SMALL MODULAR NUCLEAR REACTORS

Smaller and Smarter?

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by

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Outline of Presentation

- What are Small Modular Reactors (SMRs)?
- Why are they being promoted?
- **What are the design features of Integral Pressurized Water Reactors?**
- What are the regulatory/technical concerns?
- What is the future for SMRs?
Small Modular Reactors (SMRs)

- Less than 300 MWe
  - 45-300 MWe designs proposed

- Modular design
  - Factory built

- Integrated Pressurized Water Reactors (iPWRs)
  - NuScale
  - B&W (mPOWER)
  - Westinghouse
  - Holtec (SMR-160)

- Gas- or liquid metal - cooled designs
U.S. Electricity Sources

- Coal: 50%
- Nuclear: 20%
- Natural Gas: 16%
- Hydroelectric: 7%
- Renewables: 2%
- Other: 2%
- Oil: 3%
WHY NUCLEAR?

- Energy Security is National Security
  - Uranium is a domestic source of energy

- Competitive Costs
U.S. Electricity Production Costs
1995-2011, In 2011 cents per kilowatt-hour

Production Costs = Operations and Maintenance Costs + Fuel Costs. Production costs do not include indirect costs and are based on FERC Form 1 filings submitted by regulated utilities. Production costs are modeled for utilities that are not regulated.

Source: Ventyx Velocity Suite
Updated: 5/12
WHY NUCLEAR?

- Energy Security is National Security
  - Uranium is a domestic source of energy

- Competitive Costs

- No Climate-Change Releases
Sources of Emission-Free Electricity 2011

- Solar, Wind & Geothermal: 11.0%
- Hydro: 25.7%
- Nuclear: 63.3%
WHY NUCLEAR?

- Energy Security is National Security
  - Uranium is a domestic source of energy

- Competitive Costs

- No Climate-Change Releases

- Proven Record
U.S. Nuclear Power Plants
Advantages of SMRs

- Small size = small capital cost
  - U.S. utilities have trouble financing large projects
  - Build up capacity one small unit at a time
  - [BUT need to also be competitive on cost/kW installed]

- Small size = shorter construction time

- Small size attractive in certain markets
  - Remote locations
  - Small grids
    - Developing countries
    - Coal plant replacement
Coal Plant Replacement

\[ \Sigma = 120 \text{ GW(e)} \]

SMR
Most of the Emerging Export Market Opportunity is for Small to Medium Reactors (SMRs)

(1) Total Capacity of Electrical Generation in 226 Countries (MWe)

- 0 - 50 MWe: 22% (22%)
- 50 - 100 MWe: 6% (5980 MWe)
- 100 - 250 MWe: 10% (10930 MWe)
- 250 - 500 MWe: 9% (5648 MWe)
- 500 - 720 MWe: 3% (284 MWe)
- 720 - 750 MWe: 3% (209 MWe)
- 750 - 1000 MWe: 3% (365 MWe)
- 1000 - 2000 MWe: 7% (2010 MWe)
- 2000 - 5000 MWe: 14% (5060 MWe)
- 5000 - 10000 MWe: 7% (7010 MWe)
- 10000 - 695120 MWe: 19% (132220 MWe)

Right sized reactors take advantage of emerging nuclear and energy system trends.

1 A. Minato, CRIEPI
Advantages of iPWRs

- Small size = innovative design = low $/kW?

- Factory built
  - Improved quality due to replication in factory
  - Transported via standard methods
“Complexity” Versus “Simplicity”
Advantages of iPWRs

- Small size = innovative design = low $/kW?

- Factory built
  - Improved quality due to replication in factory
  - Transported via standard methods

- Meets electric demand incrementally

- Enhanced safety
  - Passive safety
  - No large piping
Dilbert, you have been chosen to design the world's safest nuclear power plant.

This is the greatest assignment that any engineer could hope for. I'm flattered by the trust you have in me.

By "safe" I mean "not near my house."
Advantages of iPWRs

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- Based on existing PWR technology
PWR Concept

Reinforced concrete containment structure
Steel containment shell
Steam generator and heat exchanger
Steel pressure vessel
Control rods
Super-hot water under pressure
Fuel assemblies
Steam
Water
Condenser
Steam is cooled back to water
Note how everything is self-contained. Nothing leaves the system except heat energy

Pressurised Water Reactor (PWR)
Steam spins the turbine
Generator
KWE
Condenser cooling water
European Pressurized Water Reactor (EPR) ...
NPPs In Finland
Smaller and Smarter?
General Features of mPower

- ~125 MWe
- Internal steam generator
- Standard PWR fuel
- Large primary coolant inventory
- Small penetrations into primary coolant system at top of RPV
- Diverse, redundant internal CRDMs
- No boron in primary coolant
- 4-year fuel cycle
Lower Vessel

57 CRDMs using a common design
PWR Fuel Element
Balance of Plant

- Conventional steam cycle
- BOP operation not credited for design basis accidents
  - Reactor can be cooled without feedwater flow to the steam generator
  - All fuel can be cooled for a minimum of 72 hours without any BOP system
- Air or water condensers

Conventional Air-Cooled Condenser Steam Cycle

B&W mPower
125 MWe Module
General Features of NuScale iPWR

- 45 MWe per module

- Natural circulation cooling (no pumps, pipes, valves)
  - Eliminates some accident scenarios
  - Improves economics

- Two steam generators and pressurizer inside reactor pressure vessel
  - No primary piping breaks can cause loss-of-coolant accident

- Secondary cooling circuit utilizes simple off-the-shelf turbine-generator
Reactor Vessel and Containment

- Containment is in reactor pool

- Modules separated by a wall in the reactor pool (which also provides the containment support)

- Containment is maintained in a partial vacuum

Reference: NuScale Power Overview of NuScale Design Slides, April 2, 2009
Other Features

- Nuclear steam supply system is factory built
  - Prefabricated and shipped by rail, truck, or barge

- Large natural heat sink
  - Simplifies and enhances safety case

- Below grade reactor
  - Enhances security and safety

- Up to 12 modules at one site
Cross-sectional view of 6 modules
Normal Cooling

- Helical coil OTSG
- Two tube banks
  - 536 tubes / bank
  - ~1.6 cm OD
  - Avg length 30 m
- FW inlet header and steam outlet header
Simplified Steam System

- Superheated steam
- No feedwater heaters
- “Off-the-shelf”
- 100% steam bypass
NuScale Module

Reference: NuScale Power Overview of NuScale Design Slides, April 2, 2009
Multi-Module Control Room Layout

Reference: NuScale Power Pre-Application Meeting Slides, July 24, 2008
Policy/Technical Issues

- **Control Room Staffing Levels**
  - Multiple units in one room

- **Source Term**

- **Emergency Planning**

- **Seismic Issues**
Who’s Onboard?

- **Industry/Utilities**
  - mPower: TVA/Bechtel…
  - West: Ameren Missouri, Burns&McDonnell, GD Electric Boat…
  - NuScale: Fluor, Curtiss Wright

- **Nuclear Regulatory Commission**
  - New licensing requirements

- **Department of Energy**
  - $450M in support of SMR development
The Future?

- Promising technologies
- Lots of competition
- Regulatory hurdles
- Technical hurdles