<td>CAREM-25</td>
<td>Site excavation for CAREM-25 was started in September 2011, construction of a demo plan starts soon in 2012</td>
</tr>
<tr>
<td>Japan</td>
<td>4S</td>
<td>Toshiba had promoted the 4S for a design certification with the US NRC for application in Alaska and newcomer countries.</td>
</tr>
<tr>
<td>China</td>
<td>HTR-PM ACP-100</td>
<td>2 modules of HTR-PM are under construction; CNNC developing ACP-100 conceptual design</td>
</tr>
</tbody>
</table>
Roles of IAEA on SMR Development

• Facilitate efforts of Member States in identifying key enabling technologies in development and addressing key challenges in deployment;

• Establish and maintain international networks with Member States, industries, utilities, stakeholders;

• Ensure coordination of Member State experts by planning and implementing training programme and knowledge transfer through technical meetings and workshops

• Develop international recommendations and guidance focusing on specific needs of newcomer countries
Status of Countries on NE Initiatives

Technology developer countries
(NPPs in operation)

Countries with NPPs

Newcomer countries

Which countries deploy SMRs?

IAEA
Definition

• IAEA:
  • Small-sized reactors: < 300 MW(e)
  • Medium-sized reactors: 300 → 700 MW(e)
  • Regardless of being modular or non-modular
  • Covers all reactors in-operation and under-development with power up to 700 MWe
  • Covers 1970s technology → post 2000s innovative technology

• Several developed countries:
  • Small reactors: < 300 MW(e)
  • Emphasize the benefits of being small and modular
  • Focus on innovative reactor designs under-development
Concept of Integral PWR based SMRs
Benefits of integral vessel configuration:
- eliminates loop piping and external components, thus enabling compact containment and plant size → reduced cost
- Eliminates large break loss of coolant accident (improved safety)
Light Water Cooled SMRs

CAREM-25
Argentina

IMR
Japan

SMART
Korea, Republic of

VBER-300
Russia

WWER-300
Russia

KLT-40s
Russia

mPower
USA

NuScale
USA

Westinghouse
SMR - USA

CNP-300
China, Peoples Republic of

ABV-6
Russia
How “small” are the iSMR vessels?

- **NuScale (NuScale)**
  - 45 MWe
  - Ø2.7 x 13.7 m

- **mPower (B&W)**
  - 180 MWe
  - Ø3.6 x 22 m

- **Westinghouse SMR**
  - 225 MWe
  - Ø3.7 x 24.7 m

- **SMR-160**
  - (Holtec)
  - Ø2.7 x 40 m
Heavy Water Cooled SMRs

EC6
Canada

PHWR-220, 540, & 700
India

AHWR300-LEU
India
Liquid Metal Cooled SMRs

CEFR
China

4S
Japan

PFBR-500
India

SVBR-100
Russian Federation

PRISM
USA
Gas Cooled SMRs

- **PBMR**
  - South Africa

- **HTR-PM**
  - China

- **GT-MHR**
  - USA

- **EM²**
  - USA
Motivations – U.S. Case

- **Economic Affordability**
  - Lower up-front capital cost
  - Better financing options

- **Load demand**
  - Better match to power needs
  - Incremental capacity for regions with low growth rate
  - Allows shorter range planning

- **Site requirements**
  - Lower land and water usage
  - Replacement for aging fossil plants
  - Potentially more robust designs

- **Grid stability**
  - Closer match to traditional power generators
  - Smaller fraction of total grid capacity
  - Potential to offset variability from renewables
Advanced Reactor Requirements

- Enhanced safety
  - Address lessons-learned from the Fukushima Daiichi nuclear accident
- Proven technology
- Standardization
- Economic competitiveness
- Plant simplification
- Improved design margin
- Human factor engineering; man-machine interface
- Regulatory infrastructure
- Constructability
- Maintainability
- Proliferation resistance and physical protection
Siting Options for New Electrical Generation

Ref: ORNL/TM-2011/157/R1

- ORNL-developed tool: OR-SAGE
  (Oak Ridge Siting Analysis for power Generation Expansion)
- Use of Geographic Information System (GIS) data sources and spatial modeling capabilities to identify candidate sites

<table>
<thead>
<tr>
<th>OR-SAGE Screening Criteria for Large and Small Reactors</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population density (people/sq mi)</td>
<td>&gt;500</td>
</tr>
<tr>
<td>Safe shutdown earthquake (ground acc)</td>
<td>&gt;0.3</td>
</tr>
<tr>
<td>Wetlands / Open Water</td>
<td>- -</td>
</tr>
<tr>
<td>Protected lands</td>
<td>- -</td>
</tr>
<tr>
<td>Slope</td>
<td>&gt;12% grade</td>
</tr>
<tr>
<td>Landslide Hazard (moderate)</td>
<td>- -</td>
</tr>
<tr>
<td>100 – year floodplain</td>
<td>- -</td>
</tr>
</tbody>
</table>
| **Streamflow/ cooling water make-up (kgpm)** within 20 miles – assumes closed-cycle cooling - limits plant to no more than 10% of resource | 200 - large  
50 - small |
| Proximity to hazardous operations – buffer (mi)        | Variable |
| Proximity to fault lines – buffer (mi)                 | Depends on length of fault |
Application of GIS for Siting Evaluations Supports Identifying Siting Challenges and Candidate Sites

Are there viable sites?
- Electrical transmission
- Population density
- **Source for make-up water**
- Seismic zones
- Hazardous operations
- Protected lands
- Siting of large vs. small reactors

Bechtel Approach

Siting information courtesy of ORNL, G. Mays
2011 Utility Working Conference
National View of Siting Options for New Nuclear Capacity

Sample Results From OR-SAGE – Land Area Suitable for Siting

<table>
<thead>
<tr>
<th>Siting Case</th>
<th>Large Reactor</th>
<th>Small Reactor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseemap</td>
<td>22%</td>
<td>31%</td>
</tr>
<tr>
<td>Aggregation Analysis</td>
<td>13%</td>
<td>24%</td>
</tr>
<tr>
<td>Technological Issues</td>
<td>Advantages</td>
<td>Challenges</td>
</tr>
<tr>
<td>----------------------</td>
<td>------------</td>
<td>------------</td>
</tr>
<tr>
<td>• Shorter construction period (modularization)</td>
<td>• Licensorability <em>(due to innovative or first-of-a-kind engineering structure, systems and components)</em></td>
<td></td>
</tr>
<tr>
<td>• Potential for enhanced safety and reliability</td>
<td>• Non-LWR technologies</td>
<td></td>
</tr>
<tr>
<td>• Design simplicity</td>
<td>• Operability performance/record</td>
<td></td>
</tr>
<tr>
<td>• Suitability for non-electric application (desalination, etc.).</td>
<td>• Human factor engineering; operator staffing for multiple-modules plant</td>
<td></td>
</tr>
<tr>
<td>• Replacement for aging fossil plants, reducing GHG emissions</td>
<td>• Post Fukushima action items on design and safety</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Non-Technological Issues</th>
<th>Advantages</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Fitness for smaller electricity grids</td>
<td>• Economic competitiveness</td>
<td></td>
</tr>
<tr>
<td>• Options to match demand growth by incremental capacity increase</td>
<td>• First of a kind cost estimate</td>
<td></td>
</tr>
<tr>
<td>• Site flexibility</td>
<td>• Regulatory infrastructure <em>(in both expanding and newcomer countries)</em></td>
<td></td>
</tr>
<tr>
<td>• Reduced emergency planning zone</td>
<td>• Availability of design for newcomers</td>
<td></td>
</tr>
<tr>
<td>• Lower upfront capital cost (better affordability)</td>
<td>• Infrastructure requirements</td>
<td></td>
</tr>
<tr>
<td>• Easier financing scheme</td>
<td>• Post Fukushima action items on institutional issues and public acceptance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Name</td>
<td>Design Organization</td>
</tr>
<tr>
<td>---</td>
<td>-------------------------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>1</td>
<td>PHWR-220</td>
<td>NPCIL</td>
</tr>
<tr>
<td>2</td>
<td>PHWR-540</td>
<td>NPCIL</td>
</tr>
<tr>
<td>3</td>
<td>PHWR-700</td>
<td>NPCIL</td>
</tr>
<tr>
<td>4</td>
<td>KLT-40S</td>
<td>OKBM Afrikantov</td>
</tr>
<tr>
<td>5</td>
<td>HTR-PM</td>
<td>Tsinghua University</td>
</tr>
<tr>
<td>6</td>
<td>CAREM-25</td>
<td>CNEA</td>
</tr>
<tr>
<td>7</td>
<td>Prototype Fast Breed Reactor (PFBR-500)</td>
<td>IGCAR</td>
</tr>
<tr>
<td>8</td>
<td>CNP-300</td>
<td>CNNC</td>
</tr>
</tbody>
</table>
## SMRs for Near-term Deployment

<table>
<thead>
<tr>
<th></th>
<th>Name</th>
<th>Design Organization</th>
<th>Country of Origin</th>
<th>Electrical Capacity, MWe</th>
<th>Design Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>System Integrated Modular Advanced Reactor (SMART)</td>
<td>Korea Atomic Energy Research Institute</td>
<td>Republic of Korea</td>
<td>100</td>
<td>Standard Design Approval Received 4 July 2012</td>
</tr>
<tr>
<td>2</td>
<td>mPower</td>
<td>Babcock &amp; Wilcox</td>
<td>United States of America</td>
<td>180/module</td>
<td>Detailed design, to apply for certification - end of 2013</td>
</tr>
<tr>
<td>3</td>
<td>NuScale</td>
<td>NuScale Power Inc.</td>
<td>United States of America</td>
<td>45/module</td>
<td>Detailed design, to apply for certification - end of 2013</td>
</tr>
<tr>
<td>4</td>
<td>VBER-300</td>
<td>OKBM Afrikantov</td>
<td>Russian Federation</td>
<td>300</td>
<td>Detailed design</td>
</tr>
<tr>
<td>5</td>
<td>SVBR-100</td>
<td>JSC AKME Engineering</td>
<td>Russian Federation</td>
<td>100</td>
<td>Detailed design for prototype construction</td>
</tr>
<tr>
<td>6</td>
<td>Westinghouse SMR</td>
<td>Westinghouse</td>
<td>United States of America</td>
<td>225</td>
<td>Detailed Design</td>
</tr>
<tr>
<td>7</td>
<td>Super-Safe, Small and Simple (4S)</td>
<td>Toshiba</td>
<td>Japan</td>
<td>10</td>
<td>Detailed design</td>
</tr>
</tbody>
</table>
## Example of SMRs for Long-term Deployment

<table>
<thead>
<tr>
<th></th>
<th>Name</th>
<th>Design Organization</th>
<th>Country of Origin</th>
<th>Electrical Capacity, MWe</th>
<th>Design Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IRIS</td>
<td>IRIS International Consortium</td>
<td>United States of America</td>
<td>335</td>
<td>Conceptual Design</td>
</tr>
<tr>
<td>2</td>
<td>Power Reactor Innovative Small Modular (PRISM)</td>
<td>GE Hitachi</td>
<td>United States of America</td>
<td>311</td>
<td>Detailed Design</td>
</tr>
<tr>
<td>3</td>
<td>AHWR300-LEU using Thorium MOX Fuel</td>
<td>BARC</td>
<td>India</td>
<td>300</td>
<td>Conceptual Design</td>
</tr>
<tr>
<td>4</td>
<td>Integrated Modular Water Reactor (IMR)</td>
<td>Mitsubishi Heavy Industries</td>
<td>Japan</td>
<td>350</td>
<td>Conceptual Design</td>
</tr>
<tr>
<td>5</td>
<td>Flexblue</td>
<td>DCNS</td>
<td>France</td>
<td>50-250</td>
<td>Conceptual Design</td>
</tr>
<tr>
<td>6</td>
<td>FBNR</td>
<td>FURGS</td>
<td>Brazil</td>
<td>72</td>
<td>Conceptual Design</td>
</tr>
<tr>
<td>7</td>
<td>VK-300</td>
<td>RIAR</td>
<td>Russian Federation</td>
<td>100/300</td>
<td>Conceptual Design</td>
</tr>
<tr>
<td>8</td>
<td>EM²</td>
<td>General Atomics</td>
<td>USA</td>
<td>240</td>
<td>Conceptual Design</td>
</tr>
</tbody>
</table>
SMR for Near-term Deployment
SMART

- **Full name**: System-Integrated Modular Advanced Reactor
- **Designer**: Korea Atomic Energy Research Institute (KAERI), Republic of Korea
- **Reactor type**: Integral PWR
- **Coolant/Moderator**: Light Water
- **Neutron Spectrum**: Thermal Neutrons
- **Thermal/Electrical Capacity**: 330 MW(t) / 100 MW(e)
- **Fuel Cycle**: 36 months
- **Salient Features**: Passive decay heat removal system in the secondary side; horizontally mounted RCPs; intended for sea water desalination and electricity supply in newcomer countries with small grid
- **Design status**: Standard Design Approval granted on 4 July 2012
 SMART – Safety Systems

- **Inherent Safety**
  - No Large Break: vessel penetration < 2 inch
  - Large Primary Coolant Inventory per MW
  - Low Power Density (~2/3)
  - Large PZR Volume for Transient Mitigation
  - Low Vessel Fluence
  - Large Internal Cooling Source (Sump-integrated IRWST)

- **Engineered Safety Features**
  - Passive Residual Heat Removal System (50 % x 4 train)
    - Natural Circulation
    - Replenishable Heat Sink (Emergency Cooling Tank)
  - Safety Injection System (100 % x 4 train)
    - Direct Vessel Injection from IRWST
  - Shutdown Cooling System (100 % x 2 Train)
  - Containment Spray System (2 Train)

- **Severe Accident Management**
  - In-Vessel Retention and ERVC
  - Passive Hydrogen Control (PARs)
SMR for Immediate Deployment
CAREM-25

- **Full name**: Central Argentina de Elementos Modulares
- **Designer**: National Atomic Energy Commission of Argentina (CNEA)
- **Reactor type**: Integral PWR
- **Coolant/Moderator**: Light Water
- **Neutron Spectrum**: Thermal Neutrons
- **Thermal/Electrical Capacity**: 87.0 MW(t) / 27 MW(e)
- **Fuel Cycle**: 14 months
- **Salient Features**: primary coolant system within the RPV, self-pressurized and relying entirely on natural convection.
- **Design status**: Site excavation started for construction in 2012
CAREM-25 – Safety Systems

• Two (2) Shutdown Systems:
  1. First SS: by Control Rods = Fast SS + Reactivity Adjust and Control System (ACS)
  2. Second SS: Boron injection

• Passive Residual Heat Removal System (PRHS):
  • Isolation Condensers

• Low Pressure Injection System:
  • Accumulators
CAREM-25 – Suppression Pool Type Containment

S/P type C/V, reinforced concrete with stainless steel liner, 0.5 MPa Design Pressure

© 2011 CNEA - Argentina
CAREM-25
Severe Accident Prevention and Mitigation

• Severe Accident Prevention:
  • A grace period extension, for SBO longer than 72 hrs., using other autonomous systems (fire extinguishing external pumps);
  • Water injection into the PRHRS pool;
  • Water injection into the PRHRS chamber;
  • Suppression pool cooling;

• Severe Accident Mitigation:
  • In-vessel Corium retention: RPV external cooling by gravity;
  • Hydrogen passive autocatalytic recombiners.

• Passive safety system and extended grace period result in very low frequency of core meltdown, the provision considered for Defence-in-Depth Level 4.
SMR for Near-term Deployment
NuScale

- **Full name:** NuScale
- **Designer:** NuScale Power Inc., USA
- **Reactor type:** Integral Pressurized Water Reactor
- **Coolant/Moderator:** Light Water
- **Neutron Spectrum:** Thermal Neutrons
- **Thermal/Electrical Capacity:** 165 MW(t)/45 MW(e)
- **Fuel Cycle:** 24 months
- **Salient Features:** Natural circulation cooling; Decay heat removal using containment; built below ground
- **Design status:** Design Certification application expected in 4th Quarter of 2013
NuScale - Decay Heat Removal System

- Two independent trains (single-failure-proof)
- Closed loop system
- Two-phase natural circulation operation
- DHRS heat exchangers nominally full of water
- Supplies the coolant inventory
- Primary coolant natural circulation is maintained
- Pool provides a 3 day cooling supply for decay heat removal
NuScale - Decay heat removal using Containment

Provides a means of removing core decay heat and limits containment pressure by:
- Steam Condensation
- Convective Heat Transfer
- Heat Conduction
- Sump Recirculation

Reactor Vessel steam is vented through the reactor vent valves (flow limiter)
- Steam condenses on containment
- Condensate collects in lower containment region
- Reactor Recirculation Valves open to provide recirculation path through the core
- Provides 30+ day cooling followed by indefinite period of air cooling.
Implications of Fukushima on NuScale

- No major impact to the NuScale design is currently anticipated.
  - The NuScale design fully addresses decay heat removal for prolonged station blackout.
- As a result of the Fukushima event, NuScale will
  - Add long term air-cooling test to NuScale Integral System Test Matrix and SIET decay heat removal tests to demonstrate effectiveness of passive air-cooling with an empty reactor building pool.
  - Review Spent Fuel Pool Cooling capability under air-cooled conditions.
  - Examine role of “Island Mode” operation for multi-module plant.
  - Confirm adequacy of existing seismic design basis for NuScale (0.5g ZPA) and ensure efforts are consistent with on going industry efforts.
  - Review NRC review plan when they become available and determine applicability to NuScale.
SMR for Near-term Deployment: mPower

- **Full name**: mPower
- **Designer**: Babcock & Wilcox Modular Nuclear Energy, LLC (B&W), United States of America
- **Reactor type**: Integral Pressurized Water Reactor
- **Coolant/Moderator**: Light Water
- **Neutron Spectrum**: Thermal Neutrons
- **Thermal/Electrical Capacity**: 530 MW(t) / 180 MW(e)
- **Fuel Cycle**: 48-month or more
- **Salient Features**: integral NSSS, CRDM inside reactor vessel; Passive safety that does not require emergency diesel generator
- **Design status**: Design Certification application expected in 4th Quarter of 2013
mPower – Inherent Safety Features

- **Low Core Linear Heat Rate:**
  - Low power density reduces fuel and clad temps during accidents
  - Allows lower flow velocities that minimizes flow induced vibration effects

- **Large Reactor Coolant System Volume:**
  - Allows more time for safety system response in the case of accident
  - More coolant is available during SBLOCA providing continuous cooling to protect the core

- **Small Penetrations at High Elevations:**
  - Increase the amount of coolant left in the vessel after a SBLOCA
  - Reduce rate of energy release to containment resulting in lower containment pressures
mPower – Containment System

- Underground containment, fuel storage and ultimate heat sink;
- Metal containment vessel;
- Volume limits internal pressure for all design basis accidents;
- Simultaneous refuelling and NSSS equipment inspections;
- Environment suitable for human occupancy during normal operation
• **Full name**: Super-Safe, Small and Simple
• **Designer**: Toshiba Corporation, Japan
• **Reactor type**: Liquid Sodium cooled, Fast Reactor – but not a breeder reactor
• **Neutron Spectrum**: Fast Neutrons
• **Thermal/Electrical Capacity**: 30 MW(t)/10 MW(e)
• **Fuel Cycle**: without on-site refueling with core lifetime ~30 years. Movable reflector surrounding core gradually moves, compensating burn-up reactivity loss over 30 years.
• **Salient Features**: power can be controlled by the water/steam system without affecting the core operation
• **Design status**: Detailed Design
4S – Passive Decay Heat Removal

- Natural air draft and natural circulation
  - **RVACS**: Natural air draft outside the guard vessel
  - **IRACS**: Natural circulation of sodium and air draft at air cooler

---

**Core temperature during loss-of-power only with natural circulation**

RVACS: Reactor Vessel Auxiliary Cooling System,
IRACS : Intermediate Reactor Auxiliary Cooling System
4S – Radionuclide Containment

- Fuel
- Fuel cladding
- Reactor vessel (trap effect by sodium)
- Containment
  - Guard vessel
  - Top dome
  - Mitigation of sodium fire by nitrogen gas inside the top dome
- Reactor building
### Safety Related Issues

<table>
<thead>
<tr>
<th><strong>4S’s safety design to mitigate and prevent from severe accident</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Station black out (SBO)</strong></td>
</tr>
<tr>
<td>Core damage is avoidable without any emergency power supply by passive decay heat removal system with natural circulation, not necessary the pump. There is no limitation for duration time.</td>
</tr>
<tr>
<td><strong>Spent fuel pool</strong></td>
</tr>
<tr>
<td>No need for spent fuel pool due to long-term cooling (about 1 year) after the long-term operation (i.e., 30 years) and then stored in dry cask for the 10MWe-4S.</td>
</tr>
<tr>
<td><strong>Final heat sink in emergency situations</strong></td>
</tr>
<tr>
<td>Air is the final heat sink (RVACS and/or IRACS), not depending on water and any emergency power (passive decay heat removal system).</td>
</tr>
<tr>
<td><strong>Containment system reliability</strong></td>
</tr>
<tr>
<td>Containment system is consisted of top dome and guard vessel.</td>
</tr>
<tr>
<td><strong>Earthquakes</strong></td>
</tr>
<tr>
<td>Supporting the reactor building by seismic isolator.</td>
</tr>
<tr>
<td><strong>Tsunami / Flood</strong></td>
</tr>
<tr>
<td>Redundant shutdown system and passive decay heat removal system without external power supply and emergency power system. Reinforced reactor building to protect from massive water intrusion by design for water-tightness.</td>
</tr>
<tr>
<td><strong>Aircraft hazard</strong></td>
</tr>
<tr>
<td>Constructed underground.</td>
</tr>
</tbody>
</table>
SMR for Immediate Deployment
SVBR-100

- **Designer**: JSC AKME Engineering – Russian Federation
- **Reactor type**: Liquid metal cooled fast reactor
- **Coolant/Moderator**: Lead-bismuth
- **System temperature**: 500°C
- **Neutron Spectrum**: Fast Neutrons
- **Thermal/Electric capacity**: 280 MW(t) / 101 MW(e)
- **Fuel Cycle**: 7 – 8 years
- **Fuel enrichment**: 16.3%
- **Distinguishing Features**: Closed nuclear fuel cycle with mixed oxide uranium plutonium fuel, operation in a fuel self-sufficient mode
- **Design status**: Detailed design
SVBR-100 Safety Principles

Chemically inert lead-bismuth coolant
Inherent (by-nature) safety – for free

Fast reactor First circuit low pressure

Integral design of the reactor components: core, pumps, SG, etc.

Stability & simplicity under normal operation

Tolerance to the design and beyond-design basis accidents

By-design safety
### Current Newcomer Countries Plan

<table>
<thead>
<tr>
<th>Country</th>
<th>Grid Capacity in GWe</th>
<th>Current Deployment Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bangladesh</td>
<td>5.8</td>
<td>2 x 1000 MWe PWRs in Rooppur in 2018</td>
</tr>
<tr>
<td>Vietnam</td>
<td>15.19</td>
<td>4 x 1000 MWe PWRs in Ninh Thuan #1 by 2020</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 x 1000 MWe PWRs in Ninh Thuan #2 by 2025</td>
</tr>
<tr>
<td>Jordan</td>
<td>2.6</td>
<td>2 x 1000 - 1100 MWe PWR in + possible interest in SMR</td>
</tr>
<tr>
<td>UAE</td>
<td>23.25</td>
<td>4 x 1400 MWe PWR in Braka by 2018</td>
</tr>
<tr>
<td>Belarus</td>
<td>8.03</td>
<td>2 x 1200 MWe PWR in Ostrovets by 2018</td>
</tr>
<tr>
<td>Turkey</td>
<td>44.76</td>
<td>4 x 1200 MWe PWR in Akkuyu by 2022</td>
</tr>
<tr>
<td>Malaysia</td>
<td>25.54</td>
<td>2 x 1000 MWe LWRs, 1st unit by 2021</td>
</tr>
<tr>
<td>Indonesia</td>
<td>32.8</td>
<td>2 x 1000 LWRs, with potential interest of deploying Small Reactors for industrial process and non-electric applications by 2024</td>
</tr>
</tbody>
</table>

**Commercial Availability limits Newcomer Countries in SMR Technology Selection**
## Reactors Under Construction with SMR category

<table>
<thead>
<tr>
<th>Country</th>
<th>Reactor Model</th>
<th>Output (MWe)</th>
<th>Designer</th>
<th>Number of units</th>
<th>Site, Plant ID, and unit #</th>
<th>Commercial Start</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>PHWR 700</td>
<td>640</td>
<td>NPCIL</td>
<td>2</td>
<td>Kakrapar 3 and 4</td>
<td>6/2015 and 12/2015</td>
</tr>
<tr>
<td></td>
<td>PHWR 700</td>
<td>640</td>
<td>NPCIL</td>
<td>2</td>
<td>Rajashtan units 7 and 8</td>
<td>6/2016 and 12/2016</td>
</tr>
<tr>
<td></td>
<td>PFBR 500</td>
<td>500</td>
<td>IGCAR</td>
<td>1</td>
<td>PFBR Kalpakkam</td>
<td>2015</td>
</tr>
<tr>
<td>Pakistan</td>
<td>CNP-300</td>
<td>300</td>
<td>CNNC - China</td>
<td>2</td>
<td>Chasnupp 3 and 4</td>
<td>12/2016</td>
</tr>
<tr>
<td>Romania</td>
<td>CANDU-6</td>
<td>620</td>
<td>AECL</td>
<td>3</td>
<td>Chernavoda units 3, 4 and 5</td>
<td>2016, 2017, 2018</td>
</tr>
<tr>
<td>Russian Federation</td>
<td>KLT-40S</td>
<td>30</td>
<td>OKBM Afrikantov</td>
<td>2</td>
<td>Akademik Lomonosov</td>
<td>2012</td>
</tr>
<tr>
<td>Slovak</td>
<td>VVER-440</td>
<td>405</td>
<td>OKB Gidropress</td>
<td>2</td>
<td>Mochovce 3 and 4</td>
<td>~ 2018</td>
</tr>
<tr>
<td>China</td>
<td>HTR-PM (GCR)</td>
<td>200</td>
<td>Tsinghua Univ./ Harbin</td>
<td>1</td>
<td>Shidaowan unit 1</td>
<td>2017 ~ 2018</td>
</tr>
<tr>
<td>Argentina</td>
<td>CAREM-25</td>
<td>27</td>
<td>CNEA</td>
<td>1</td>
<td>Formosa unit-1</td>
<td>2017 ~ 2018</td>
</tr>
</tbody>
</table>
Issues from Fukushima Nuclear Accident

• Design Basis Accident (DBA) → Multiple external initiating events beyond design bases and consequential common cause failures
• Extended station blackout mitigation
• Ultimate heat sink for core and containment cooling in severe accident
• Reliability & Diversity of emergency power supply
• Optimization of the grace period (i.e. operator response time)
• Hydrodynamic capability of containment; options for filtering and venting
• Hybrid, passive and active engineered safety features
• Safety impact of multiple-modules – first of a kind engineering
• Accident management, emergency response capability and costs
• Seismic and cooling provisions for spent fuel pool
• Hydrogen generation from steam-zirconium reaction; recombiner system
• Environmental impact assessment and expectation
• Control room habitability in post accident environment
Summary

- SMR is an attractive option to enhance energy supply security in newcomer countries with small grids and less-developed infrastructure;
- SMRs may require substantially less water, depending on deployment schemes
- Innovative SMR concepts have common technology development challenges:
  - licensability, competitiveness, control room staffing for multi-unit sites, etc.,
- Need to address lessons-learned from the Fukushima accident into the design development and plant deployment
… Thank you for your attention.