IAEA Project 1.1.5.2 on SMR Technology Development and Update of Global SMR Development

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SMR: Rationale of developments

A nuclear option to meet the need for flexible power generation for wider range of users and applications

**Economic**
- Lower Upfront capital cost
- Economy of serial production

**Modularization**
- Multi-module
- Modular Construction

**Flexible Application**
- Remote regions
- Small grids

**Smaller footprint**
- Reduced Emergency planning zone

**Replacement for aging fossil-fired plants**

**Potential Hybrid Energy System**

**Better Affordability**
- Shorter construction time

**Wider range of Users**

**Site flexibility**
- Reduced CO₂ production

**Integration with Renewables**
### Status and major accomplishment in Technology Developer Countries

<table>
<thead>
<tr>
<th>Countries</th>
<th>Recent Milestone</th>
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<tr>
<td>Argentina</td>
<td>CAREM25 is in advanced stage of construction. Aiming for fuel loading &amp; start-up commissioning in 2019</td>
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<td>Canada</td>
<td>CNSC is performing design reviews for several innovative SMR designs, mostly non-water cooled, including molten salt reactors (MSR)</td>
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| China                   | • HTR-PM is in advanced stage of construction. Commissioning expected in 2018.  
                          | • ACP100 completed IAEA generic reactor safety review. CNNC plans to build ACP100 demo-plant in Hainan Provence in the site where NPPs are already in operation.  
                          | • China has 3 floating SMR designs (ACP100S, ACPR50S and CAP-F)  |
| Republic of Korea       | SMART (100 MWe) by KAERI certified in 2012. SMART undertakes a pre-project engineering in Saudi Arabia, for near-term construction of 2 units. |
| Russian Federation      | • Akademik Lomonosov floating NPP with 2 modules of KLT40S is in advanced stage of construction. Aiming for commissioning in 2019.  
                          | • AKME Engineering will develop a deployment plan for SVBR100, a eutectic lead bismuth cooled, fast reactor. |
| United Kingdom          | • Rolls-Royce recently introduced UK-SMR, a 450 MW(e) PWR-based design; many organizations in the UK work on SMR design, manufacturing & supply chain preparation  
                          | • UK Nuclear AMRC to develop a module demonstrator for the UK-SMR  
                          | • Develop an understanding of modules and underpin early stage design principles |
| United States of America| • The US-NRC has started design review for NuScale (600 MW(e) from 12 modules) from April 2017, aiming for FOAK plant deployment in Idaho Falls.  
                          | • TVA submitted early site permit (ESP) for Clinch River site, design is still open. |
## Status and accomplishment in Embarking Countries

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<tr>
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| **Saudi Arabia** | • Vision 2030 → National Transformation Program 2020: Saudi National Atomic Energy Project:  
• K.A.CARE performs a PPE with KAERI to prepare a construction of 2 units of SMART  
• An MOU between K.A.CARE and CNNC on HTGR development/deployment in KSA |
| **Indonesia** | • Through an open-bidding, an experimental 10 MW(th) HTR-type SMR was selected in March 2015 for a basic design work aiming for a deployment in mid 2020s  
• Site: R&D Complex in Serpong where a 30 MW(th) research reactor in operation  
• BAPETEN, the regulatory body has issued a site license |
| **Jordan** | • Jordan, Saudi Arabia and Republic of Korea is to conduct a feasibility study for a deployment of SMART in Jordan  
• Technology assessment workshop with the IAEA |
| **Poland** | • HTGR for process heat application to be implemented in parallel to large LWRs  
• 10 MW(th) experimental HTGR at NCBJ proposed possibly with EU cooperation |
| **Tunisia** | • STEG, the National Electricity and Gas Company is active in performing technology assessment for near-term deployable water-cooled SMRs |
| **Kenya** | • Requested support on human capacity building for Reactor Technology Assessment that covers SMRs through IAEA-TC Project, to be implemented in 2018 |
# Project 1.1.5.2 for 2018 - 2019

<table>
<thead>
<tr>
<th>Task #</th>
<th>Title of Task</th>
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<tbody>
<tr>
<td>1.1.5.2 (1)</td>
<td>General Management</td>
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<tr>
<td>1.1.5.2 (2)</td>
<td>Design, Manufacturing Process and Technology Qualification of Novel Components for Integral PWR type Small Modular Reactors</td>
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<tr>
<td>1.1.5.2 (3)</td>
<td>Technology Assessment for Deploying Floating Power Units with Small Modular Reactors in Developing Countries with Remote Areas</td>
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<tr>
<td>1.1.5.2 (4)</td>
<td>Design and Operation Aspects of Water-cooled Small Modular Reactors</td>
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<tr>
<td>1.1.5.2 (5)</td>
<td>Design and performance assessment of passive engineered safety features in advanced SMRs, implemented as <strong>CRP I32010</strong></td>
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<td>1.1.5.2 (6)</td>
<td>Generic User Requirements of Developing Countries for Small and Medium-sized Reactors and their application</td>
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<tr>
<td>1.1.5.2 (7)</td>
<td>Provide education and training on technology assessment for near term water-cooled reactors and SMRs as a service to the Member States</td>
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<tr>
<td>1.1.5.2 (8)</td>
<td>Development of Approaches, Methodologies and Criteria for Determining the Technical Basis for Emergency Planning Zone (EPZ) for SMR Deployment, implemented as <strong>CRP I31029 (NS and NE)</strong></td>
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Project 1.1.5.2 (SMR): **Key Activities**

**Meetings:**
- Launching the new Technical Working Group for SMR: *The 1st TWG Meeting for Small, Medium-sized or Modular Reactors, Vienna, 23 - 26 April 2018*

**Coordinated Research Projects**
- 2nd RCM for CRP I32010 on Design and Performance Assessment of Passive Engineered Safety Features in SMRs, Vienna, 7 – 10 May 2018
- 1st RCM for CRP I31029 on Development of Approaches, Methodologies and Criteria for Determining the Technical Basis for EPZ for SMR Deployment, Vienna, 14 – 17 May 2018

**New Projects**
- TCEU project on Facilitating Capacity Building for SMRs: Developments, Safety Assessment, Licensing and Utilization (2018-19)
- New Peaceful Uses Initiatives (Extra Budgetary) proposals for *generic users’ requirements, reactor technology assessment and IT Tool for SMR*
- SMR proposal to be submitted to EU H2020
Project 1.1.5.2 (SMR): Outputs

**Publications**

- NES Technology Roadmap for SMR Deployment (to be submitted to the Publication Committee in May 2018) – inter departments collaboration
- TECDOC on Deployment Indicators for SMRs: Methodology, Analysis of Key Factors and Case Studies - A joint activity with NEPK/PESS
- TECDOC Status of Environmental Impact Assessment Approaches for SMR Deployment – a joint activity with NA/TEL Seibersdorf
- TECDOC Options to Enhance Energy Supply Security using Hybrid Energy Systems based on SMRs – inter divisions collaboration
- Revision and update of biannual SMR compendium

**Other Outputs**

- In cooperation with Nuclear Infrastructure Development Section: adaptation of milestone approach to the case of SMR
- Support NPTDS Water-cooled Reactors Team:
  - Introduce a Basic E-Toolkit for Reactor Technology Assessment – based on the Nuclear Energy Series report No. NP-T-1.10 (2013)
  - Workshop on SMR RTA to Embarking Countries
  - Workshop on the IAEA iPWR simulator
Identification of Potential Infrastructure Issues for SMR Deployments

• As an Action Item from the SAGNE Meeting in April 2017: A Joint NIDS-NPTDS Consultancy Meeting held in July 2017 – referencing to the Milestone Approach (NES NG-G-3.1, Rev. 1)

• Purpose:
To assess, if the Milestone Approach is adaptable for the evaluation of the status of national nuclear infrastructure development when countries opting SMRs

• Conclusions:
– The Milestone Approach is applicable for the evaluation of the infrastructure for SMR deployment;
– The deployment of new technologies introduce uncertainties that may impact siting process (e.g. impact of the technical information on the credibility of the bounding envelope)

• SMRs deployment may present specific implications on: Safeguards, emergency preparedness (EPZ), national position, management and nuclear safety (e.g. application of safety requirements)

• Invited external experts from: Canada, China, Saudi Arabia and Romania
Coordinated Research Projects


• Key objective: Report Verification & Validation methods for SMR’s engineered safety features performance assessment;
• Participants from 11 Member States’ organizations: CNEA, UOIT, CNNC/NPIC, ENRRA, BATAN, BARC, ENEA, KAERI, LEI, PAEC and Rolls-Royce, plc.

CRP I31029 on Development of Approaches, Methods and Criteria for Determining Technical Basis for EPZ for SMR Deployment (2018 – 2020)

• A Joint CRP between Department of Nuclear Energy and Department of Nuclear Safety & Security
• Key objective: address aspects of emergency preparedness & response (EPR) specific for SMR deployment, particularly the size of EPZ;
• Participants from 15 Member States’ organizations: CNEA, CNL, CNPE, SNERDI, INET, VTT, BATAN, SOREQ, Toshiba, KAERI, EC-JRC, PAEC, K.A.CARE, STEG, CRARISK, ANL, TAMU, and Rolls-Royce, plc.
SAGNE-2018 Recommendations

• The Department of Nuclear Energy should pursue cooperation with the Department of Nuclear Safety & Security with a focus on reviewing and streamlining SMR safety and licensing requirements on EPZ and Emergency Preparedness and Response (EPR), backed by technological innovation;

• The ToR of the TWG-SMR should be revised to explicitly include in the areas where TWG will provide advice: “design for safety” and “non-electric applications and cogeneration”
### SMR for Non-Electric Applications

#### Reactor Types
- **Very high temperature reactors**
- **Gas-cooled fast reactors**
- **Molten Salt reactors**
  - Supercritical water-cooled reactors
  - Sodium-cooled fast reactors
  - Liquid metal cooled reactors

#### Temperature Ranges
- 100°C to 1200°C

#### Applications
- **District heating**
- **Seawater desalination**
- **Pulp & paper manufacture**
- **Methanol production**
- **Heavy oil desulfurization**
- **Petroleum refining**
- **Methane reforming hydrogen production**
- **Thermochemical hydrogen production**
- **Coal gasification**
- **Blast furnace steel making**
Marine-based SMRs (Examples)

KLT-40S
- Compact-loop PWR
- 60 MW(e) / 200 MW(th)
- Core Outlet Temp.: 322°C
- Fuel Enrichment: < 5%
- FPU for cogeneration
- Once through SG, passive safety features
- Fuel cycle: 30 months
- To be moored to coastal or offshore facilities
- Completion of conceptual design programme

ACPR50S
- Compact-loop PWR
- 35 MW(e) / 150 MW(th)
- Core Outlet Temp.: 316°C
- Fuel Enrichment: 18.6%
- FPU for cogeneration
- Without Onsite Refuelling
- Fuel cycle: 36 months
- Spent fuel take back
- Advanced stage of construction, planned commercial start: 2019 – 2020

FLEXBLUE
- Transportable, immersed nuclear power plant
- PWR for Naval application
- 160 MW(e) / 530 MW(th)
- Core Outlet Temp.: 318°C
- Fuel Enrichment: 4.95%
- Fuel Cycle: 38 months
- Passive safety features
- Transportable NPP, submerged operation
- Up to 6 module per on shore main control room
- To be moored to coastal or offshore facilities
- Completion of conceptual design programme

SHELF
- Transportable, immersed NPP
- Integral-PWR
- 6.4 MW(e) / 28 MW(th)
- 40,000 hours continuous operation period
- Fuel Enrichment: < 30%
- Combined active and passive safety features
- Power source for users in remote and hard-to-reach locations;
- Can be used for both floating and submerged NPPs

Floating Power Units (FPU)
- Compact-loop PWR
- 35 MW(e) / 150 MW(th)
- Core Outlet Temp.: 316°C
- Fuel Enrichment: 18.6%
- FPU for cogeneration
- Without Onsite Refuelling
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Images reproduced courtesy of OKBM Afrikantov, CGNPC, DCNS, and NIKIET
## Status of Deployment Timeline

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<thead>
<tr>
<th>Year</th>
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### KLT-405
- Barge Prep, Fuel Loading
- Operation→2060

### HTR-PM
- Graphite, Pebble Loadings
- Operation→2060

### CAREM
- Construction
- Fuel loading
- Operation→2060

### ACP1000
- Construction
- Fuel loading
- Operation→2085

### SMART
- Post SDA Licensing
- Construction
- Fuel loading
- Operation→2085

### NuScale
- Design Certification Review (42 months)
- Construction
- Fuel loading
- Operation→2085
Current Challenge: Construction Management

Reasons for delayed are varied, including to incorporate safety lessons learned.

Technology alone does not shorten construction time.

Large Reactors connected to Grid since 1990:
- China
- Japan
- Republic of Korea
- Russia

N-th of a kind 36 month target.
SMR: Advantages, Issues & Challenges

Technology Issues
- Shorter construction period (modularization)
- Potential for enhanced safety and reliability
- Design simplicity
- Suitability for non-electric application (desalination, etc.)
- Replacement for aging fossil plants, reducing GHG emissions

Non-Techno Issues
- Fitness for smaller electricity grids
- Options to match demand growth by incremental capacity increase
- Site flexibility
- Reduced emergency planning zone
- Lower upfront capital cost (better affordability)
- Easier financing scheme

Technology Issues
- Licensability (FOAK designs)
- Non-LWR technologies
- Operability and Maintainability
- Staffing for multi-module plant; Human factor engineering;
- Supply Chain for multi-modules
- Advanced R&D needs

Non-Techno Issues
- Economic competitiveness
- Plant cost estimate
- Regulatory infrastructure
- Availability of design for newcomers
- Physical Security
- Post Fukushima action items on institutional issues and public acceptance
Thank you!

For inquiries on SMR, please contact:
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