6th INPRO Dialogue Forum on Global Nuclear Energy Sustainability: Licensing and Safety Issues for Small and Medium-sized Nuclear Power Reactors (SMRs)

29 July - 2 August 2013
IAEA Headquarters, Vienna, Austria

Status of Global SMR Development and Prospects for Deployment

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Outline

- Motivation – Driving Forces
- Status of Countries on SMR Initiatives
- What’s new in global SMR development and deployment?
- Practical Categorization of SMR Design & Technology
- SMR for Immediate and Near-Term Deployments
- Perceived Advantages and Challenges
- Advanced Design Features & Technologies
- Incorporating Lessons Learned from the Fukushima Daiichi Accident in SMR Technology Assessment
- Focus of IAEA Activities on SMR Technology Development for 2014 - 2015
Motivation – Driving Forces …

- The need for flexible power generation for wider range of users and applications;
- Replacement of aging fossil-fired units;
- Potential for enhanced safety margin through inherent and/or passive safety features;
- Economic consideration – better affordability;
- Potential for innovative energy systems:
  - Cogeneration & non-electric applications
  - Hybrid energy systems of nuclear (SMR) with renewables

**Small and remote grid**

**Desalination**

**District heating**

**Driving cargo ships**

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Which countries deploy SMRs?

- Technology developer countries (NPPs in operation)
- Countries with NPPs
- Newcomer countries

Status of Countries on SMR Initiatives

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# What’s New in Global SMR Development?

<table>
<thead>
<tr>
<th>Country</th>
<th>Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>Site excavation for CAREM-25 prototype was started in September 2011; first concrete pour expected by end 2013</td>
</tr>
<tr>
<td>China</td>
<td>2 modules of HTR-PM under construction; CNNC developing ACP-100 which will be constructed by 2015 SNERDI developing CAP-150 and CAP-FNPP</td>
</tr>
<tr>
<td>France</td>
<td>DCNS originated <strong>Flexblue</strong> capsule, 160 MWe, 60-100m seafloor-moored, 5-15 km from the coast, off-shore and local control rooms</td>
</tr>
<tr>
<td>India</td>
<td>The <strong>Prototype FBR</strong> prepared for start-up commissioning. 4 units of <strong>PHWR-700</strong> under construction, 4 more units to follow. <strong>AHWR300-LEU</strong> at final detailed design stage and ready for construction.</td>
</tr>
<tr>
<td>Italy</td>
<td>Politecnico di Milano (POLIMI) and universities in Croatia &amp; Japan are continuing the development of IRIS design - previously lead by the Westinghouse Consortium</td>
</tr>
<tr>
<td>Japan</td>
<td>Toshiba had promoted the 10 MWe 4S for a design certification with the US NRC for application in Alaska and newcomer countries.</td>
</tr>
</tbody>
</table>
### SMART

On 4 July 2012, the Korean Nuclear Safety and Security Commission issued the Standard Design Approval for the 100 MWe SMART – the first iPWR received certification.

### KLT-40S

- **SVBR-100**
- **BREST-300**
- **SHELF**

Construction of 2 modules of barge-mounted KLT-40s near completion; Lead Bismuth cooled **SVBR-100** & Lead-cooled **BREST-300** to deploy by 2018, **SHELF** seabed-based conceptual design.

### mPower

- **NuScale**
- **W-SMR**
- **SMR-160**

Some have utilities to deploy in specific sites. B&W received US-DOE funding for **mPower** design. The total funding is 452M$/5 years for 2 out of 4 competing iPWR based-SMRs. The mPower got the award in the first round. The DOE will have 2nd round of funding award in November 2013.

Introducing the IAEA in 2012
## Reactors Under Construction in 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>PFBR-500 (a prototype)</td>
<td>500</td>
<td>IGCAR</td>
<td>1</td>
<td>Kalpakkam</td>
<td>2013</td>
</tr>
<tr>
<td>Russian Federation</td>
<td>KLT-40S (ship-borne)</td>
<td>30</td>
<td>OKBM Afrikantov</td>
<td>2</td>
<td>Akademik Lomonosov</td>
<td>2013</td>
</tr>
<tr>
<td>Pakistan</td>
<td>CNP300</td>
<td>320</td>
<td>CNNC/NPIC</td>
<td>2</td>
<td>Chashma units 3 and 4</td>
<td>2017 – 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 (a prototype)</td>
<td>27</td>
<td>CNEA</td>
<td>1</td>
<td>CAREM-25</td>
<td>2017 ~ 2018</td>
</tr>
</tbody>
</table>
Practical Categorization of SMRs

- **Advanced SMRs**
  - *including modular reactors and integrated PWRs*

- **Innovative SMRs**
  - *including small-sized Gen-IV reactors with non-water coolant/moderator*

- **Converted and Modified SMRs**
  - *Including barge-mounted floating NPP and seabed-moored submarine-like reactors*

- **Conventional SMRs**
  - *Those of Gen-II technologies and still being deployed*
Practical Categorization of SMRs

- **Advanced SMRs** *(incl. Modular and integrated-PWRs)*

CAREM-25  
Argentina

SMART  
Korea, Republic of

VBER-300  
Russia

WWER-300  
Russia

mPower  
USA

NuScale  
USA

Westinghouse SMR - USA

ACP-100  
China

CAP-150  
China

CEFR  
China

4S  
Japan

PFBR-500  
India

HTR-PM  
China

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Practical Categorization of SMRs

- **Advanced SMRs** *(incl. Modular and integrated-PWRs)*
  - Each module has a dedicated turbine generator
  - Modularity permits scaling to any size

*Courtesy of NuScale Power, USA.*
(cont’d) Practical Categorization of SMRs

- **Innovative SMRs**

  - IMR
    - Japan
  - AHWR300-LEU
    - India
  - GT-MHR
    - USA
  - PRISM
    - USA
  - EM²
    - USA
  - PBMR
    - South Africa
(cont’d) Practical Categorization of SMRs

- **Converted/Modified SMRs**

  - **Small CNPP**
  - **FPU with KLT-40S RPs**
    - KLT-40s
    - Russian Federation
  - **Flexblue**
    - France
  - **SVBR-100**
    - Russian Federation
(cont’d) Practical Categorization of SMRs

- *Conventional SMRs*

CNP-300 from China’s CNNC/NPIC for Chashma NPPs 1 – 4 in Pakistan

PHWRs 220, 540, and 700 NPCIL, India
## 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>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>2</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>3</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>4</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>5</td>
<td>Westinghouse SMR</td>
<td>Westinghouse</td>
<td>United States of America</td>
<td>225</td>
<td>Detailed design, to apply for certification - end of 2013</td>
</tr>
<tr>
<td>6</td>
<td>VBER-300</td>
<td>OKBM Afrikantov</td>
<td>Russian Federation</td>
<td>300</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>
# SMRs for Immediate Deployment

<table>
<thead>
<tr>
<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>PHWR-220</td>
<td>NPCIL</td>
<td>India</td>
<td>220</td>
<td>16 units in operation</td>
</tr>
<tr>
<td>PHWR-540</td>
<td>NPCIL</td>
<td>India</td>
<td>540</td>
<td>2 units in operation</td>
</tr>
<tr>
<td>PHWR-700</td>
<td>NPCIL</td>
<td>India</td>
<td>700</td>
<td>4 units under construction</td>
</tr>
<tr>
<td>CNP-300</td>
<td>CNNC</td>
<td>China, Republic of</td>
<td>300</td>
<td>3 units in operation, 2 units under construction</td>
</tr>
<tr>
<td>Prototype Fast Breed Reactor (PFBR-500)</td>
<td>IGCAR</td>
<td>India</td>
<td>500</td>
<td>Under construction – Commissioning in mid 2012</td>
</tr>
<tr>
<td>KLT-40S</td>
<td>OKBM Afrikantov</td>
<td>Russian Federation</td>
<td>70</td>
<td>2 units under construction</td>
</tr>
<tr>
<td>HTR-PM</td>
<td>Tsinghua University</td>
<td>China, Republic of</td>
<td>250</td>
<td>Detailed design, 2 modules under construction</td>
</tr>
<tr>
<td>CAREM-25</td>
<td>CNEA</td>
<td>Argentina</td>
<td>27</td>
<td>Started site excavation in Sept 2011, construction in 2012</td>
</tr>
</tbody>
</table>
### Perceived Advantages and Challenges

**IAEA Observation**

<table>
<thead>
<tr>
<th>Technological Issues</th>
<th>Advantages</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Shorter construction period (modularization)</td>
<td>• Licensability (<em>due to innovative or first-of-a-kind engineering structure, systems and components</em>)</td>
</tr>
<tr>
<td></td>
<td>• Potential for enhanced safety and reliability</td>
<td>• Non-LWR technologies</td>
</tr>
<tr>
<td></td>
<td>• Design simplicity</td>
<td>• Operability performance/record</td>
</tr>
<tr>
<td></td>
<td>• Suitability for non-electric application (desalination, etc.).</td>
<td>• Human factor engineering; operator staffing for multiple-modules plant</td>
</tr>
<tr>
<td></td>
<td>• Replacement for aging fossil plants, reducing GHG emissions</td>
<td>• Proliferation Resistance &amp; Physical Protection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Post Fukushima action items on design and safety</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Non-Technological Issues</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Fitness for smaller electricity grids</td>
<td>• Economic competitiveness</td>
</tr>
<tr>
<td></td>
<td>• Options to match demand growth by incremental capacity increase</td>
<td>• First of a kind cost estimate</td>
</tr>
<tr>
<td></td>
<td>• Site flexibility</td>
<td>• Regulatory infrastructure (<em>in both expanding and newcomer countries</em>)</td>
</tr>
<tr>
<td></td>
<td>• Reduced emergency planning zone</td>
<td>• Availability of design for newcomers</td>
</tr>
<tr>
<td></td>
<td>• Lower upfront capital cost (better affordability)</td>
<td>• Infrastructure requirements</td>
</tr>
<tr>
<td></td>
<td>• Easier financing scheme</td>
<td>• Post Fukushima action items on institutional issues</td>
</tr>
</tbody>
</table>
# Advanced Design Features & Technologies

<table>
<thead>
<tr>
<th><strong>Advanced Features</strong></th>
<th>** Adopted by**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple-modules deployment</td>
<td>Almost all SMR designs</td>
</tr>
<tr>
<td>Integrated nuclear steam supply system, with in-vessel steam generators</td>
<td>SMART, mPower, W-SMR, ACP-100, NuScale, CAREM-25, CAP-150</td>
</tr>
<tr>
<td>Helical-coil steam generators</td>
<td>IRIS, NuScale, SHELF, HTR-PM</td>
</tr>
<tr>
<td>Natural-circulation of Primary Coolant</td>
<td>CAREM-25, NuScale, AHWR300-LEU, ABV-6</td>
</tr>
<tr>
<td>Horizontally-mounted RCPs</td>
<td>SMART, mPower, ACP-100, IRIS</td>
</tr>
<tr>
<td>Internal control rod drive mechanisms</td>
<td>mPower, IRIS</td>
</tr>
</tbody>
</table>
| **Passive engineered safety features** – *eliminate the need of EDG* | Almost all SMR designs – *incorporate lessons learned from the FDA*
| Digital instrumentation & control | Almost all SMR designs |
| Below grade construction | NuScale, mPower |
| Barge-mounted floating NPP | KLT-40S, CAP-FNPP |
| Sea-bed moored SMR operated from a coast control room | Flexblue, SHELF |
| Non-water cooled SMRs | HTR-PM, SVBR-100, 4S, PFBR-500, … |

**Common Issues:** Verification of advanced features, codes & standards, and *technology assessments*
Anticipated Issues on Instrumentation & Control

- Specific Operational and Process Characteristics
  - First of a kind structure, system and component engineering;
  - New plant dynamic behaviour and special architectures
  - Innovative reactors with long fuel cycles and extended operation
  - Non-water coolants/moderators and extreme remote environments

- Improved Functionality
  - Multi-modules plant operation
  - Flexible operation (requirements for extreme load-follow capability)
  - Non-electric applications
  - Control of Nuclear-RES Hybrid energy systems

- I&C to satisfy specific safety requirements in post-Fukushima
  - Revisit defence-in-depth, diversity, redundancy, independency of safe reactor trip versus ESF actuations
  - I&C for Non-Electric Emergency Core Cooling Systems

- Technological Needs
  - Sensor technologies for integral-PWRs’ process monitoring and measurements
  - Digital I&C

- Cyber-Security & Communications
  - SMRs deployment in remote-areas
  - Emergency planning zone

- Address Human-Performance Issues
CM on Incorporating Lessons Learned from the FDA in SMR Technology Assessment for Design of Engineered Safety System (30 May-1 June 2012)

• Achieved Objectives:
  • Presented technical lessons-learned from the sequence of events of the Fukushima accident to be incorporated in the design of engineered safety features of various small-reactor technology currently under development;
  • Discussed the impact of the accident to the current international R&D activities on SMR technology development
  • To advise the IAEA on the identification of subjects of near-term and long-term international R&D activities in SMR technology development, in the area of advanced engineered safety features designs, focusing on non-electric emergency core and containment cooling system designs and performance evaluation
  • Participants: India (BARC), Indonesia (BATAN), Italy (Polimi), Japan (Tokyo Institute of Technology), Republic of Korea (KAERI), Russia (OKBM Afrikantov), and USA (GE-Hitachi Nuclear Energy)

• Based on the lessons learned from FDA, the participants provided recommendations on the possible countermeasure/technology development to be adopted in the design of advanced integral type water cooled SMRs.
### Recommendations:

<table>
<thead>
<tr>
<th>Country</th>
<th>Recommendations</th>
</tr>
</thead>
</table>
| India   | • Larger margin in advanced plant irrespective of plant location.  
          • Development of accident management skills under extreme conditions. |
| Indonesia | • Consideration of volcano eruption and tsunami simultaneously.  
             • Protection of system and components from volcanic dust. |
| Italy   | • Consideration of “plug-in” water and electricity supplies in early design phase.  
          • Determination of optimum grace period. |
| Japan   | • Ensure switchboards integrity.  
          • Location of spent fuel pool should be reconsidered. |
| Korea   | • Passive cooling of spent fuel pool.  
          • Periodic inspection and testing of SSCs need to be strengthened. |
| Russia  | • Scope of PSA needs to be extended to include various external hazards.  
          • Off-site resources should be timely with no long delays. |
| USA     | • Multiple unit threat needs to be considered for SMR deployment.  
          • Plans/procedures to bring equipment from the closest adjacent NPP. |
Focus of IAEA Activities on SMR Technology Development for 2014 - 2015

1. Formulation of roadmap for technology development and deployment - including countries requirements, regulatory and business issues

2. Defining safety-performance, operability, maintainability and constructability indicators to assist countries in assessing advanced SMR technologies

3. Development of Guidance and Tools to Facilitate Countries with Planning for SMRs Technology Implementation
   - Reactor Technology Assessment Methodology for SMR
   - Approaches for Environmental Impact Assessment for SMR

4. CRP on the Design and Performance Assessment of Non-Electric Engineered Safety Features in Advanced Small Reactors

Emphasize the Need to Facilitate Capacity Building in New Entrants on SMR Technology Assessment by Identifying Common Positions on Specific SMR Issues
… Thank you for your attention.