Small Modular Reactors & waste management issues

8th May 2014, Bucharest

International Framework For Nuclear Energy Cooperation – Infrastructure development working group meeting

Dan Mathers

Business Leader Fuel Cycle Solutions

Outline

NATIONAL NUCLEAR LABORATORY

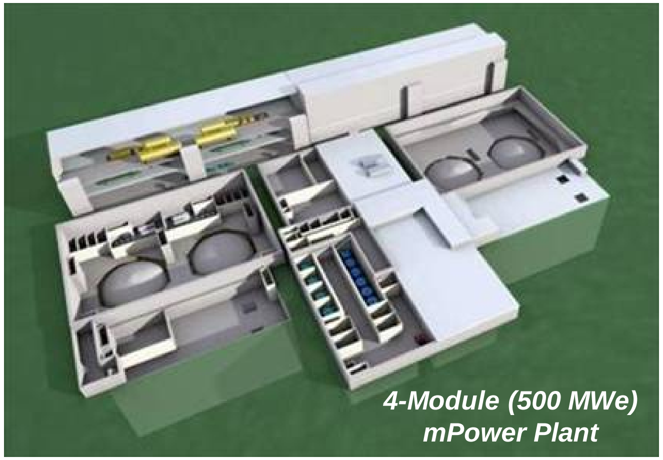
- There is increasing international interest in small modular reactors (SMRs)
- Brief survey of SMR systems
  - Timescales, pros & cons
- Whole systems view focusing on economic competitiveness and whole plant engineering

SMR Definition

- Various definitions apply
  - IAEA stipulate output < 300 MW electrical (MWe) unit size
  - But IAEA also consider < 500 MWe as small
  - Designs range from 10 MWe to 600 MWe
- Modular implies multiple units grouped together sharing common facilities and staff
  - Potential applications as single units
  - Or as multiple units making up a large power station
  - Implied assumption that there will be significant savings from multiple units

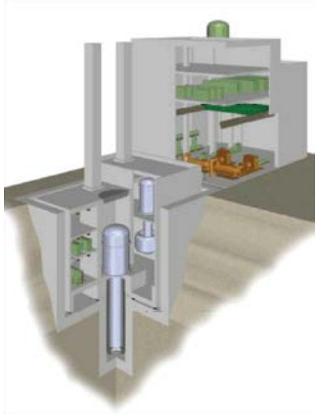
SMR Niches

- Multiple unit modular power plants

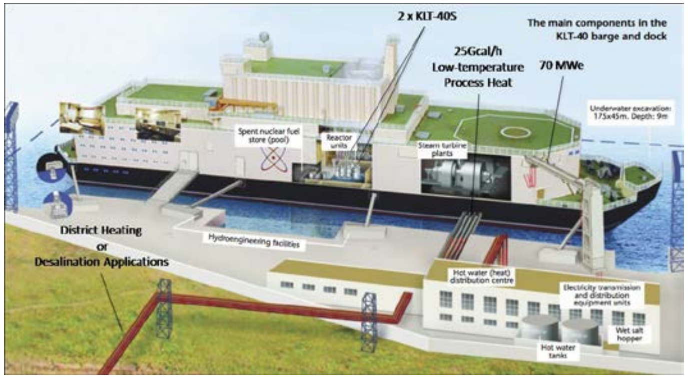


- Small plants suited to developing countries
  - Energy decarbonisation is a global issue and every available option will be required
- Desalination

- Small autonomous power sources for remote locations



- Barge mounted units



SMR Survey

NATIONAL NUCLEAR LABORATORY

- Many SMR designs are under development world-wide
  - Dominated by Light Water Reactors (LWRs)
  - LWR designs heavily based on existing design experience and therefore closest to potential deployment
- Furthest developed designs are probably at least 10 years from commercial deployment
  - US Department of Energy helping to finance design of two prototypes
  - Less developed designs at least 15 to 20 years from deployment
- Difficult to compare the pros and cons of the different designs because they are at different stages of development
  - Utilities will decide which are deployed and they will be focusing on economics and financing considerations
  - Only a few of the many proposed designs will ever make it to commercial deployment

Name	Capacity	Type	Developer
CNP-300	300 MWe	PWR	CNNC, operational in Pakistan
PHWR-220	220 MWe	PHWR	NPCIL, India
KLT-40S	35 MWe	PWR	OKBM, Russia
CAREM	27 MWe	PWR	CNEA & INVAP, Argentina
HTR-PM	2x105 MWe	HTR	INET & Huaneng, China
VBER-300	300 MWe	PWR	OKBM, Russia
IRIS	100-335 MWe	PWR	Westinghouse-led, international
Westinghouse SMR	225 MWe	PWR	Westinghouse, USA
mPower	180 MWe	PWR	Babcock & Wilcox + Bechtel, USA
SMR-160	160 MWe	PWR	Holtec, USA
ACP100	100 MWe	PWR	CNNC & Guodian, China
SMART	100 MWe	PWR	KAERI, South Korea
NuScale	45 MWe	PWR	NuScale Power + Fluor, USA
PBMR	165 MWe	HTR	PBMR, South Africa; NPMC, USA
Prism	311 MWe	FNR	GE-Hitachi, USA
BREST	300 MWe	FNR	RDIPE, Russia
SVBR-100	100 MWe	FNR	AKME-engineering, Russia
EM2	240 MWe	HTR, FNR	General Atomics (USA)
VK-300	300 MWe	BWR	RDIPE, Russia
AHWR-300 LEU	300 MWe	PHWR	BARC, India
CAP150	150 MWe	PWR	SNERDI, China
SC-HTGR (Antares)	250 MWe	HTR	Areva
Gen4 module	25 MWe	FNR	Gen4 (Hyperion), USA
IMR	350 MWe	PWR	Mitsubishi, Japan
Fuji MSR	100-200 MWe	MSR	ITHMSI, Japan-Russia-USA

Source: World Nuclear Association

NUSCALE & HOLTEC (USA)

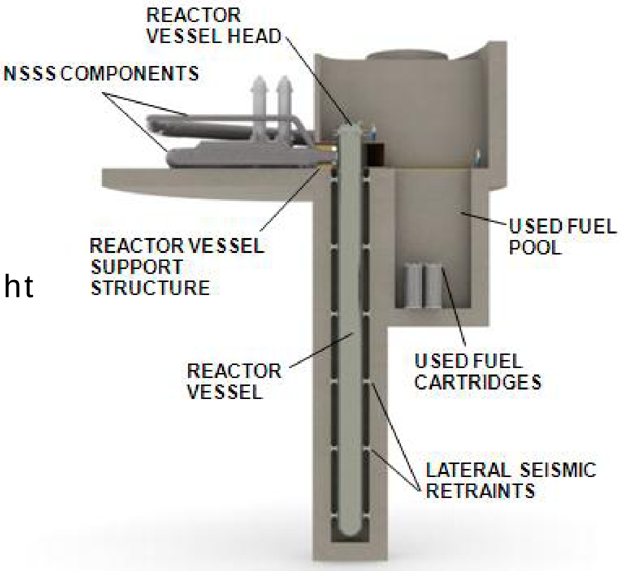
NATIONAL NUCLEAR LABORATORY

NUSCALE

- 45 MWe
- Integral PWR
- Reactor vessel submerged in water pool
- Natural circulation
- 17x17 fuel assembly
- 1.8 m core active height

HOLTEC

- 145 MWe
- Integral PWR
- Natural circulation
- 17x17 fuel assembly
- 3.6 m active core height



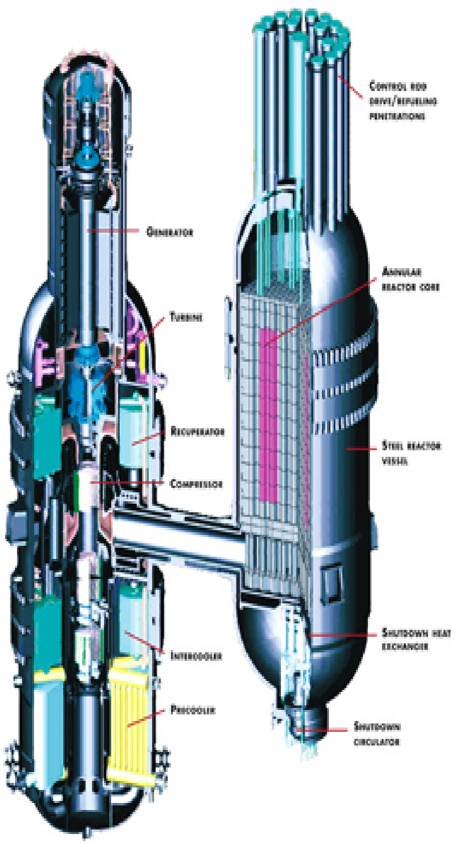
B&W mPower & WESTINGHOUSE SMR (USA)

NATIONAL NUCLEAR LABORATORY

- mPower
  - 180 MWe
  - Integral PWR
  - Forced circulation
  - 69 17x17 fuel assemblies

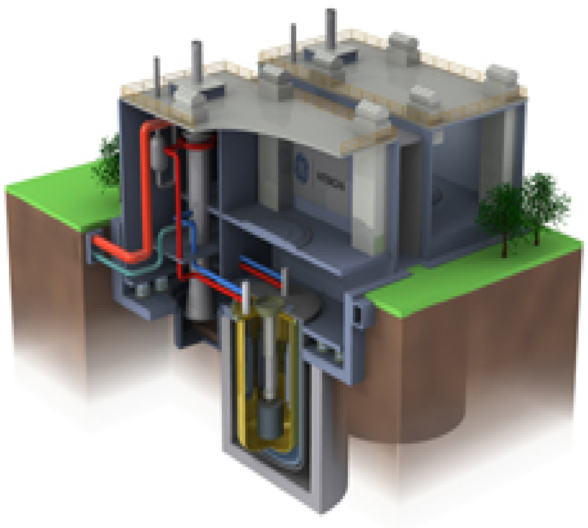
- Westinghouse SMR
  - 225 MWe
  - Integral PWR
  - Forced circulation
  - 89 17x17 fuel assemblies
  - 2.44 m active core height

General Atomics GT-MHR & GE-Hitachi PRISM (USA)



GT-MHR

- 285 MWe
- High Temperature Reactor (HTR)
- Ceramic TRISO fuel
- Helium coolant
- Graphite moderator
- Fuel compact in prismatic fuel blocks



PRISM

- 622 MWe
- Sodium cooled fast spectrum reactor
- Metal fuel
- Passive safety

SMR Economic Levers

NATIONAL NUCLEAR LABORATORY

- Lower construction costs from a combination of:
  - Simplified design
  - Increased modularity/factory build
  - Multiple design replications – mass production
  - Application of advanced manufacturing techniques
  - Shorter construction time
- Lower finance costs from:
  - Shorter construction time
  - Self-financing model where the first module starts to generate the revenue to finance the construction of subsequent modules and limit the borrowing requirement
- Lower operating and maintenance costs from a combination of:
  - Simplified design with reduced maintenance needs
  - Deployment of multiple modules run by a 400 to 500 strong workforce comparable to large plants
- Increased supply chain opportunities with host countries potentially able to manufacture a higher proportion of systems

SMR Economic Challenges

- All the drivers in favour of SMR economics are currently theoretical and need to be demonstrated to work in practice – this is the biggest challenge they face
  - No current SMR has a complete engineering design which is needed before a full engineering cost estimate can be made
    - Economic figures for SMR designs are often just projections with little supporting basis
    - In many cases the projected economics might look attractive at the conceptual stage, but may no longer do so when engineering reality sets in

SMR System Features

NATIONAL NUCLEAR LABORATORY

- Simplified or passive safety
  - Integral systems layout
  - Large coolant masses for high thermal inertia
  - High vertical heights to enhance natural convection
  - Passive designs
  - Need to address multiple units in close proximity after Fukushima
  - Some designs use natural circulation in normal operation
- Underground siting of cores
- Long refuelling cycles
  - Autonomous power sources have very long life cartridge cores (15 to 30 years)

SMR Systems Challenges

NATIONAL NUCLEAR LABORATORY

- Integral designs will need extensive validation
  - Integrating plant components may increase importance of interactions between components
  - Even for most fully developed designs
- Small size does not necessarily improve safety
- Natural circulation systems with require extensive R&D to validate system behaviour
- Underground siting may improve protection in some scenarios, but not necessarily all scenarios
- Regulatory requirements
  - SMR designs will need to go through the full licensing process

Waste Management

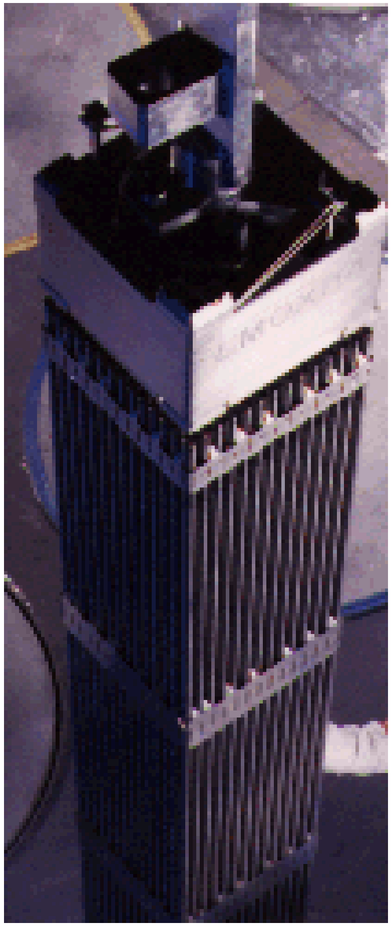
NATIONAL NUCLEAR LABORATORY

Context

- Wholesale power is 60% consumer price of electricity
- Cost of wholesale nuclear:
  - Pre-development 7%
  - Capital 70%
  - Operation & Maintenance 15%
  - **Fuel 6%**
  - **Decommissioning 2%**

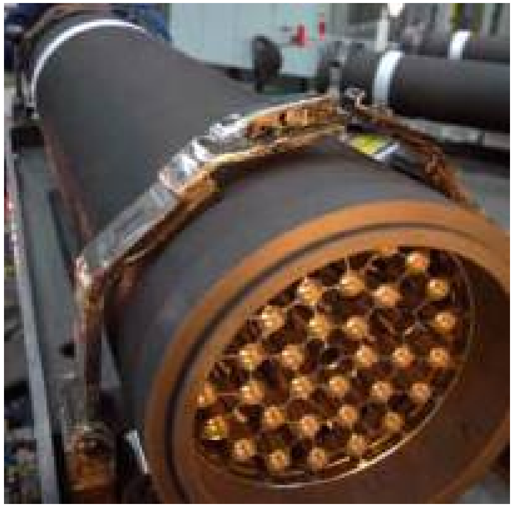
SMR waste management

- Small PWR's
  - If no change in fuel then:
    - Fuel waste per GWe similar to PWR's but: fuel may not achieve high burnups (inability to shuffle in small cores), fuel throughput could be higher therefore greater volume of spent fuel
    - Slightly larger % of structural waste (pressure vessel is larger fraction of total surface to volume ratio)
    - Assume fuel is pond stored for ~20yrs, followed by dry store or repro
    - Key issues remain for plant decommissioning Co-60 from vessel/pipes/internals, C-14, Ni and Fe isotopes.



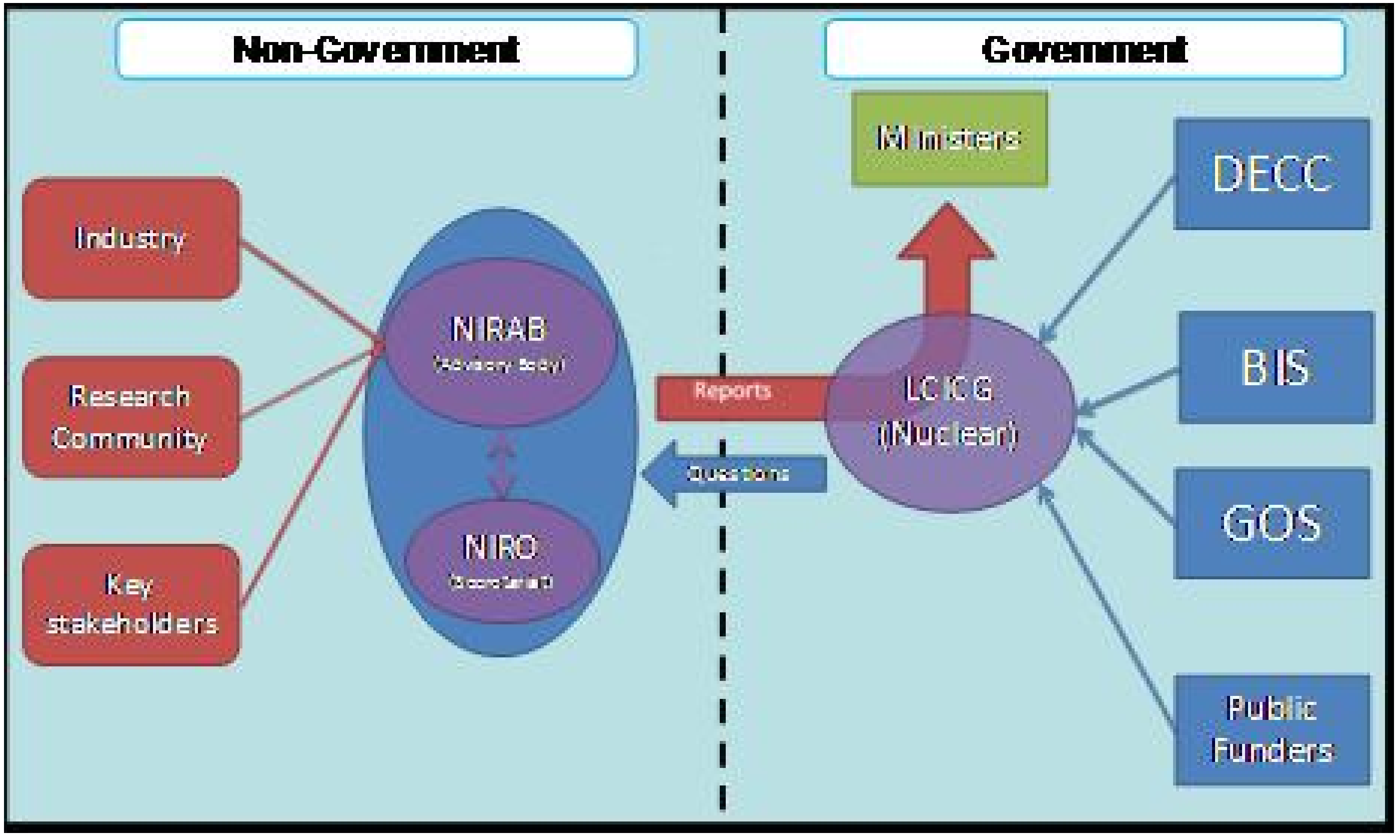
SMR waste management

- Small HTR's
  - Triso fuels possible – retain fission products, impractical to reprocess: assume high proliferation resistance (aqueous and pyro-processing both not practical)
  - Assume fuel is stored 100-150 years (may require H_e gas coolant)
  - Key issues remain for plant decommissioning from activated cylindrical steel core and graphite brick reflector C-14, Cl-36 isotopes. (H_e cooled so no graphite weight loss as in AGR)



UK feasibility study

- “Understand and evaluate the economic and technical claims made by SMR designers and to identify the most appropriate way to utilise UK skills and expertise to maximum effect in the developing SMR market and the means to commercially connect these”



SMR Conclusions

- SMRs represent an alternative to large scale nuclear
  - Potentially a good fit in the international context for developing or small countries
  - Expands options for nuclear contribution to energy decarbonisation
- Theoretical advantages abound
  - But economic and business case will be the over-riding factor
  - Need to be careful not to exaggerate the potential benefits
- Though there are many SMR designs being promoted, many are not developed to the point where there exists an engineered design
  - By definition, any new design starts off with all the advantages
  - The question is whether these advantages will remain once engineering reality intervenes

NATIONAL NUCLEAR LABORATORY

NATIONAL NUCLEAR
LABORATORY