The Future of Small and Medium Sized Nuclear Reactors

2009 and Beyond

Presentation Outline

- Distinguish from Large Commercial Reactors
- History
- Application
- Current Presence in the United States and Internationally
- Pros and Cons
- Case Studies
- Summary: The Future of Small and Medium Sized Reactors (SMRs)

SMR Reactors vs. Large Commercial Reactors

SMR vs. Large: Output

SMR Reactors:

- The IAEA defines “Small” Reactors those with an output under 300 MWe.
- Today a medium sized reactor would be one with an output between 500 to 700 MWe
- MWe = Mega Watts of electricity as apposed to a MWt, which is Mega Watts of thermal energy

- Large Reactors:
- According to the NRC large commercial plants today generate between 1000 and 1700 MWe

SMR vs. Large: Cost of Generation

- SMRs:
- It is a difficult to give an accurate average cost because of the range in sizes, designs, whether it is off-grid or on-grid, etc.
- However, each company that is designing new units claims that the cost will be competitive with large scale nuclear power.
- The Department of Energy (DOE) has estimated that a 50 MWe unit in the U.S. will cost between 5.4 to 10.7 cents/kwh depending on the above parameters

- Large Units:
- The World Nuclear Association estimates the cost of nuclear power from large reactors to be in the range of 3.5 to 5.5 cents/kwh

SMR vs. Large: Cost of Construction/Operation

SMRs:

- Private companies are estimating that new units built on site will cost between $23 to $30 million dollars.
- Add the extra costs and you approach $50 million per unit
- 2-3 years to construct

Large Reactors:

- To build a large reactor in the U.S. today several costs are involved:
  - Construction costs
  - Operating cost
  - Waste disposal cost
  - Decommissioning costs
- When combined, large reactors end up costing between $6 to $10 billion dollars
- 7-10 years to construct

SMR vs. Large Sizes

- Small reactors can be the size of a garage, a small shed, or a hot water heater.
- Some have both above ground and underground components
- For example a 10 MWe unit built by Toshiba will take up very little above ground space compared to a large reactor:
  - 22 x 16 x 11 m (72 x 52.5 x 36 ft)
- Large reactors themselves do not take up much more space then an average sized warehouse, but when you add cooling towers, multiple units, and possibly cooling reservoirs they can take up over one thousand acres
- The Clinton, Illinois Reactor, including a cooling reservoir, covers over 5,000 acres

Drastic Difference

- On the left you see the actual SMR core.
- On the Right is a photo of two average sized cooling towers for a large reactor.

The History of Small and Medium Sized Reactors

The U.S. Experience

- All SMR plants in the U.S. have been a result of Military or Academic research.
- The Military:
  - Operated a small reactor in Antarctica from 1962-72 (1.5 MWe)
  - A small Army program dedicated to small reactor development started in 1950s: One successful unit operated for 35 years up until 1997 (67 MWe)
  - The Navy has developed several small reactor designs for submarines are still being used on submarines.
    - Some current commercial designs are based off the Navy designs

The International Experience

- More than 50 SMRs designs have been developed by many national or international programs through the years
- Several countries with Nuclear technology capabilities have invested considerable more time and money on small reactor development than the U.S.
  - Russia: Several reactors currently operating in Siberia
  - India: A Canadian design operating at 220 MWe
  - Pakistan: Operating a Chinese 300 MWe design
  - China: Several in operation of varying outputs; heavy current investment
  - Japan: Several designs in operations and heavy investment in new designs and production
  - Europe: Same as with Japan and China (especially France)

SMR Data

Reactor data was retrieved from the IAEA's Power Reactor Information System in November 2009

- Example of a medium sized floating reactor

In Operation:	133
Under Construction:	12
Number of countries with SMRs:	28
Total Generating Capacity GWe:	60.3

Small and Medium Sized Reactors

Applications

U.S. Experience: Military and Academic Research

- In the U.S., nearly all the development and use of small/medium reactor has taken place through government research and use.
- Academic institutions have also contributed to the development of SMR technology.
- Why No Commercial Applications?
  - Three mile Island- No plants in the last thirty years...period
  - NRC licensing structure- No meant for SMRs
  - Abundance of other energy sources for investment in technology

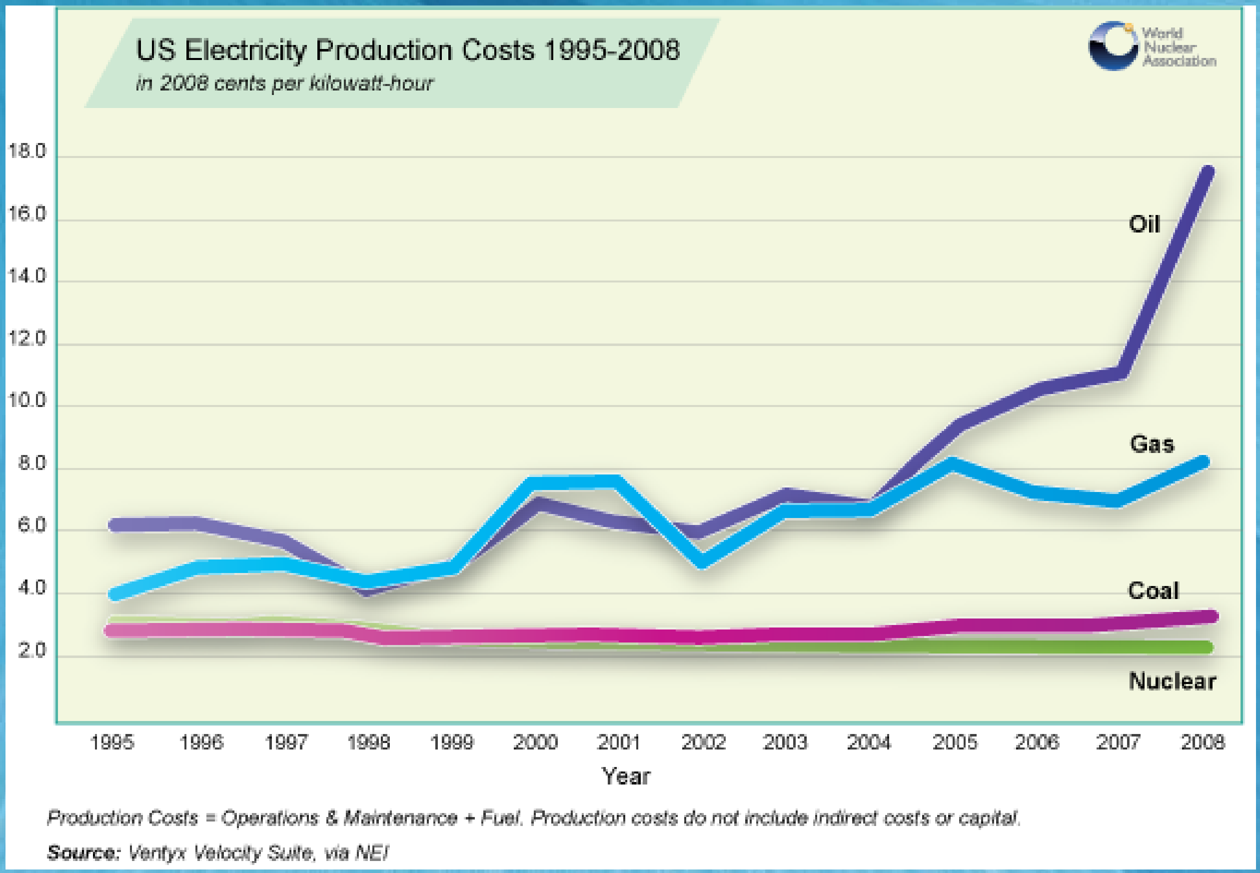
Current and Future Commercial Applications:

- Plants can be built independently by private companies for many applications and have been around the world:
  - Off-grid isolation at remote otherwise hard to reach sites
  - Many units combined together as part of a larger system
  - Used in desalination where heat and electricity for this purpose is scarce or expensive
  - Residential- may simply be more cost effective and stable rates
  - Industrial- Same as with residential
  - Thermal- the steam used to heat industrial facilities or residential (Siberia is very cold and isolated)

Small and Medium Sized Reactors

Pros and Cons

First, Nuclear Power in General Has Many Pros...



And Cons...

Why Small Reactors Can Work:

- 1. Good for the Environment
- 2. Good for the Grid and lack there of one
- 3. They are small and do not use much land
- 4. Can be quite economical
- 5. Safe & Secure

Good for the Environment

- With the ominous concerns and potential regulation of green house gas emissions SMRs have almost zero emissions.
- Would not be affected by Cap and Trade
  - Government may give incentives for companies to use SMRs to decrease emissions
- No heating of nearby waters

Good for the Grid:

- When used within a any grid, SMRs ease pressure from grid when it is overburdened. Users, in some places, can also sell electricity back to utilities
- Cost effective alternative for areas with little or no access to the main grid
  - Developing countries
  - Isolated populations
  - Also, often times large nuclear reactor's outputs far exceed what such a grid could handle.
- Distributed Generation- Could become cost effective for large industrial facilities or communities to generation their own on-site power

Easy on Land Use

- Most of the reactors in production today are designed to be placed underground, with only a small building if any above ground
- May be placed in isolated areas or right by the costumers- Flexibility
- No onsite construction because SMRs can be built at the factory and transported by truck or train:
  - little detrimental effect on land from construction as with large plants
  - As a result, few siting issues when being licensed

Economical:

- Built similar to a car on a production line in standard designs that are easily transportable
- Construction time is short compared to large facilities, resulting in less initial capital investment
- Competitive electricity rates in many areas
- Passive safety system reduce costs
- Far less maintenance
- Infrequent, simple refueling and little waste storage
- A facility that has combines many SMRs in an array that supplies a large amount of power would not need to go completely off line to refuel. Incremental shutdowns and refueling
- Because of size and core temperature easier to recycle heat or use heat in co-generation
- Remotely Monitored
- Long life times and time between refueling

Safe & Secure

- Passive systems- no mechanically or electrically triggered safety systems
- Very little waste to store
- Only needs to be refueled every 10 to 30 years
- Waste is not as radioactive as with large facilities
- Core underground - hard task for a terrorist to dig up
- Fuel is not enriched enough to enrich into weapons grade plutonium or uranium

SMRs Cons

- Initial Costs: Up to $30 Million for one unit
  - Hard for a developing community to afford
- Some waste to store... Where? For how long? At what cost?
- The Licensing Process in the U.S. is quite lengthy and Incompatible with SMRs:
  - The New Reactor licensing process at the NRC is designed for large reactors.
  - Fee structure at the NRC is set up for large scale reactor projects.
- Public perception of nuclear power- Not in my backyard mentality could bring extra litigation costs

A Case Study: Siberia

- A remote corner of Siberia has 4 units at a co-generation plant.
- 62 MWt each (MWt is in thermal units)
- These units produce steam that is used for heating and also produce 11 MWe of net electricity each
- Have performed well since 1976.
- Much cheaper than fossil fuel alternatives in the region

The Future of SMRs

Promise/Incentives

Hindrances

Current Projects

Predictions

Positive Outlook

- The IAEA predicts that there will be up to 1,000 small reactors around the world by 2040
- A global revival of interest in Nuclear energy in general with a strong focus on SMRs
  - A desire to reduce capital costs
  - Technological advancements making SMRS more affordable
  - Strong interest in easing pressure on grid and providing off-grid power sources
- Global energy demand will increase by 50% over the next 35 years
- Carbon emission will increase by the same percentage over the same time

Outlook in the U.S. - The Elephant in the room

A Two-fold Problem:

- NRC licensing
- Fee structure

Solutions:

- NRC Action
- Congressional help…

N.R.C. Licensing

- The Nuclear Regulatory Commission is the Federal Agency in charge of licensing all commercial nuclear reactors in the United States.
- NRC regulations are specifically designed to license large reactors and the lengthy process coincides with the amount of time it usually takes to construction a large plant.
- The Siting process alone takes drastically longer than a factory built SMR would ever need. The commitment of time and money to obtain a construction and operating license is far out of proportion to the simplicity of a typical SMR.
- In October of 2009, the NRC held one of several workshops to discuss the licensing issue.
- On this first problem, the Chairman essentially punted by saying that the decision to change the process for SMRs was a political decision of negotiations and compromises, and the safety function of the NRC does not go to that type of process
- Alternative Solution- DOE help as they are doing with the first wave of new large reactor licensing-Cost Sharing and DOE helping with fees

The NRC Fee Structure

- Current NRC regulation governing annual fees requires each nuclear reactor operator to pay the same annual fee, regardless of the size of the reactor
- In March of 2009 the NRC published an Advance Notice of Proposed Rulemaking regarding fees
- The proposed rule offers a generic solution to establish a variable annual fee structure based on the licensed power limits
- The public has comment on the proposal and is currently awaiting the NRC to take the next step
- The future of SMRs in the United States is deeply dependant on the NRC's ability and will to be flexible because when it is not litigation and licensing costs start to skyrocket...ask any applicant from the 70s and 80s

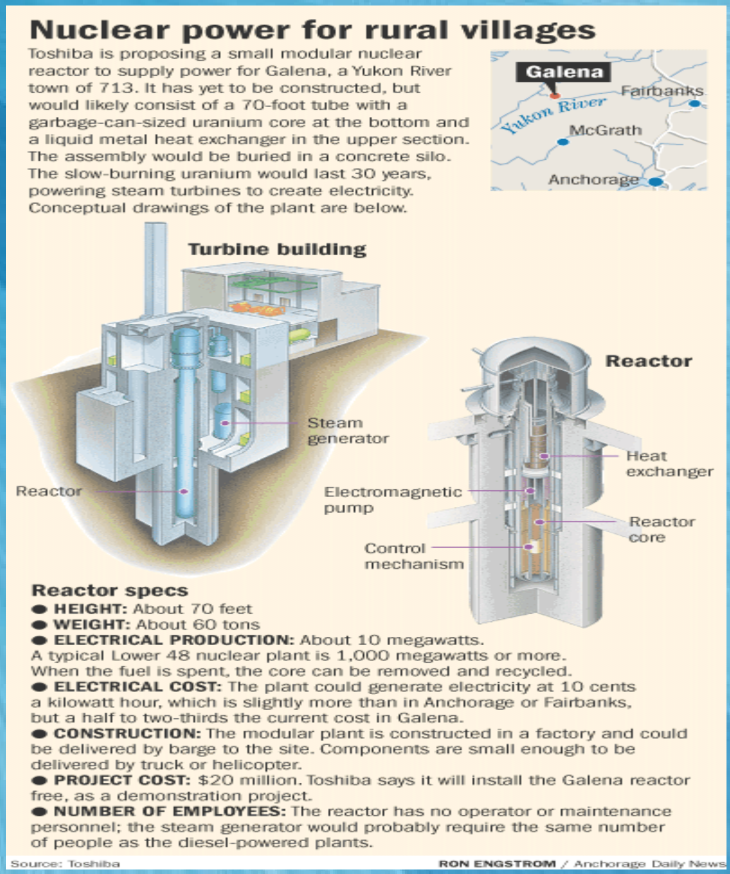
Congress Getting Involved

- Congress has already appropriated funding for research on both small modular plants(those that are assembled on site from factory made modules or parts) and other preassembled advanced designs
- Recently, a Democratic Senator has proposed a bill that could slowly make its way through Congress:
  - The Nuclear Energy Research Initiative Improvement Act of 2009 would give the federal government authority to research whether small-scale, modular reactors are a feasible contributor to the nation's energy supply.
- Finally, based on the words from the NRC chairman, Congress may have to get involved with reactor licensing by either forcing the NRC to amend its regulations or pass new regulation that would give SMRs an alternative path of obtaining a license.

Current Projects Underway

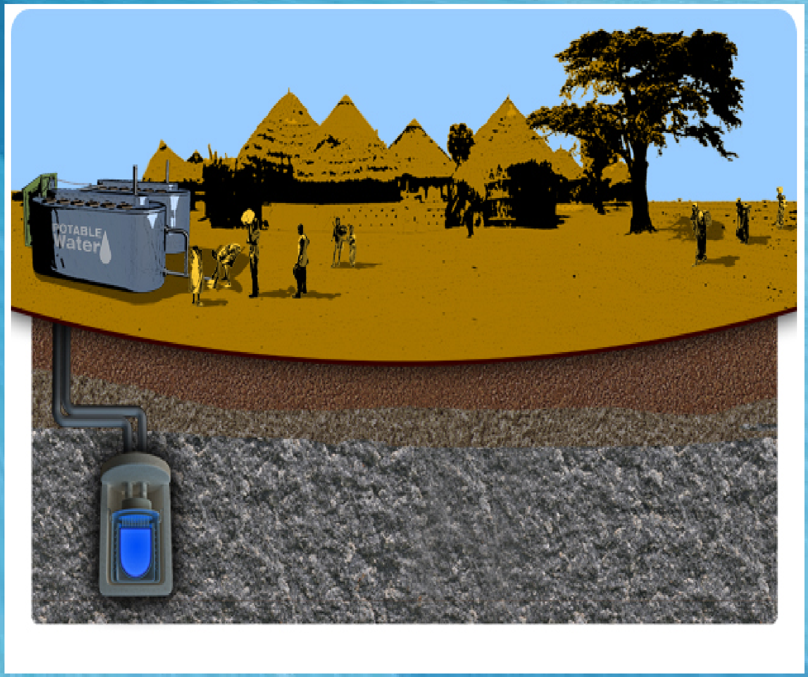
Toshiba 4S

- Toshiba is investing heavily in micro-reactors.
- In 2008, invested $300 million in a new company called Nuclear Innovation North America LLC
- If all goes well the plant could be operating by 2012, but licensing problems have already started
- Toshiba has not yet submitted a Design Certification to the NRC.
- Toshiba plans to submit the design by early 2010



Hyperion Power Module

- The government laboratory at Los Alamos that developed the first atomic bomb has licensed its SMR technology to a company called Hyperion
- Above ground profolio the size of a garden shed
- Powers 20,000 homes in the U.S.; 60,000 homes in developing countries
- 1.5 meters across by 2.5 meters high. Can be shipped by train or truck
- Electricity for 10 cents a kilowatt hour anywhere in the world
- Must be refilled every 7 to 10 years.



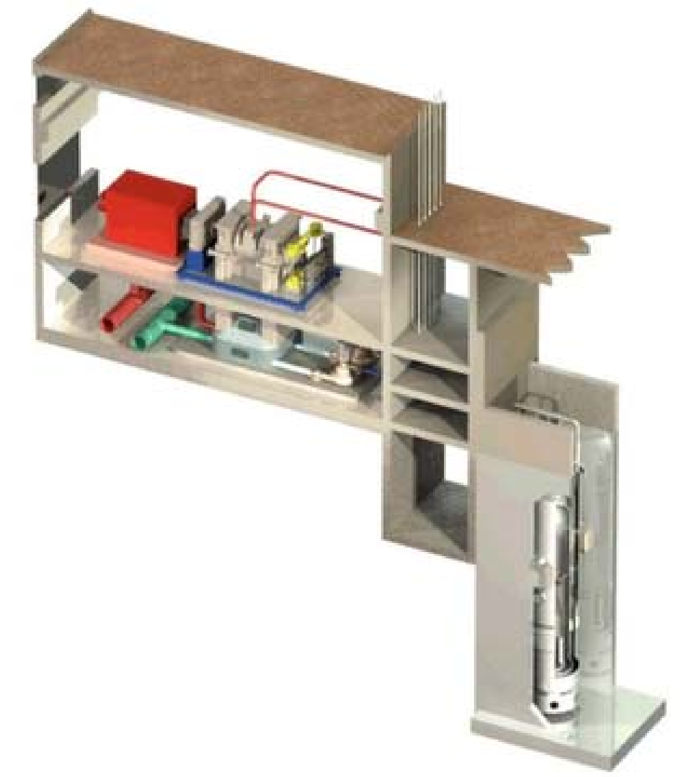
Hyperion's Pitch...

i. ŅUnlike giant nuclear reactors requiring ten years to construct under daunting conditions, these concrete Ņnuclear batteriesŅhave no moving parts, no potential to go supercritical or meltdown, and reportedly cannot be easily tampered with. The extremely small amount of hot nuclear fuelŃ too hot to handle--would immediately cool if exposed to air.Ó-technical sources

- The company plans to submit a design application next year
- Starting production within 5 years and already has 100 orders
- Three Hyperion factories are being built to produce some 4,000 micro reactors, each one selling for approximately $25 million

NuScale Power

- The Company is a spin off from an Oregon State Research Project.
- First American company to submit plans to the NRC
- More of a Medium sized reactor- 65 feet long (reactor unit 14 ft; Large Westinghouse AP1000 120 feet in diameter). 45 MWe -powering 45,000 homes
- Built and serviced on-site
- Unit parts manufactured at the factory then shipped by train or truck, but not many parts compared with large reactors
- First facility to begin operation in 2018



Single-unit side view of the NuScale system design

Advanced Technologies a Reality.

Many advanced designs are only 5 -10 years from production:

- Advanced Light Water Reactors- (Cooled by water)
  - Pebble Bed Modular Reactors
  - A Russian boiling water reactor -Co-generation: heating for desalination & electricity
  - Babcock & Wilcox mPower reactor
- High Temperature Gas Cooled Reactors (HTR- cooled by gas)
  - China's HTR-10 is a pebble bed gas cooled experimental reactor
  - One being developed in Africa by a consortium based on German expertise
- Hydrogen Moderated Reactor (potassium, liquid metal cooled
  - The Hyperion Power Module as discussed
  - GE and Hitachi design -the PRISM- liquid metal-cooled
- Molten Salt Reactor

Summary

Modern Small Reactors are simplified efficient designs, can be mass produced economically, and will dramatically reduce siting costs. The high level of passive safety technology combined with the lack of an environmental impact makes SMRs a wise choice for certain future energy needs.

U.S. Still Behind, but Catching Up

In the U.S.:

- Many companies working to manufacture and sell SMRs in the U.S.
- Main hold up is the N.R.C.
- The NRC has recently announced there are at least 7 design/concepts that fit into the SMR category and may soon apply for a license

Internationally:

- Many companies in several countries far along in the design and even production process
- Licensing is not an issue in most cases

Where you are likely to find SMRs in the next 15 to 25 years:

From the International Atomic Energy Agency:

- Countries with small and medium sized electricity grids or limited energy demand growth;
- Villages, towns and energy intensive industrial sites that are remote from existing grids;
- Rapidly growing cities in developing countries with limited investment capability; and
- Future merchant plants in liberalized electricity markets, in both developed and developing countries, that might value the reduced investment risk associated with incremental small capacity additions.