Global Nuclear Power Seminar

24 Nov 2010
JOI (Japan Bank for International Cooperation)
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Nuclear Power – 4 Topics

1. Global markets
2. Strategic issues
3. Role of government
4. Small reactors
1. Global markets

- Reactor designs
- Global league tables
- Nuclear costs
1. Global markets

Reactor design evolution

- Generation I
  - Early Prototype Reactors
    - Shippingport
    - Dresden, Fermi I
    - Magnox

- Generation II
  - Commercial Power Reactors
    - LWR-PWR, BWR
    - CANDU
    - VVER/RBMK

- Generation III
  - Advanced LWRs
    - ABWR
    - System 80+
    - AP600
    - EPR

- Generation III+
  - Evolutionary Designs Offering Improved Economics
    - 

- Generation IV
  - Highly Economical
  - Enhanced Safety
  - Minimal Waste
  - Proliferation Resistant

Timeline:
- Gen I: 1950
- Gen II: 1960
- Gen III: 1970
- Gen III+: 1980
- Gen IV: 1990

Dates:
- 2000
- 2010
- 2020
- 2030
1. **Global markets**
Gen III, III+ attributes

- Attributes of Gen III, III+ designs
  - Large size
  - Aircraft crash resistance
  - Lower Core Damage Frequency (CDF)
  - Passive safety (e.g. AP1000, ESBWR)
  - Longer refueling cycle & higher fuel burnup
  - Modular, top-down construction (e.g., ABWR, AP1000)
  - 60 year operating life
  - Load-following & part-load capability
1. Global markets
Gen II+, III & III+ reactor designs

- AP1000
- VVER-1200
- CPR 1000
- ABWR
- EPR
- VVER-1000
- OPR 1000
- APR 1400
- APWR
- ESBWR

- In operation
- Under construction
- Planned
- Proposed

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1. Global markets
Gen II+, III, III+ by country

- China: In operation, Under construction, Planned
- Russia: Under construction, Planned
- India: Planned
- USA: Planned
- ROK: Planned
- Japan: Planned
- UAE: Planned
- Turkey: Proposed
- Vietnam: Proposed

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1. Global markets
Overnight capital costs

Source: OECD 2010, Table 3.7a, overnight costs in USD/kWe

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1. Global markets
High overnight capital cost

Source: EIA 2009 Annual Energy Outlook; 2008 overnight cost including contingency in 2007 $/kW; nuclear = OECD Range
1. Global markets
Long lead time for nuclear

Source: EIA 2009 Annual Energy Outlook input assumptions for construction (lead time); development period is estimate

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2. Strategic issues

- Consolidation
- Cost and perception of risk
- Size of nuclear build programs
- Developing countries
2. Strategic issues
Industry Consolidation

- 1980s
  - MinAtom
  - Siemens
  - Framatome
  - Babcock & Wilcox (USA)
  - Mitsubishi Heavy Ind.
  - Combustion Engineering
    - ASEA
    - Brown Boveri et cie

- 1990s
  - MinAtom
  - Siemens
  - Framatome
  - Mitsubishi Heavy Ind.
  - Asea Brown Boveri (ABB)

- 2000s
  - MinAtom
  - Siemens
  - Framatome ANP
  - Mitsubishi Heavy Ind.
  - BNFL

- 2006
  - MinAtom
  - Siemens
  - AREVA NP
  - Mitsubishi Heavy Ind.
  - Westinghouse

- 2010
  - MinAtom
  - Siemens
  - AREVA NP
  - Mitsubishi Heavy Ind.
  - Westinghouse

MinAtom is consolidated into MinAtom, Siemens, Framatome, Babcock & Wilcox (USA), Mitsubishi Heavy Ind., Combustion Engineering, ASEA, and Brown Boveri et cie. The diagram shows the consolidation process from 1980s to 2010, highlighting key companies like Framatome, Siemens, Mitsubishi Heavy Ind., and Westinghouse.
2. Strategic issues
New industry competitors

- South Korean companies – offering APR1400 to export market
- Chinese nuclear companies – talking about selling Chinese version of AP1000 and CPR1000 into export market
- India looking to sell its PHWR to smaller countries with new nuclear programs
- New companies with small and innovative reactor designs (e.g., B&W, Hyperion, NuScale)
### 2. Strategic issues

**Risk - nuclear cost overruns in USA**

<table>
<thead>
<tr>
<th>Reactor construction starts (units)</th>
<th>Projected overnight cost ($/kW)</th>
<th>Actual overnight cost ($/kW)</th>
<th>% Overrun</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966-67 (11)</td>
<td>$612</td>
<td>$1,279</td>
<td>109%</td>
</tr>
<tr>
<td>1968-69 (26)</td>
<td>$741</td>
<td>$2,180</td>
<td>194%</td>
</tr>
<tr>
<td>1970-71 (12)</td>
<td>$829</td>
<td>$2,889</td>
<td>248%</td>
</tr>
<tr>
<td>1972-73 (7)</td>
<td>$1,220</td>
<td>$3,882</td>
<td>218%</td>
</tr>
<tr>
<td>1974-75 (14)</td>
<td>$1,263</td>
<td>$4,817</td>
<td>281%</td>
</tr>
<tr>
<td>1976-77 (5)</td>
<td>$1,630</td>
<td>$4,377</td>
<td>169%</td>
</tr>
</tbody>
</table>

2. Strategic issues

Risk - Cost estimates seen as escalating

Source: “The Economics of Nuclear Reactors,” Mark Cooper, June 2009
2. Strategic issues

Risk - FOAK & learning curve

- Conceptual cost estimates
- Detailed engineering & licensing
- EPC contracts
- Actual cost first unit
- Learning on additional units reduces time and cost
- Long production lines for standard unit components

Years

Unit Cost

Concept FOAK Learning Mature
2. Strategic issues
Size of Nuclear build programmes

- Low costs linked to large build programme
- High demand growth = high nuclear potential
  - China, India, etc
- Lower demand growth = lower nuclear potential
  - USA, Europe
  - High cost to shift supply to nuclear
    - Shut down existing coal units?
    - Impose significant carbon tax?
2. Strategic issues
South Korean view of world market

The world’s nuclear power plant market by 2030

- Asia: 386 plants (109 operating, 35 under construction, 94 plant development confirmed, 148 being planned)
- Europe: 323 plants (197 operating, 13 under construction, 20 plant development confirmed, 93 being planned)
- North America: 162 plants (122 operating, 3 under construction, 15 plant development confirmed, 22 being planned)
- Others: 47 plants (8 operating, 1 under construction, 6 plant development confirmed, 32 being planned)

Source: Ministry of Knowledge Economy
2. Strategic issues
Developing countries

- High growth rate, but some hurdles
  - Multiple smaller countries, multiple sales
  - Lack of physical and administrative infrastructure
  - Financial viability

- Nuclear power development models
  - IAEA – slow - build infrastructure, then NPP
  - UAE – fast - buy infrastructure and build NPP
  - Russia – faster - build and operate nuclear IPP
3. Role of Government

- State capitalism & national nuclear champions
- Potential roles for Japanese government
- International nuclear initiatives
3. Role of Government
State capitalism & nuclear power

Gov’t orders large reactor fleet

Nuclear industrial capacity developed

Fully integrated nuclear supply chain

Gov’t captures significant learning curve benefits

Export market sales?

Gov’t long-term strategy for nuclear power

Nuclear is low cost energy option

Outside vendors?
3. Role of Government
French nuclear fleet

- 1958 - Framatome founded; obtains Westinghouse PWR license
- 1968 - Seven 900 MWe units ordered
- 1974 - OPEC oil crisis; Sixteen 900 MWe units ordered
- 1976 - Ten 900 MWe units and twenty 1,300 MWe units ordered
- Four 1,500 MWe N4 units
3. Role of Government
Nuclear fleets

- No fleet
- Multiple units
- Multiple identical units
  - Sequential build
  - Bulk purchase
3. Role of Government
Nuclear fleet benefits

<table>
<thead>
<tr>
<th>Organization &amp; Management</th>
<th>Multiple Identical Units</th>
<th>Learning Curve Effects</th>
<th>Volume Orders</th>
<th>Mobilize Teams</th>
<th>Industry &amp; Employment</th>
</tr>
</thead>
</table>
| A single organization with a unified approach and economies of scale to accomplish:  
  - Training  
  - Purchasing  
  - Management  
  - Engineering  
  - Regulatory affairs | • Training  
  • Simulator  
  • Operators and management  
  • Refueling outage skills & equipment  
  • New procedures & equipment modifications  
  • Shared spare parts, special tools, and strategic spares | Learning from:  
  • People involved in construction and operation of multiple units  
  • Modification of the design or the construction approach and schedule  
  • Documenting and sharing lessons learned  
  • Vendors build in learning for later bids | Volume orders may allow upstream component suppliers to invest in longer production lines due to bulk procurement  
Volume orders may bring discounts from NPP vendors that reflect expected learning curve benefits and upstream component savings | Sequencing of construction is key  
Teams move from one project to the next without interruption (also may allow simultaneous work on multiple units)  
Teams could work on similar tasks for many units, allowing significant commitment to hiring & training | French nuclear industrial development is model  
Investment in new production facilities  
Over time, such local suppliers should be able to use their experience (and their own learning curve benefits) to become competitive suppliers in the export market |
3. Role of Government
Integrated nuclear power industry

- Financing
- R&D
- Licensing
- Engineering
- Components and construction
- Operation and maintenance
- Front and back - Nuclear fuel cycle
- Training and education
3. Role of Government
South Korea in UAE

- My personal view of factors leading to UAE selection of South Korea
  - Low price (made possible by South Korea’s nuclear fleet, integrated supply chain, learning curve)
  - Recent and current nuclear construction experience (OPR1000 & APR1400 units in South Korea)
  - National commitment to deliver on time
  - High credibility as a result of South Korea’s role in earlier UAE energy and engineering projects
High credibility and strong commercial relationship based on energy and engineering projects over more than 10 yrs

- Layyah – desalination
- Burj Khalifa – world’s tallest building
- Jebel Ali – Palm island & “M” power & desalination
- Al Taweelah – power & desalination
- Umm Al Nār - desalination
- Shuweihāt – power & desalination
- Ruwais - pipeline, desalination & refinery
- Fujairah – power & desalination

*Dubai
*Abu Dhabi
*Braka NPP
3. Role of Government
Multi-national nuclear initiatives

- Nuclear Fuel Cycle
  - Front end – effective markets + proposals for international nuclear fuel bank (IAEA, NTI)
  - Back end – difficult issues, multiple approaches proposed (e.g., IFNEC/GNEP)

- NPT & Nuclear Suppliers Group
  - Trade may be eroding purpose (India, Pakistan)
  - Iran sanctions may set precedents elsewhere

- Nuclear Liability
4. Small Reactors
Potential benefits

- Lower total plant cost – easier to fund
- Shorter construction time – easier planning
- Smaller size & dispersed locations (less transmission, lower single shaft risk)
- Higher thermal efficiency (He Brayton cycle, supercritical CO2 cycle)
- Longer fuel cycle – exotic reactor concepts
- Safer – lower accident and proliferation risk
4. **Small Reactors**

**Key issues**

- Licensing in LWR-focused nuclear regulatory regimes
- Timing and cost of commercial product
- Will benefits overcome lost scale economies?
- Operational issues and exotic BOP
- Size of market needed for “mass production” business approach
Conclusions – 4 Topics

1. Global markets – Competition and market share
2. Strategic issues – Cost, risk and new markets
3. Role of government - State Enterprises are strong
4. Small reactors – promising, but far from certain
Questions?
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