Center for Climate and Energy Decision Making

5th Annual Meeting

"Reducing GHG Emissions Through Low Carbon Electricity Generation"

Floating Small Modular Reactors

21 May 2015

Michael J. Ford

Floating Small Modular Reactors - Context

- Prior work by Morgan, Azevedo, Abdulla and Prasad has examined potential and implications of SMR development

Progress in Nuclear Energy 80 (2015) 102–109

Contents lists available at ScienceDirect

Progress in Nuclear Energy

journal homepage: www.elsevier.com/locate/pnucene

Review

Nonproliferation improvements and challenges presented by small modular reactors

Shikha Prasad [a,*], Ahmed Abdulla [b], M. Granger Morgan [b], Inês Lima Azevedo [b]

Expert assessments of the cost of light water small modular reactors

Ahmed Abdulla[1], Inês Lima Azevedo, and M. Granger Morgan

Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA 15213

Edited by William C. Clark, Harvard University, Cambridge, MA, and approved April 26, 2013 (received for review January 9, 2013)

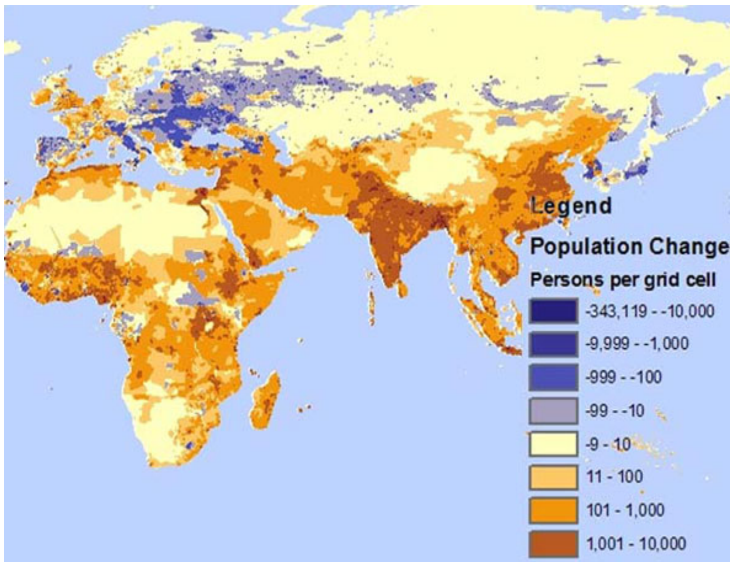
AHMED ABDULLA
M. GRANGER MORGAN

Nuclear Power for the Developing World

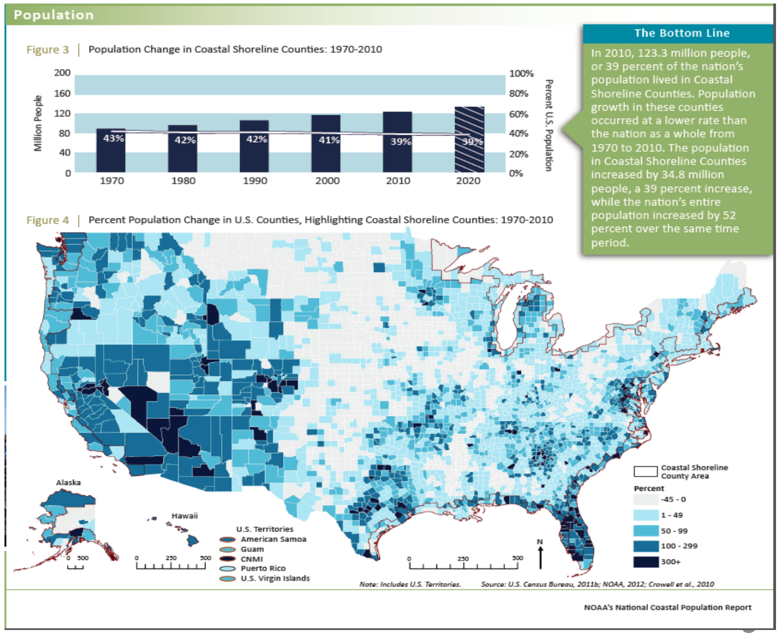
Small modular reactors may be attractive in many developing nations. Here is a blueprint for how to build them efficiently and ensure maximum safety.

SMRs – A GHG Reduction Option?

- Population trends indicate continued coastal migration (McGranahan, et.al; NOAA; US Census…)
- Increased energy demand expected worldwide (IEA, EPA, EIA…)
- Climate change risks increasing for coastal communities (IPCC AR5; McGranahan, et.al)
- Existing coastal energy infrastructure increasingly at risk from flooding and extreme events (Heberger; Brown, et.al)
- Policy postulate: New generating capacity for coastal communities should be clean, safe, reliable, have low probability of proliferation AND should be adaptable to address increased energy demand, climate risk and GHG reduction goals
- Can Floating SMRs play a role?



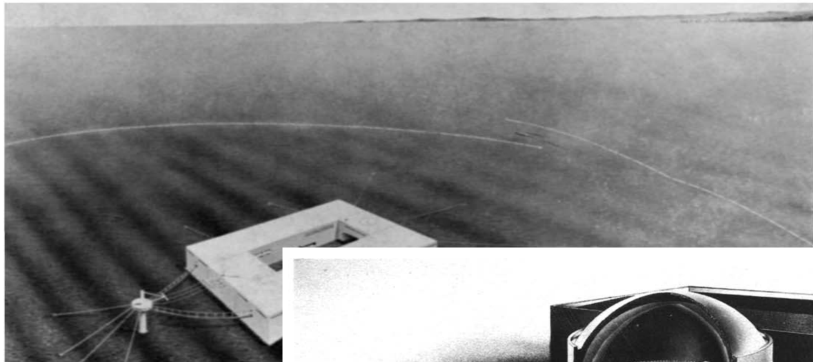
http://coastalcare.org/sections/inform/poor-coastal-development/



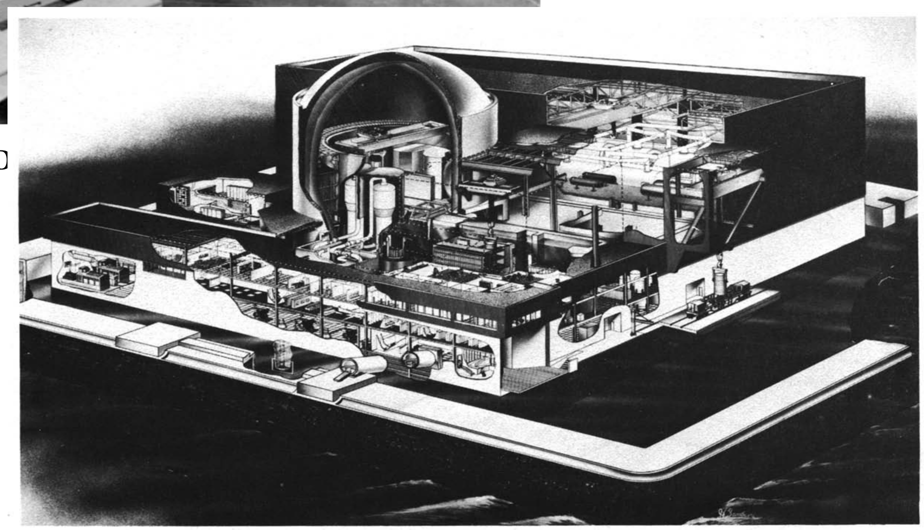
http://stateofthecoast.noaa.gov/features/coastal-population-report.pdf

Floating SMRs – Not a new idea

http://wikimapia.org

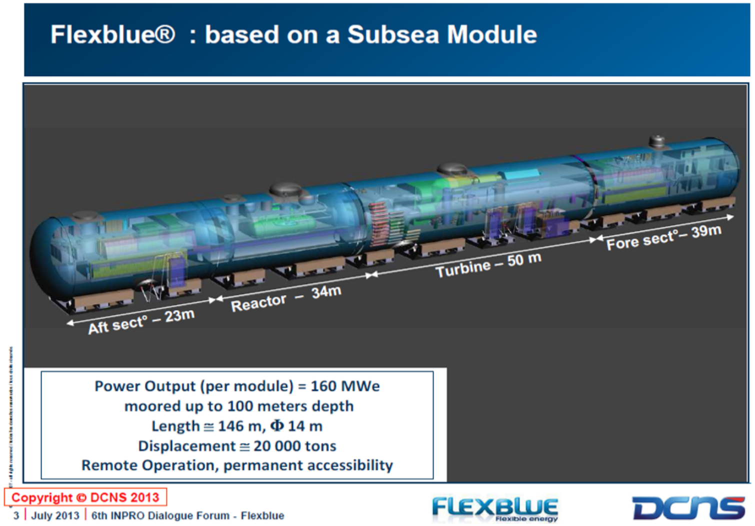


Hammond, R.P., Okrent, D
power plants.

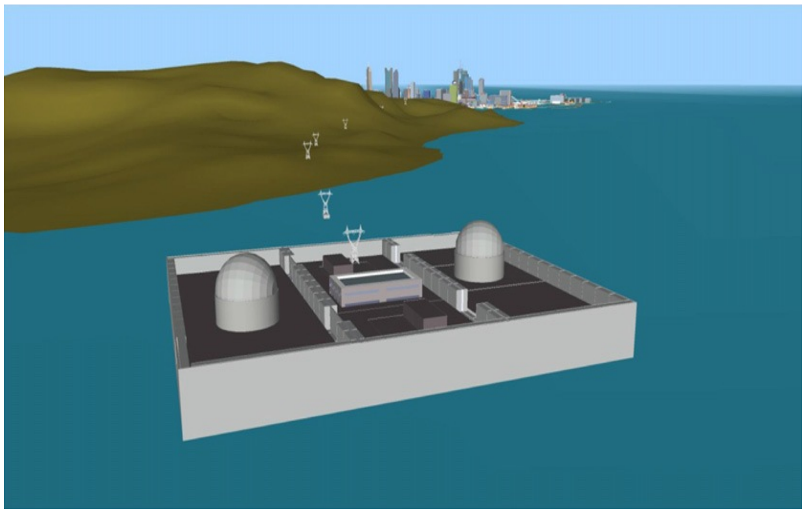


OFFSHORE NUCLEAR POWER PLANTS; Richard S. ORR and Clinton DOTSON

Floating SMRs – Current Concepts



http://newsoffice.mit.edu/2014/mit-offshore-floating-nuclear-plant-group-crowdsource-ideas-new-reactor-design



Lee, K.H., Lee, K.H., Lee, P.S., Jeong,Y.H., Kim, J.K., 2011. A new concept of ocean nuclear power plant (ONPP). Nuclear Engineering and Design 254 (2013) 129– 141

Photo source: http://www.industrytap.com

Floating SMRs – Examining Siting Issues

Initial Research Focus

IAEA Siting Criteria	IAEA Siting Criteria
Nuclear Power Plant Parameter Envelope	Nuclear Power Plant Parameter Envelope
Health, Safety and Security Factors	Health, Safety and Security Factors
Magnitude and Frequency of natural external events	Magnitude and Frequency of natural external events
Human Induced events	Human Induced events
Radiological Impact	Radiological Impact
Security and Safeguard	Security and Safeguard
Essential Supplies	Essential Supplies
Engineering and cost factors	**Engineering and cost factors**
Suitability of water for cooling	Suitability of water for cooling
Suitability of existing electricity Infrastructure	Suitability of existing electricity Infrastructure
Location of major load centers and selling price	Location of major load centers and selling price
Suitability of transport infrastructure	Suitability of transport infrastructure
Technology considerations	Technology considerations
Impact of existing facilities	Impact of existing facilities
Site development and construction costs	Site development and construction costs
Multi-unit sites	Multi-unit sites
Physical Security and Protection considerations	Physical Security and Protection considerations
Stakeholder opinion	Stakeholder opinion
Regional regulatory and legal processes	Regional regulatory and legal processes
Socio-economic factors	Socio-economic factors
Future land use planning and sites ownership	Future land use planning and sites ownership
Regional economy	Regional economy
Local Society	Local Society
Landscape	Landscape
Noise	Noise
Environmental Considerations	Environmental Considerations
General eco-system characteristics	General eco-system characteristics
Aquatic ecology and marine impact	Aquatic ecology and marine impact
Terrestrial ecology	Terrestrial ecology
Freshwater Impact	Freshwater Impact
Air Quality	Air Quality

Floating SMRs – study questions

- What are the key economic factors for land based vs. floating SMR deployment?
  - Overnight cost and Cost-Overrun Potential
  - Material cost
  - Electrical transmission mode (submarine, underground, above ground)
  - Unique floating development, operations and maintenance costs (dry-docking, refueling, decommissioning)
- Is there a water withdrawal “opportunity benefit” for floating SMR deployment?
- How does a floating deployment method impact the Emergency Planning Zone?

Floating SMRs – initial approach

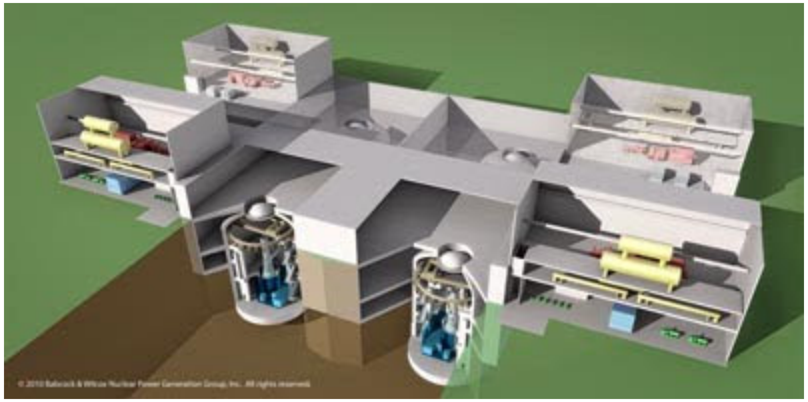
- Engineering Economic Model (@Risk, “R”, Top Rank)
- Initial Factors included in model:
  - Overnight Cost (Abdullah, Azevedo, Morgan Elicitation)
  - Cost Over-run Probability Factors (Shipbuilding, Nuclear Shipbuilding, Newbuild Nuclear)
  - Material Cost (steel/concrete)
  - Transmission Cost
  - Operations Cost (Manpower)
  - Dry-docking cost
  - Refueling Cost
  - Decommissioning Cost
  - Excursions
    - Inland freshwater “opportunity costs” (land based factor)
    - Depth of deployment (pierside to deep-water)
- TBD – Add’l Benefit, EPZ, Radiological Risk

Floating SMRs – initial approach

- Engineering Economic Model (@Risk, “R”, Top Rank)
- Initial Factors included in model:
  - Overnight Cost (Abdullah, Azevedo, Morgan Elicitation)
  - Cost Over-run Probability Factors (Shipbuilding, Nuclear Shipbuilding, Newbuild Nuclear)
  - Material Cost (steel/concrete)
  - Transmission Cost
  - Operations Cost (Manpower)
  - Dry-docking cost
  - Refueling Cost
  - Decommissioning Cost
  - Excursions
    - Inland freshwater “opportunity costs” (land based factor)
    - Depth of deployment (pierside to deep-water)
- TBD – Add’l Benefit, EPZ, Radiological Risk

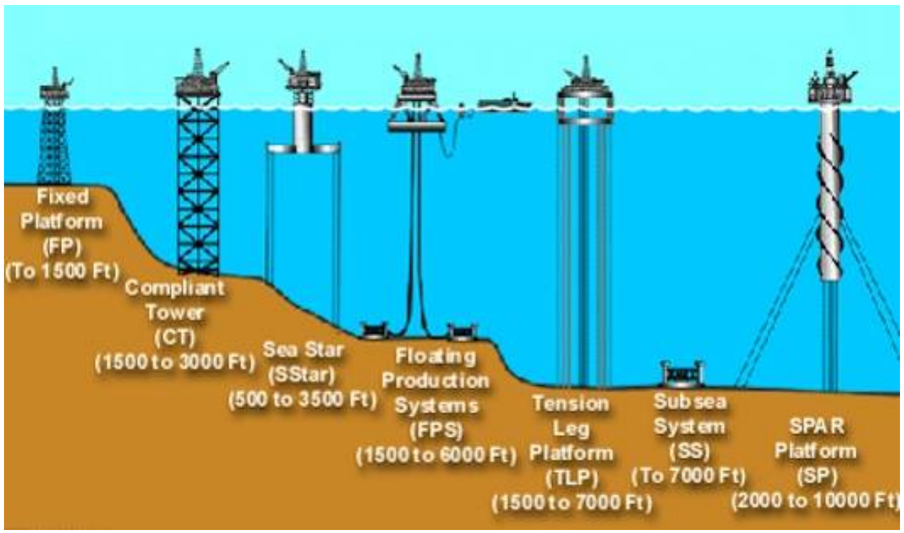
SMR Approaches Modeled

- **Land Based:**



B&W SMR – Photo accessed: http://alfin2300.blogspot.com/2010_07_01_archive.html

- **Floating:**

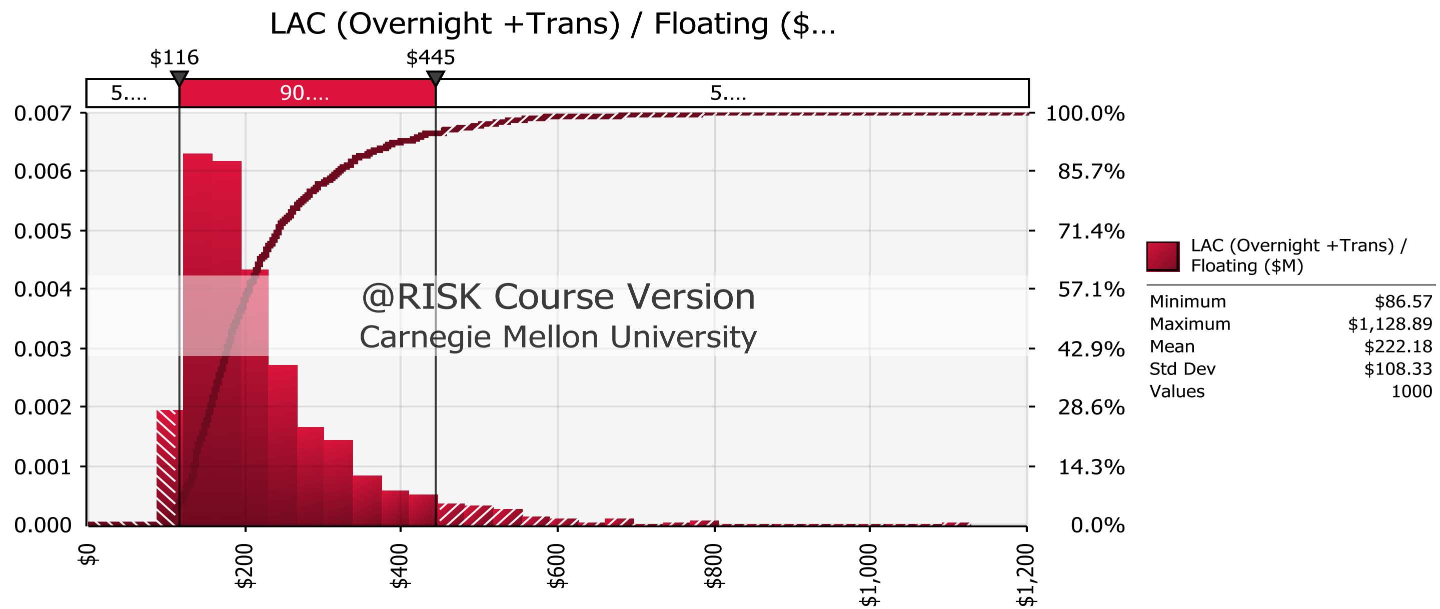


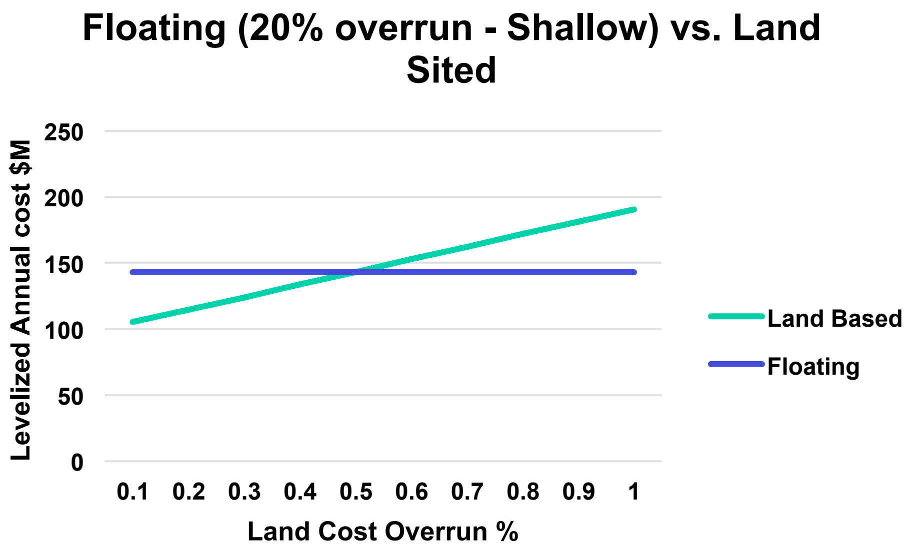
+

http://www.mnn.com/earth-matters/energy/stories/types-of-offshore-oil-rigs

http://www.bollingershipyards.com/news-resources/Bollinger-Re-delivers-Articulated-Tug-Barge-Unit-to-Bouchard

Floating SMRs – (Very)Preliminary findings





- Historical Mean U.S. Land Site Cost Overrun (GW Scale 1970s): ~200% (EIA)
- Current GW Scale: ~20-60% (2012 World Bank)
- Cost Overrun Range U.S. Nuclear Shipbuilding (NOAK) : 15-30% (GAO; Northrop Grumman)

Floating SMRs – Research Support

- Special thanks to Granger Morgan, Ahmed Abdulla and Inês Azevedo
- Partial funding support provided by the MacArthur Foundation