Small Modular Reactors

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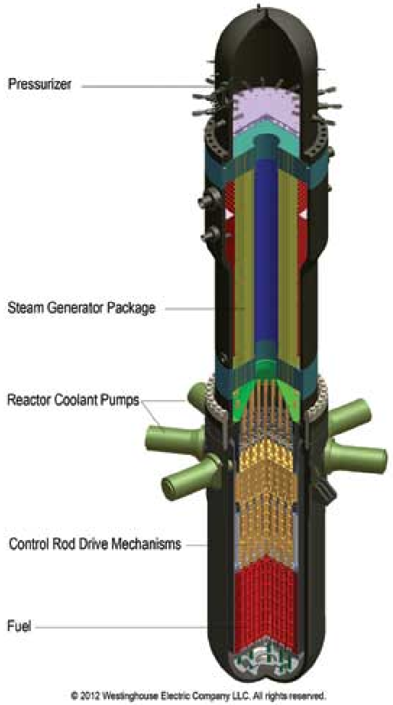
Outline

- There is increasing international interest in small modular reactors (SMRs)
- This presentation will consider why the interest in SMRs and their potential role in the UK



SMR definition

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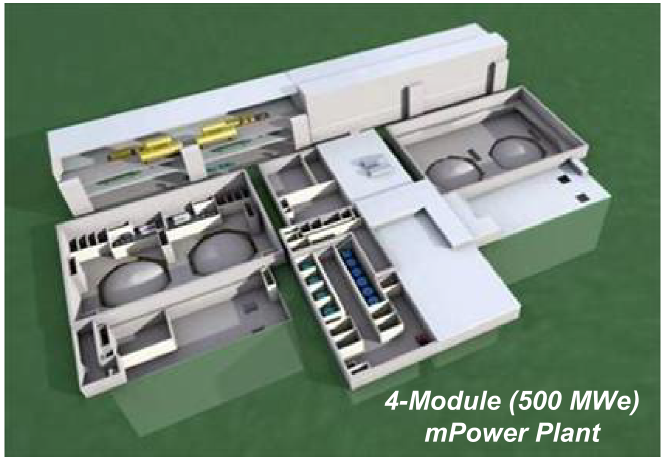
- Various definitions apply
  - IAEA stipulate output < 300 MW electrical (MWe) unit size
  - But IAEA also consider < 500 MWe as small
  - Designs range from 10 MWe to 600 MWe
    - Lower end range a bit higher than large wind turbines
    - Upper end comparable with existing UK reactors (MAGNOX & AGR)
- 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

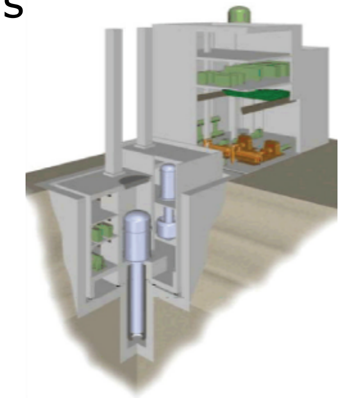
SMR niches

- Multiple unit modular power plants



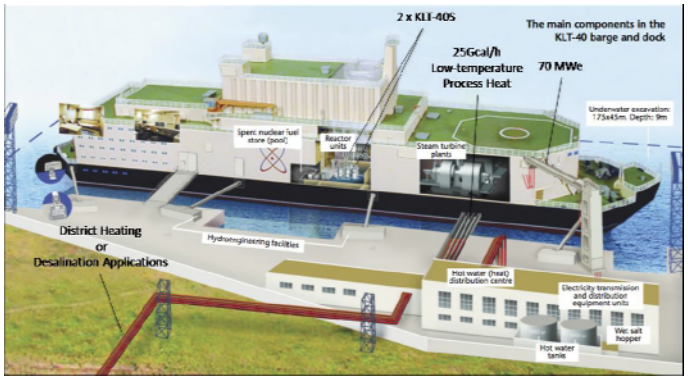
4-Module (500 MWe) mPower Plant

- Small autonomous power sources for remote locations



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

- Barge mounted units



Plant sizes

- Nuclear units sizes have historically increased eg French PWR fleet:
  - 1st generation 900 MWe
  - 2nd generation 1300-1500 MWe
  - 3rd generation 1650 MWe
- Large plants benefit from scaling factors:
  - Construction costs per MWe lower for large plants
  - Similar workforce need independent of plant size
- In developing countries plants > 600 MWe may be too large for the grid and the cash flow too onerous to finance
  - Challenge will be to make the smaller plants cost effective in this market
- In developed countries SMRs would need to be grouped into large power stations to be competitive
  - Challenge will be to demonstrate economic parity or near parity for a multiple unit power station compared with a single or twin-unit conventional power station
- Small module sizes may make additional sites viable
  - Siting near cities may be possible if no requirement for offsite evacuation

NUSCALE (USA)

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

HOLTEC INTERNATIONAL HI-SMUR (USA)

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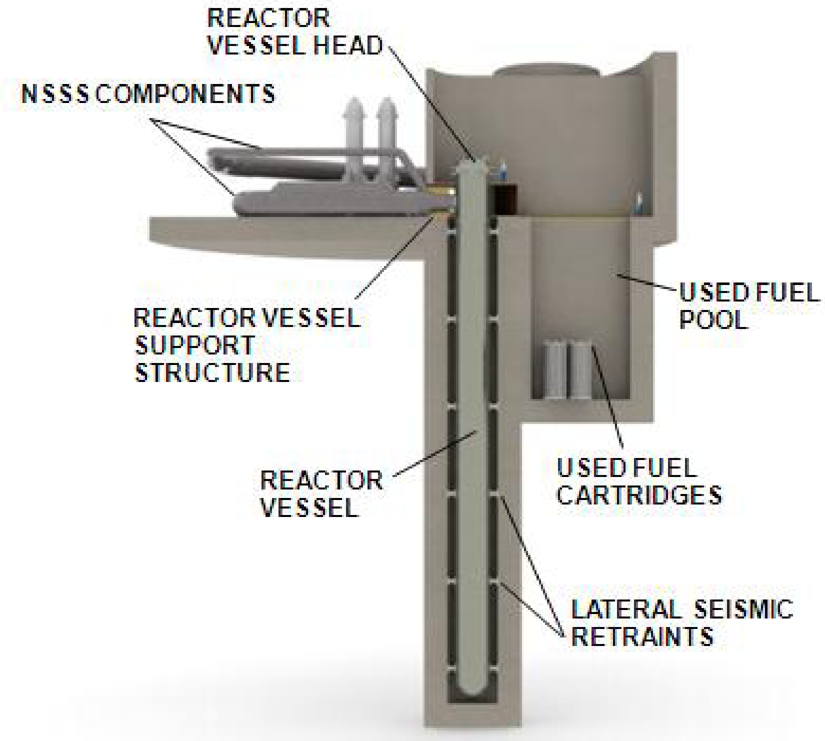
- 145 MWe
- Integral PWR
- Natural circulation
- 17x17 fuel assembly
- 3.6 m active core height
- 5.2 m^3 core volume
- ~30 MW/tHM specific rating
- Cartridge refuelling module



mPower (B&W) (USA)

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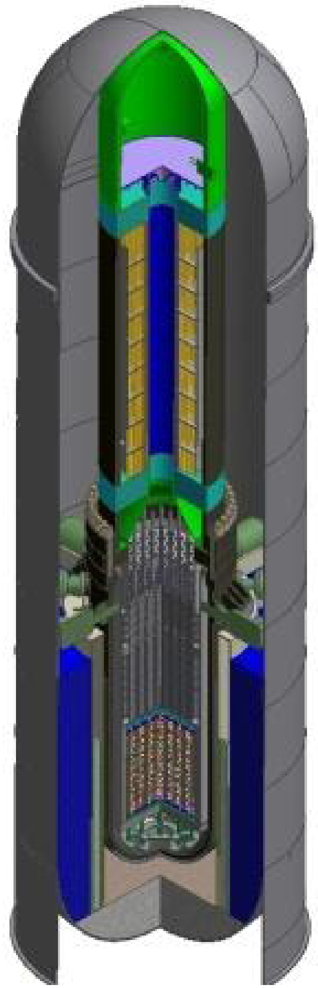
- 125 MWe
- Integral PWR
- Forced circulation
- 69 17x17 fuel assemblies
- 4.5 year refuelling cycle (single batch core)
- ~23 MW/tHM specific rating
- ~35 GWd/t burnup
- No soluble boron reactivity control

WESTINGHOUSE SMR (USA)

- 225 MWe
- Integral PWR
- Forced circulation (external coolant pump motors)
- 89 17x17 fuel assemblies
- 2.44 m active core height
- 9.6 m^3 core volume
- ~30 MW/tHM specific rating
- Soluble boron reactivity control



General Atomics GT-MHR (USA)

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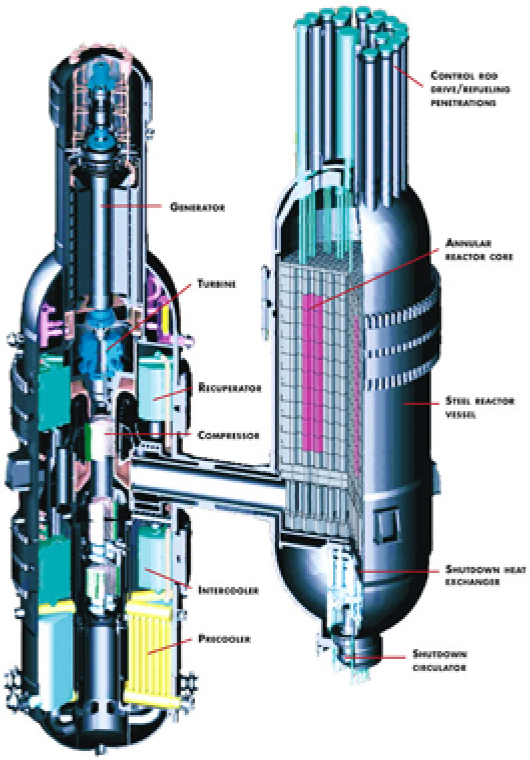
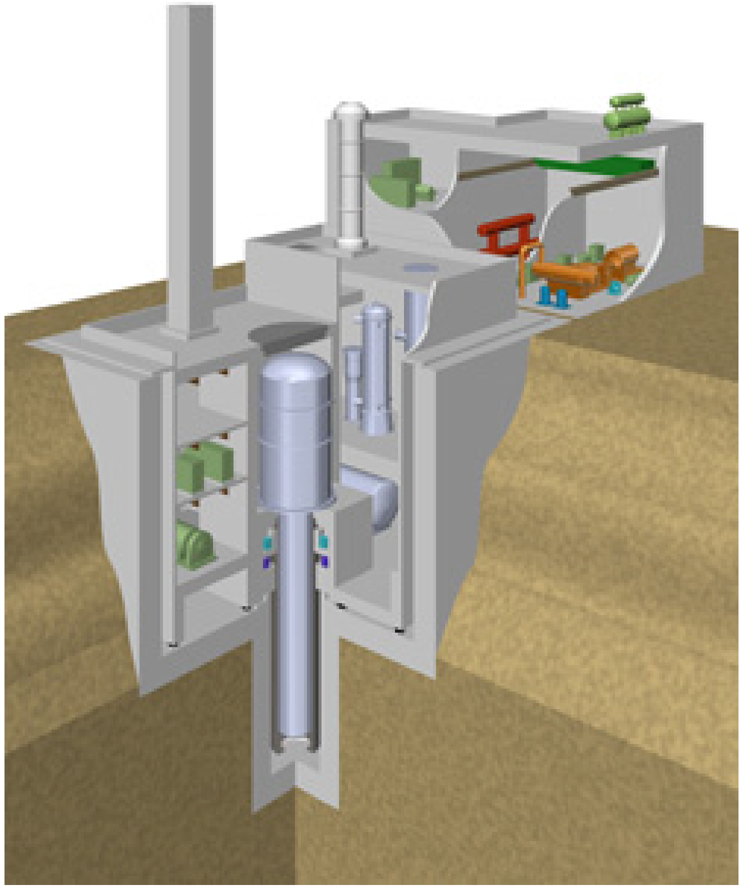
- 285 MWe
- High Temperature Reactor (HTR)
- Ceramic TRISO fuel
- Helium coolant
- Graphite moderator
- Fuel compact in prismatic fuel blocks
- Core can dissipate decay heat without active systems



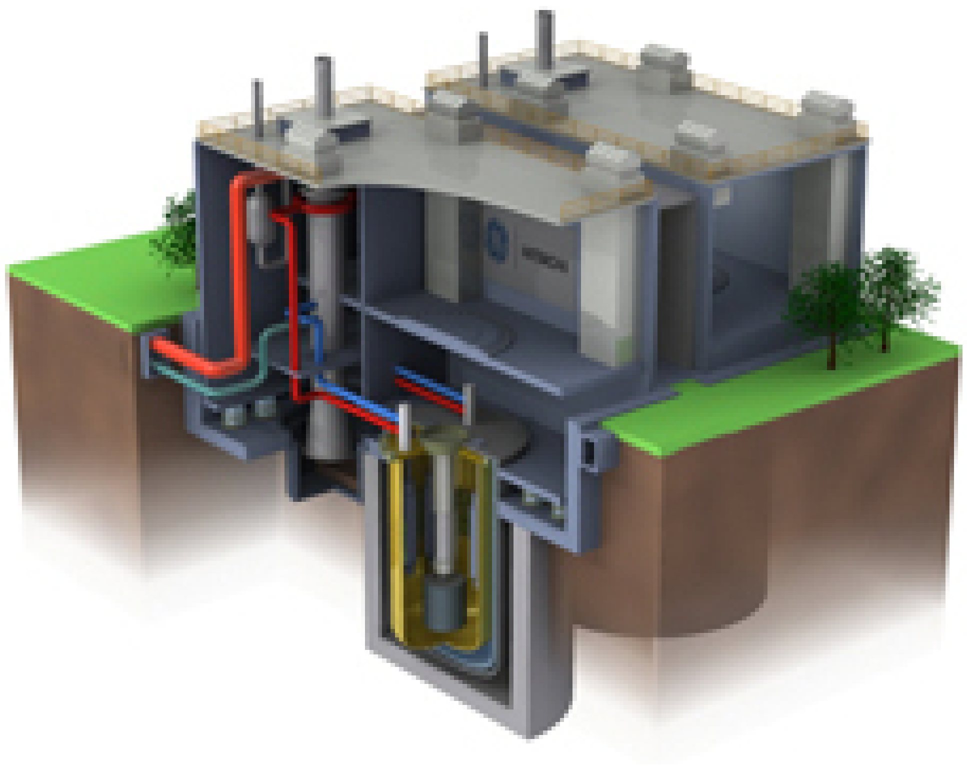
Toshiba 4S

- 30 MWt
- 10 MWe
- Liquid-metal cooled (sodium) fast spectrum reactor
- 18 hexagonal fuel assemblies - U-10%Zr Alloy with 19.9% enrichment
- Refueling interval 30 years
- Cartridge refuelling module inaccessible on-site



GE-Hitachi PRISM

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



Commonly occurring features of SMRs

- Simplified or passive safety
  - Large coolant masses for high thermal inertia
  - High vertical heights to enhance natural convection
  - Natural convection to manage decay heat
  - Small size does not necessarily improve safety
  - Need to address multiple units in close proximity after Fukushima
- Underground siting of cores
  - Underground siting may improve protection in some scenarios, but not necessarily all scenarios
- Long refuelling cycles
  - Autonomous power sources have very long life cartridge cores (15 to 30 years)
  - Facilitated by low specific ratings

SMR competitiveness in UK

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- Implied assumption is that large power stations provide the best fit to the UK grid and that large unit sizes gain on economies of scale
  - Engineering costs usually scale this way
  - But much of the capital cost of a nuclear plant is actually the cost of finance and SMRs allow the possibility of phased construction with potential savings on financing cost and reduced financial risk
- Challenge for SMRs in UK will be to demonstrate benefits from:
  - Replication of small modules
  - Domestic supply chain
  - Factory construction and installation
  - Construction cost and operational cost savings from simplified design
  - Reduced cost and financial risk exposure
- Alternative missions
  - Plutonium disposition
  - Industrial heat source
  - Decarbonisation of transport – hydrogen production, electric vehicles or synthetic hydrocarbon fuels

UK requirements

- Need to satisfy statutory requirements for safety & radiological doses (Office of Nuclear Regulation) and environmental discharges (Environment Agency)
  - Statutory requirements are agnostic about approaches used (eg active versus passive safety)
- Systems will need to go through consent processes:
  - Justification
  - Generic Design Assessment (GDA)
  - Site planning application
  - Pre-Construction Safety Report (PCSR)
  - Pre-Operation Safety Report (POSR)
  - Continued Operation Safety Report (COSR)
- Staffing levels
  - A case will need to be made to ONR that the overall staff requirement for a power station containing multiple SMR units could be no more onerous

Conclusions

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- 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
- Small but not small
  - Although the proposed designs are small in terms of output, they are often not small in terms of physical size
- 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 is capable of improving on the competition!

Recommendations

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- To progress SMRs further in the UK assessing:
  - The economics of SMRs in the UK including the potential financial models
  - Siting for SMRs in the UK to determine if there are any advantages to be gained over larger nuclear plants
  - Potential role of SMRs for district heating, industrial heat supply and plutonium management.
  - UK skills and manufacturing base for SMRs