Small and Medium Sized Reactors (SMR)

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Definitions

According to IAEA
• SMR = Small and Medium Sized Reactors
  – Small-sized reactors → smaller than 300 MWe
  – Medium-sized reactors → from 300 to 700 MWe
  – Regardless of being modular or non-modular
  – Covers all reactors in-operation and under-development with power < 700 Mwe
  – Covers 1970s technology to 2000s innovative technology

According to recent trends
• SMR = Small Modular Reactors
  – Small-sized reactors → smaller than 300 Mwe
  – Emphasize the benefits of being small and modular
  – Focus on innovative reactor designs under-development
Modular?

- The reactor is factory-built in smaller modules and it is assembled on site like a Lego.

- A nuclear unit is composed of various reactor modules. Individual reactor modules can be added at separate times depending on power demand needs.
NuScale Plant
12 modules, 45 MWe each produces a total 540 MWe
Global Development and Deployment

• Many SMRs (with 1970s and 1980s technologies) have long been in operation and many are under construction

• Dozens of concepts for innovative SMRs are under development: Argentina, Brazil, Canada, China, France, India, Japan, Republic of Korea, Russia, South Africa, USA, and some emerging countries.

• A number of companies are developing SMRs - each has unique features and varying megawatt capacity.

• None of the innovative SMRs are commercially available
Types

• Light Water Cooled SMRs
  – Deployment = 10 years
  – CAREM, mPower, W-SMR, NuScale, Smart, ACP-100, KLT-40

• Non-LWR fast reactor SMRs
  – Deployment = 15 -20 years
  – Liquid metal or gas cooled (4S, PRISM, PBMR)

• Advanced designs
  – Deployment = 20+ years
  – Molten salt, others?
Operational Benefits

• Safety
  – Passive safety systems
  – Integral designs

• Flexibility
  – Adaptable to grid size
  – Suitable for remote areas
  – Electricity or process heat

• Simplicity
  – Less components, cabling, piping
  – Factory fabrication
  – Reduced construction times

• Security
  – Below grade emplacement
Economic Benefits

• Expected to be competitive with large LWR costs/KWe ($4-5K/KWe)
  – Economies of series vs economies of scale

• Lower initial construction costs
  – Affordability vs low capital cost

• Electrical capacity can be added in smaller increments to match demand growth
FIGURE 1 Comparison of Size of Investment (i.e., Overnight Cost) with Average Annual Revenues of Investor-Owned Nuclear Utilities

Source: “Small Modular Reactors – Key to Future Nuclear Power Generation in the U.S.,” University of Chicago, Nov 2011
FIGURE F.1 Firm’s Investment in Nuclear Reactor Project for SMRs and GW-LWRs

Source: “Small Modular Reactors – Key to Future Nuclear Power Generation in the U.S.”, University of Chicago, Nov 2011
Technology Advantages

- Shorter construction period
  - Modularization
  - Factory fabrication
- Potential for enhanced reliability and/or safety (??)
- Reduced complexity in design and human factors
- Suitability for non-electrical applications (i.e. process heat and desalination)
- Grid appropriate
  - Tolerance to grid instabilities
  - Suitable to distributed grids
  - Capable of load following (??)
Technology Challenges

- Licensability
  - delays due to design innovation
- Non-LWR technologies
- Operability
- Spent fuel management and waste handling policies
- Impact of innovative design and fuel cycle to proliferation resistance
Non-Technical Advantages

- Suitable for smaller electricity grids
- Options to match demand growth by incremental capacity increase
- Site Flexibility
- Lower upfront investment capital cost per installed unit
- Easier financing scheme
Non-Technical Challenges

• Economic competitiveness
  – economies of scale vs economies of series
  – First-of-a-kind cost estimate vs Nth-of-a-kind
• Proposed reduced emergency planning zone
• Regulation for fuel or NPP leasing
• Limited market opportunities
• Availability of design for newcomers
• Infrastructure requirements
  – Supply chain
  – Manufacturing capabilities
Big Picture Concerns

• First of a kind engineering
• Innovative fuel/core design and fuel cycle
• Viability of multiple-modules station (post-Fukushima)
• Proliferation resistance and physical security
• Ergonomics and control room staffing
• Emergency planning zone
• Mechanistic source term
• Standardization and licenses for manufacturing
• Technology transfer and proprietary design protection
• Codes and Standards
• Users and Owners issues
Conclusions

• SMR maybe an attractive nuclear power option
  – for countries with small electricity grids and/or less-developed electrical infrastructure
  – More affordable

• Potential for near-term deployment but much work yet to be done

• Innovative SMR concepts have similar technology development challenges: licensability, competitiveness, financing schemes

• Economics: $/kWe to be built? $/kWe-hr to operate?

• Needs to implement lessons-learned from Fukushima events into the design, safety, economic, financial, licensing, and public acceptance for SMRs
CAREM (Central Argentina de Elementos Modulares)

- Developed by INVAP and Argentine CNEA
- Prototype: 25 MWe
- Expandable to 300 MWe
- LWR
- Integral reactor
- Passive safety
- Used for electric and non-electric applications
- Nuclear Safety Assessment under development
- Prototype planned for 2012 in Argentina’s Formosa province
B&W mPower

- LWR
- Integral reactor
- Scalable, modular
- 125 – 750 MWe
- 5% enriched fuel
- 4 year refueling cycle
- Passive safety
- Air-cooled condenser
- Lifetime capacity of spent fuel pool
NuScale

- Oregon State University (USA)
- 45 MWe
- LWR
- Integral reactor
- Modular, scalable
- Passive safety
- Online refueling (??)
- Working on Design Certification with US NRC.
SMART

- Korea Atomic Energy Research Institute
- 330 MWe
- Used for electric and non-electric applications
- LWR
- Integral reactor
- Passive Safety
Westinghouse SMR

- An integral PWR
- 225 MWe
- Innovative packaging of proven components
- Industry-proven equipment designs
- Compact reactor coolant system and containment
- One reactor per unit
ACP-100

- CNNC in China
- 100 MWe
- LWR Integral
- Up to 8 modules per unit
- Prototype planned for Putian City
KLT-40
KLT-40

• NOT LAND BASED: on a ship
• Reactor output: 300 MWt, 60 MWe net
  – Efficiency: 23.3 %
  – Target Availability: 85 %
  – Plant life: 40 yr
• 4 loop PWR with load follow capability
• Electric and non-electric applications
Power Reactor Innovative Small Module (PRISM)

- GE-Hitachi
- Liquid metal (Na)
- Metal fuel
- 311 MWe
- Part of a strategy to close the nuclear fuel cycle

Figure 2: PRISM Reactor power block used to produce electricity from spent nuclear fuel.
4S (Super Safe, Small and Simple)

- Toshiba & CRIEPI of Japan
- 50 MWe
- Sodium Cooled Fast Reactor
- 10 – 30 year refueling period
- Submitted for US NRC Pre Application Review
- Proposed for Galena, Alaska
TerraPower Travelling Wave Reactor

- A reactor that breeds its own fuel
- The fission reaction takes place in a small area of the reactor and moves to where the fissionable fuel is being created.
- Breed-and-burn
PBMR (Pebble Bed Modular Reactor)

- ESKOM, South Africa Government, Westinghouse
- Helium Gas Cooled
- 165 MWe
- Electrical and non-electrical applications
- Project mothballed in 2010