Approaches for Reactor Technology Assessment and Selection: Case Study on SMRs

Dr. M. Hadid Subki
Technical Lead, SMR Technology Development
Division of Nuclear Power, Department of Nuclear Energy

Contact: M.Subki@iaea.org
Programme Brief

• IAEA Programme on Reactor Technology Assessment and Selection: The Assessment Process and Approach

• In-charge Officers at the Division of Nuclear Power:
  • Dr. Mark Harper (m.harper@iaea.org)
  • Dr. Katsumi Yamada (k.yamada@iaea.org)
  • Dr. Hadid Subki (m.subki@iaea.org)
  • Initial developer of the Draft NE Series Report: Dr. Stephen P. Schultz (Consultant, USA)

• Planned publication:
  • Fall 2012
Outline: Key Discussion Questions

- What is it?
- When do I perform it?
- Who should do it?
- How is it to be done?
- Why should it be done?

IAEA Programme Plans to Support Technology Assessment and Selection
Technology Assessment and Selection

What is it?

➡️ Purpose

• **OVERALL**: Determines NPP technology to fulfil energy delivery needs using a systematic process beginning with Policy Objectives
• Assists in refining Infrastructure development
• Develops specific questions to obtain the information from vendors that is required to perform the Technology Assessment
• Develops technical requirements for the bid specification
• Provides the technical core for performing the bid evaluation
• Delivers documented decision-making rationale for the technology choice

➡️ Content

• The structured technical evaluation documenting the Policy Objectives and requirements and how well they will be met
Technology Assessment and Selection
The “give” and the “take”

What will the IAEA process approach provide:

- A decision-making tool kit for Technology Assessment and Selection
- Approaches for information gathering and assessment that are designed to be technology-neutral
- A process that should allow increased level of detail as it moves from requirements for the bid specification to performing the bid evaluation to monitoring project implementation

What does the IAEA process approach expect:

- The Technology Assessment and Selection is performed and completed by the Member State
- The Member State has responsibility and authority for technology decisions that are made at any stage in the process
Technology Assessment within Infrastructure Development

When do I perform it?

MILESTONE 1
Ready to make a knowledgeable commitment to a nuclear programme

MILESTONE 2
Ready to invite bids for the first NPP

MILESTONE 3
Ready to commission and operate the first NPP

PHASE 1
Considerations before a decision to launch a nuclear power programme is taken

PHASE 2
Preparatory work for the construction of a NPP after a policy decision has been taken

PHASE 3
Activities to implement a first NPP

Maintenance and continuous infrastructure improvement

~ 10 – 15 years

INFRASTRUCTURE DEVELOPMENT PROGRAMME
Ownership and the Assessment Task Team members are critical success factors

- Owner/Operator shall take full responsibility for the conduct and results of the Technology Assessment
- Technical / managerial Technology Assessment Task Team is assembled with its mission to report the results directly to the (top) decision-maker
- Task Team with full expertise in design, engineering, construction, and operation of facility and its environment
- Consultants should be used as required to supplement the Task Team with specific expertise, reporting to the Task Team management
Key Discussion Questions

- What is it?
- When do I perform it?
- Who should do it?
- How is it to be done?
- Why should it be done?

IAEA Programme Plans to Support Technology Assessment and Selection
Technology Assessment and Selection Process: Basic Steps (Slide 1)

1. Establish a competent Technology Assessment Team/Group
   • Organization & HR

2. Develop the key criteria and requirements based on relevant policy goals and objectives, such as
   • National energy plan
   • National infrastructure: the grid, site, and environmental characteristics
   • Local conditions: industry, economy, workforce, and demography
   • Regulatory and safety requirements, emergency planning needs
   • Economics: plant costs and financing expectations
   • Security, physical protection and safeguard requirements
   • Performance requirements

3. Assure that the relative importance of each of the selected policy goals and objectives has been established

4. Identify NPP designs and technologies that are commercially available and have the potential to meet the general criteria
5. Identify and evaluate key technical features and requirements that are tied to the policy goals and objectives

6. Develop specific input requirements and associated questions for technology holders to obtain consistent information required to perform the assessment

7. Determine factors and importance weighting associated with the assessment elements and features

8. Evaluate influences or quantify uncertainty and risk assessment factors

9. Perform assessment and derive rankings using decision-making process approaches

10. Integrate and validate the results of the combined assessments
Common User Considerations (CUC)

- Sustainability of the nuclear power programme
- Demand for power generation capacity
- Electrical grid characteristics
- Site Characteristics
- Environmental Impact
- Nuclear safety, regulatory framework, and licensability
- Radiation protection
- Nuclear fuel cycle policies
- Nuclear Waste Management
- Safeguards
- Security and emergency planning
- National participation, industrial development
- Human resource development
- Economics on the nuclear energy system (NES)
- Financing of NES Projects
## Results of Newcomer Countries Survey (1)

<table>
<thead>
<tr>
<th>Selected Elements</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standardization and simplification</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Reactor safety</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Plant performance and operability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Proven technology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Economy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Constructability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

*1 is the most important, 6 is the least important
Results of Newcomer Countries Survey (2)

Average Rankings

- Standardization and Simplification
- Constructability
- Economics
- Reactor Safety
- Plant Performance and Operability
- Proven Technology
### Results of Newcomer Countries Survey (3)

#### Tally of Rankings (Qualitative)

<table>
<thead>
<tr>
<th>Selected Elements</th>
<th>IMPORTANT</th>
<th>LESS IMPORTANT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standardization and simplification</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Reactor safety</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>Plant performance and operability</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Proven technology</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Economy</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Constructability</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>

- What do the above survey results show or imply on nuclear newcomer countries preference?
- What could be the rationale?
- What do nuclear industries and/or expanding nuclear countries perceive?
Results of Newcomer Countries Survey (4)
Example of Key Elements of the General Criteria:

- Economics of construction and operation; Funding availability
- Performance throughout operation: economic, reliable, as expected
- Plant nuclear safety
- Strategic technical issues
- Project duration and estimation of risk
- Industrial involvement opportunities -- National Participation and Localization
- Proven technology
- Unit size
- and so forth..
Example of Relative Importance Ranking for the Key Elements in the Assessment:

1. **Economics** of construction and operation; Funding availability
2. Plant nuclear **safety**
3. Industrial involvement opportunities -- National Participation and Localization
4. Performance throughout operation: economic, reliable, as expected
5. **Strategic** technical issues
6. **Project duration** and estimation of risk
Example of Quantitative Importance Rating for the Key Elements in the Assessment:

25  Economics of construction and operation; Funding availability
20  Plant nuclear safety
20  Industrial involvement opportunities -- National Participation and Localization
15  Performance throughout operation: economic, reliable, as expected
10  Strategic technical issues
10  Project duration and estimation of risk

100
Technology Assessment and Selection

Evaluation Process Approaches

- Develop importance factors associated with the Key Criteria and the key technical features and their requirements

- Choose the evaluation process approach to be used:
  - Multi-Attribute Utility Theory and Kepner-Tregoe methodology are recommended straightforward approaches for evaluation of complex problems and systems
  - (1) Importance weighting factors are determined for each of the general criteria and key technical elements
  - (2) The performance evaluation process is structured for the general criteria and key technical elements and features for each candidate technology
  - (3) Weighting factors are applied to the key technical features performance evaluation scoring for each candidate technology

- Determine and evaluate associated risks and uncertainties:
  - Country-specific issues such as human resources development
  - Political, geo-political, and commercial considerations
  - Short term versus long term goals, objectives, and opportunities

- Process the integration of these evaluations to derive rankings
## Technology Assessment Process
### Key Features for Technology Assessment

<table>
<thead>
<tr>
<th>Feature</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Considerations and Grid Integration</td>
<td>High</td>
</tr>
<tr>
<td>Technical Characteristics and Performance</td>
<td></td>
</tr>
<tr>
<td>Major Systems and Components</td>
<td>Medium</td>
</tr>
<tr>
<td>Nuclear Fuel Performance</td>
<td>(Medium)</td>
</tr>
<tr>
<td>Radiation Protection</td>
<td>Low</td>
</tr>
<tr>
<td>Environmental Impact</td>
<td>Low</td>
</tr>
<tr>
<td>Safeguards (Not a Differentiator)</td>
<td></td>
</tr>
<tr>
<td>Plant and Site Security</td>
<td>Low</td>
</tr>
<tr>
<td>Physical Protection of Plant Systems</td>
<td>Low</td>
</tr>
<tr>
<td>Severe Accident Releases</td>
<td>Medium</td>
</tr>
<tr>
<td>Owners Scope of Supply</td>
<td>Medium</td>
</tr>
<tr>
<td>Supplier/Vendor Issues</td>
<td>High</td>
</tr>
<tr>
<td>Project Schedule Capability</td>
<td>Medium</td>
</tr>
<tr>
<td>Technology Transfer and Technical Support</td>
<td>High</td>
</tr>
<tr>
<td>Project Contracting Options</td>
<td>High</td>
</tr>
</tbody>
</table>

### Economics
- Capital Costs (High)
- O & M Costs
- Fuel Costs
- Decommissioning
Key Features for Technology Assessment
Technical Characteristics and Performance

- Size
- Plant Lifetime
- Proven Technology and Licensability
- Standardization
- Simplification
- Constructability
- Operability and Manoeuvrability
- Inspectability and Maintainability
- Plant Availability and Capacity Factor
- Sustainability – Operation for Planned Lifetime
- Reliability
- Nuclear Safety and Regulatory Issues
Key Features for Technology Assessment

Major Systems and Components

- Nuclear Steam Supply Systems (NSSS)
- Balance of Plant (BOP)
- Instrumentation & Controls Systems
- Electrical Systems
Technology Assessment and Selection Process: Establish Importance & Valuations (Steps 5-7): Examples

- Example technical features that will be scored and then linked to the key elements and their Importance Rankings in the Assessment

- Selected Key Element: Plant Nuclear Safety:
  - Core Damage Frequency
  - Large Early Release Frequency
  - PRA maturity and pedigree
  - Offsite power reliance and availability of non-electric pumps, valves,
  - Containment design for accidents and severe accidents
  - Active versus passive safety system design and operation (and experience)
  - Response to and control capability for accidents with onsite and offsite releases
  - Capability to respond to extreme external events
Technology Assessment and Selection Process:
Basic Steps in Process (Slide 2)

5. Identify and evaluate key technical features and requirements that are tied to the policy goals and objectives

6. Develop specific input requirements and associated questions for technology holders to obtain consistent information required to perform the assessment

7. Determine factors and importance weighting associated with the key assessment elements and technical features

8. Evaluate influences or quantify uncertainty and risk assessment factors

9. Perform assessment and derive rankings using decision-making process approaches

10. Integrate and validate the results of the combined assessments
### Technology Assessment Process

#### Risk and Uncertainty Areas for Consideration

<table>
<thead>
<tr>
<th>Relationship Considerations (High)</th>
<th>Relationship with Designer / Vendor</th>
<th>Relationship with Suppliers</th>
<th>Strength of Vendor/Supplier Relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Support Available (Varied)</td>
<td>Vendor Long Term Technical Support (High)</td>
<td>Experienced Utilities: Willing to Help (High)</td>
<td>User/Utility, including Owners Groups (Low)</td>
</tr>
<tr>
<td>Potential Risk Contributors (High)</td>
<td>Project Schedule Risk</td>
<td>Long Term Fuel Supply Security</td>
<td>Project Financing Assistance/Assurance (Very High)</td>
</tr>
</tbody>
</table>
Technology Assessment and Selection Process: Perform Assessment and Derive Rankings

- Apply decision-making methodology for the comparative assessment
  - Qualitative Evaluation
  - Kepner-Tregoe Process
  - Multi-Attribute Utility Theory

- Assign the importance weightings for key elements and key features and derive the scoring for key factors
  - Importance Weightings: $IW_{Element(i)} \cdot IW_{Feature(j)} \cdot Score_{Feature(j)}$

- Integrate the results for the assessment of each candidate technology

$$Candidate\ Technology\ Rating = \sum_{i, j} IW_{Element(i)} \times IW_{Feature(j)} \times Score_{Feature(j)}$$
Key Discussion Questions

What is it?  When do I perform it?  Who should do it?  How is it to be done?  Why should it be done?

IAEA program and plans to support Technology Assessment
When you have completed the Technology Assessment process, you will have identified the following:

- Important design features and critical factors in the decision-making process
- Programmatic features which are required to achieve success
- Future strategies to improve success
… Thank you for your attention.
Comprehensive Design Review of Major Systems and Components

Nuclear Steam Supply System (NSSS):

- Reactor
- Fuel Assembly
- Control Rod and Mechanism
- Reactor Internals
- Reactor Coolant System
- Reactor Water Clean Up / Chemical Volume Control System
- Residual Heat Removal and Shutdown Cooling System
- Emergency Core Cooling System
- Containment Vessel
- Fuel Pool Cooling
- Water Storage, Liquid Radwaste and Gaseous Radwaste Systems
- Main Steam Line System
- Ultimate Heat Sink
Comprehensive Design Review of Major Systems and Components

Balance of Plant (BOP)

- Main Feedwater
- Main Condenser and Condensate System
- Circulating Water
- Service Water
- Reactor Building Closed Cooling Water
- Turbine Building Closed Cooling Water
- Main Turbine Design and Steam Bypass
- Heating, Ventilation, and Air Conditioning Systems
- Feedwater Heating System
- Extraction Steam and Heater Drains
- Fire Protection System
Comprehensive Design Review of Major Systems and Components

Instrumentation and Control (I&C)

- Reactor Protection System
- Engineered Safeguards Actuation System
- Balance of Plant Engineering Safeguards Actuation System
- Feedwater Control System
- Steam Bypass Control System
- Nuclear Instrumentation
- Radiation Monitor System
- Remote Shutdown System
- Compliance with Accident Monitoring Instrumentation Criteria
- Main Control Room and Human Factors Design
Comprehensive Design Review of Major Systems and Components

**Electrical Systems**

- Offsite Power System
- Onsite Power Distribution System
- Diesel Generator
- Class 1E DC System
- Class 1E 120 Volt Instrument AC System
- Non-Class 1E DC System
- Non-Class 1E Uninterruptable Power Supply
- Transformers
- **Switchgear**