Jacobs

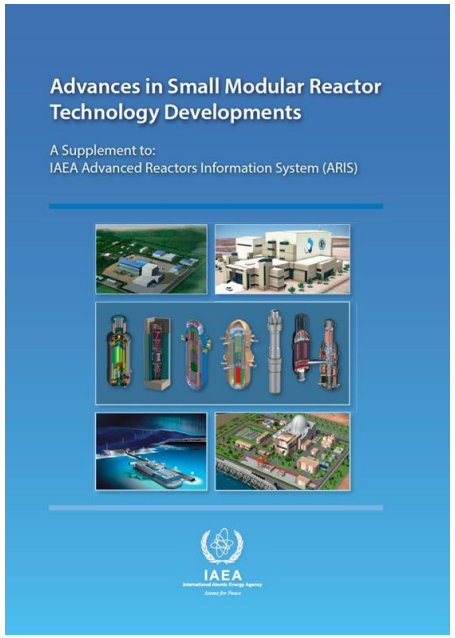
Challenging today.
Reinventing tomorrow.

Next Generation Nuclear Power
Advanced and Small Modular Reactors

Presentation by John Lillington

4 - 5th November 2020

Next Generation Nuclear Power
Advanced and Small Modular Reactors



- http://www.htfalliance.com/
- http://www.iaea.org/NuclearPower/SMR/

Scope of Presentation

My presentation will focus on following topics:

- UK Government Nuclear Strategy including Advanced Reactor (AR) R&D programmes on-going in the UK and related international perspectives. ARs here relate to Gen IV reactor technologies.
- Key latest UK R&D activities relevant to ARs, focusing on latest design developments and enhanced safety features.
- Also cover UK Government interest in Small Modular Reactors (SMRs) including the main features of SMRs in general (in comparison with large reactors).
- Include enhanced safety features and potential economic benefits of SMRs
- NB the term SMR is often used to imply small reactors of Gen III+ technology but the benefits or otherwise of modularity apply to all technologies including ARs (or AMRs - which would imply small ARs)
- BEIS Nuclear Innovation Programme:

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/754664/30.10.18_BEIS_R_D_Presentation_-_Budapest_CEN_Summit.pdf

UK BEIS AMR Programme

Reactor Technologies and aims/characteristics

- The UK Department for Business, Energy and Industrial Strategy (BEIS) has been investing in the Advanced Modular Reactor (AMR) Feasibility and Development (F&D) project since the beginning of 2018.

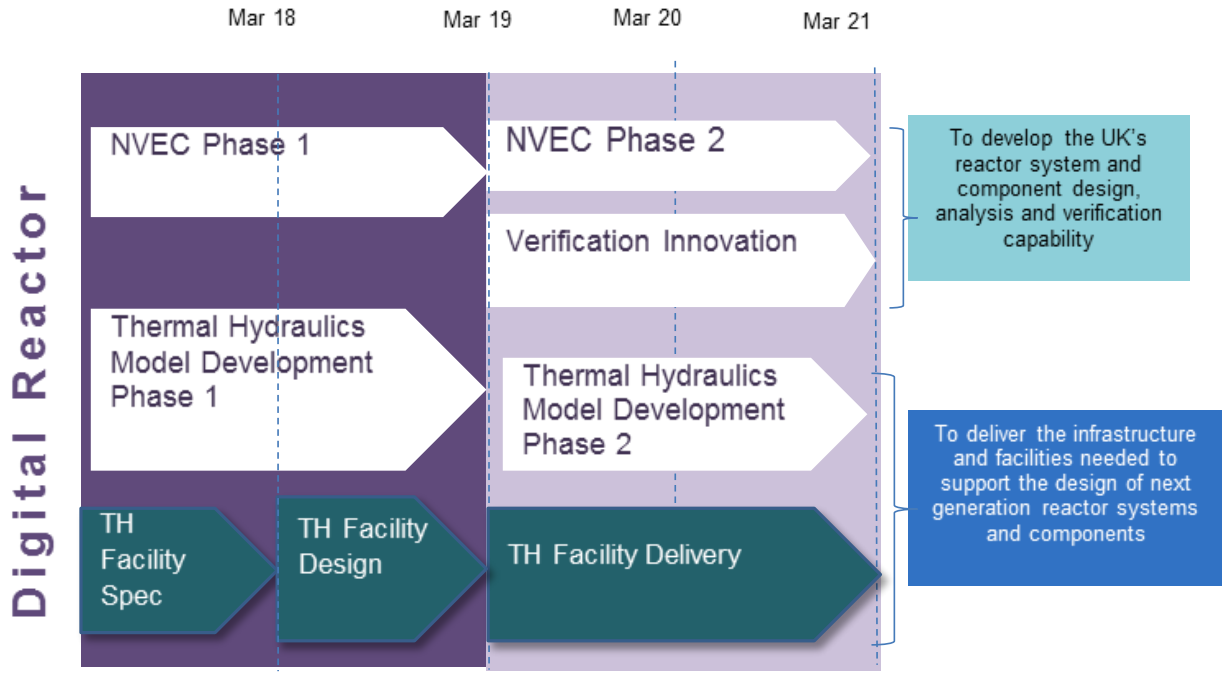
- The reactor technologies under consideration include sodium and lead cooled metal fast reactors, high temperature gas (helium) thermal reactors and molten salt fast (and thermal) reactors

- They show/share a number of the following aims/characteristics: low generation cost, amenable for off-site factory fabrication, increased grid flexibility, increased application functionality, fuel sustainability and proliferation resistance.

UK BEIS AMR Programme (Cont.)

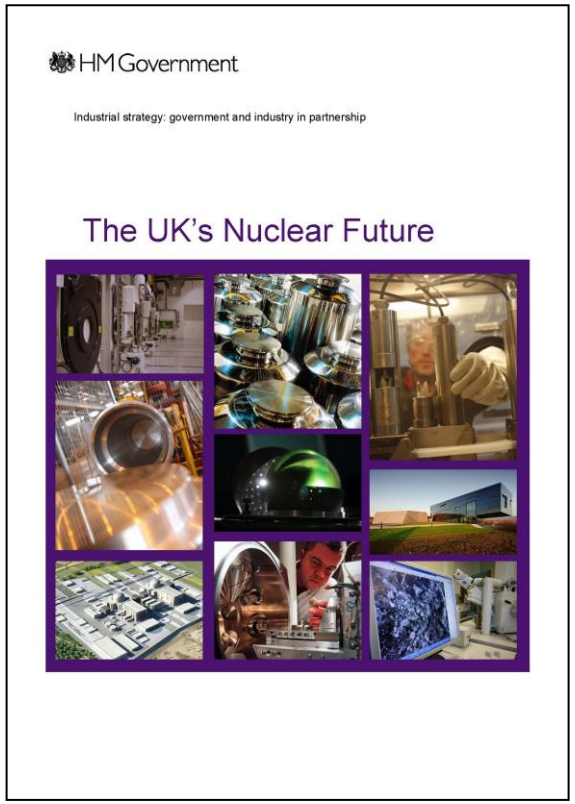
Nuclear Virtual Engineering Capability (NVEC)

Phase 1 programme completed. Phase 2 in progress.



Ref: BEIS Reactor Digital Phase 2 Programme

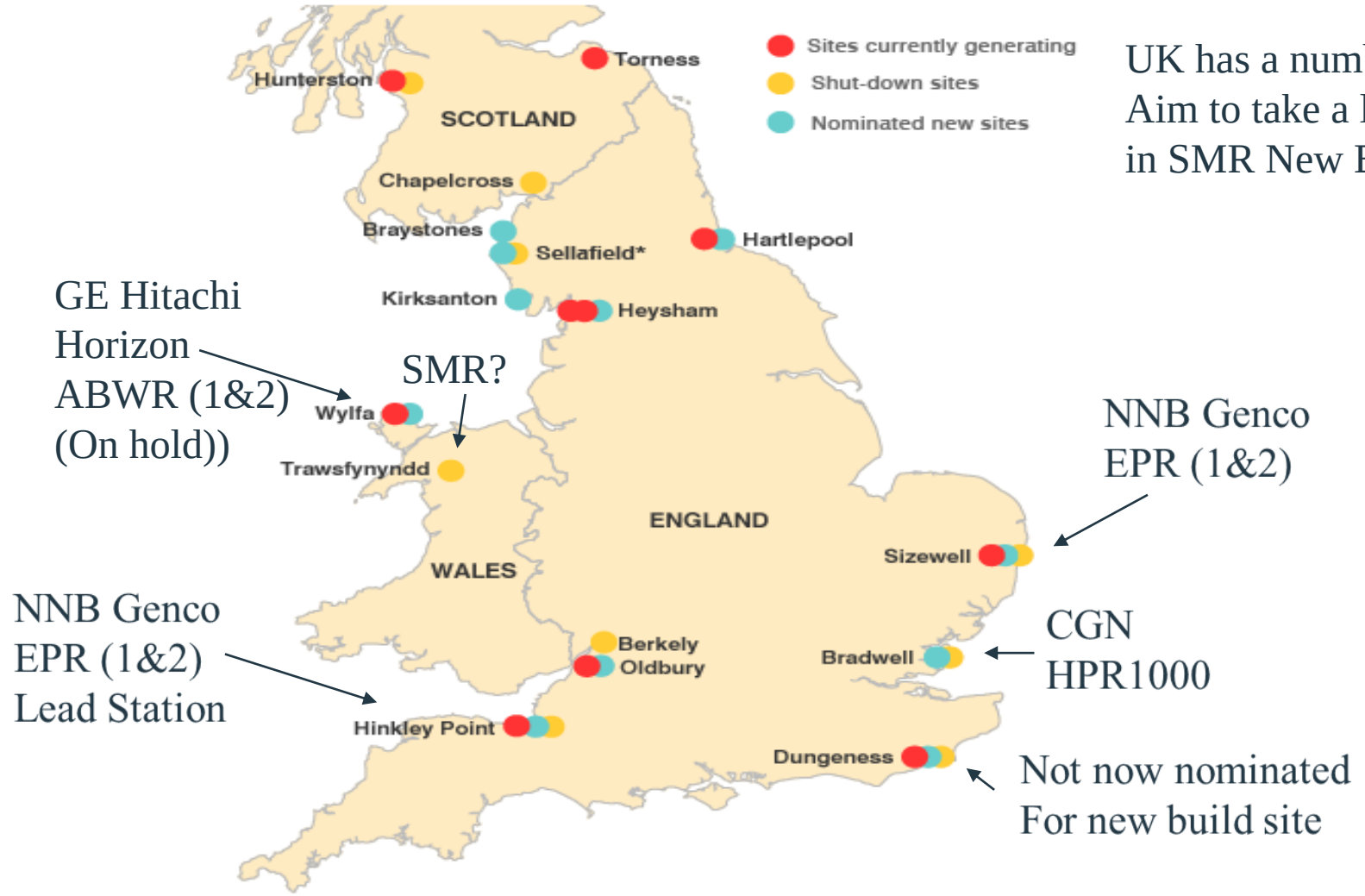
UK Government Nuclear Strategy



https://www.gov.uk/government/publications/nuclear-industrial-strategy-the-uks-nuclear-future

- UK Carbon Plan to reduce CO_2 emissions up to 2050:
  - Competition between different forms of low carbon energy generation.
- How this could be achieved:
  - Near term - Gen III/III+ LWRs
  - Medium term – Gen III+ SMRs
  - Long term – Gen IV AR & SMR & MMRs for additional applications
- Exploit opportunities for UK industry in RoW (including export of SMR technology)

UK Civil Nuclear Sites



UK has a number of licensed sites. Aim to take a lead in Europe/ RoW in SMR New Build!

*Shut-down site known as Calder Hall

SOURCE: DECC

Summary of UK Government Priorities for Nuclear R&D (including SMR R&D)

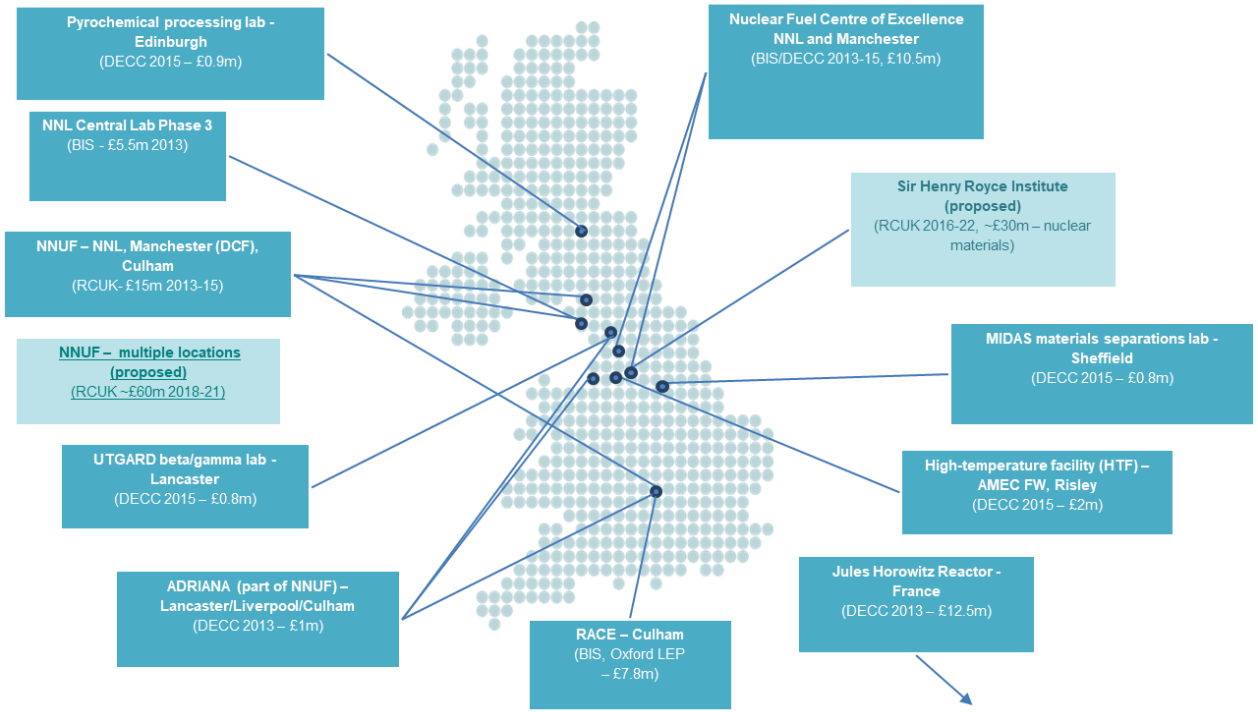
- **'Nuclear Innovation and Research Advisory Board (NIRAB)** provides independent, expert advice to Government on the research and innovation needed for nuclear energy to play a significant role in the UK's future low carbon and secure energy mix and to create the environment in which the UK nuclear industry can contribute significantly to our economy'

- **NIRAB Recommendations include:**

  - Development of strategic planning tools
    - includes emerging nuclear technologies
  - Future Fuels – e.g. Accident Tolerant Fuels (ATFs)
  - 21st Century Nuclear Manufacture:
    - Advanced manufacturing and 'plug and play' modular build in nuclear factories of the future (particularly relevant for SMRs)
  - Reactor Design:
    - Promoting UK designs whereby UK could benefit internationally (particularly relevant for SMRs)
  - Recycling Fuel for Future Reactors:
    - Cost effective technologies to deliver a secure and sustainable low carbon fuel supply

UK Research Facilities where UK Government has invested since 2013

Nuclear Advanced Manufacturing Research Centre (NAMRC)



International and National R&D Programmes

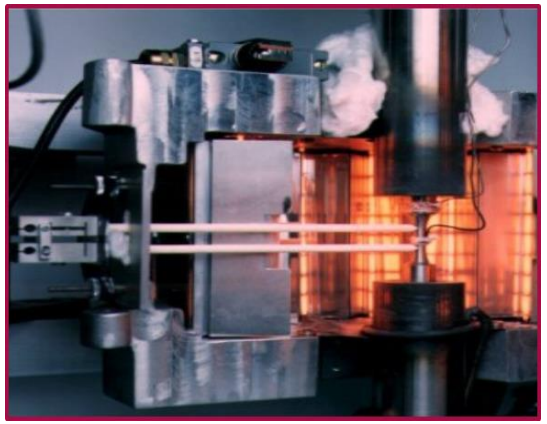
High Temperature Facility Alliance

Establish an open access high temperature materials R&D facility
Develop and deliver an exploitation plan that helps the UK play a leading role in AR technology, including SMR

Generation IV reactor programmes
EPSRC funded calls to universities
Innovate UK call to corporations,
SMEs and universities
EU-funded programmes
International programmes

Reactor Development projects
Small Modular Reactors
U-Battery initiative

Also AGR fleet continued support



http://www.htfalliance.com/

What is an SMR?

- **Small**
  - IAEA typically recognise SMR < 300 (MWe)
  - But ‘Small’ also meaning < 500 MWe – some vendors
  - ‘Micro’ ~10MWe
- **Modular**
  - Groups of multiple units
  - Units are similar
  - Manufacturing of units in a factory
- **Reactor**
  - Conventional isolated components (core, SGs, pressuriser, pumps, or
  - Integral: components in single pressure vessel

Why Small Modular Reactors (SMRs)

- Reduced capital costs per reactor compared with high capital costs of large GW scale reactors – therefore financing easier. Sequential utilisation of units.
- Could reduce the time to market, simpler designs, impact on construction, licensing etc.
- Application to smaller grid networks which could not accommodate large nuclear plants. Applies to new, in addition to ‘nuclear’ established countries.
- As a possible alternative to new fossil fuel plants on existing brown field sites.
- Flexible against demand. Easier load following. Also could support renewables e.g. wind with inconsistent power generation.
- Increased inherent safety. Also, reduced power & fission product inventories to manage in an accident situation.
- UK specific: opportunity for the industry to invest and acquire IP in a new SMR design.

Advanced Modular Reactor(AMR) Feasibility and Development Project

- Scope – to cover Advanced Modular Reactors (including Gen IV) that maximise factory manufacture and deliver:
  - Low cost electricity
  - Increased flexibility to the grid
  - Cogeneration options
  - Alternative options for commercial growth
- Phase 1 - Series of feasibility studies (2018)
- Phase 2 - Detailed R&D for successful selected designs (2019 – 2021)

Advanced Modular Reactor Feasibility and Development Project, Department of Business, Energy & Industrial Strategy, 2018

Examples of SMR Technologies

- LWR technologies
- Gen III or III+ LWRs with targeted 10 year horizons for deployment e.g.
  - RR, NuScale SMR, B&W mPower, Westinghouse SMR, ACP/ACP100+, AREVA SMR
- High Temperature Gas Reactor
  - HTR-PM
  - HTGR and Co-Generation
- Fast Reactor
  - GE-Hitachi (Na)
  - Westinghouse (Pb)
  - G4M(Pb-Bi)
  - Moltex (Molten Salt)
- Micro Generation
  - U-Battery
  - 4S (Na)
- Barge Mounted Reactor
  - KLT-40S

Most of these technologies were chosen for study in the earlier UK SMR feasibility study against the following criteria:

- Technical maturity and viability
- Maturity of safety case and certification
- Key strengths and areas for development
- Programmes to address development needs
- Available resources – people, capability, facilities and funding
- Economic viability, including IP ownership

RR SMR

UK Consortium led by Rolls-Royce
Provide 220MW to 440MW of power, depending on the configuration
Being so compact (16 metres high and 4 metres in diameter) it can be transported by truck, train or even barge
60 year design life

https://www.rolls-royce.com/media/press-releases/2019/23-07-2019-commitment-to-initial-funding-for-smr-welcomed-by-consortium.aspx

https://www.rolls-royce.com/~/media/Files/R/Rolls-Royce/documents/customers/nuclear/smr-booklet-28-sep.pdf

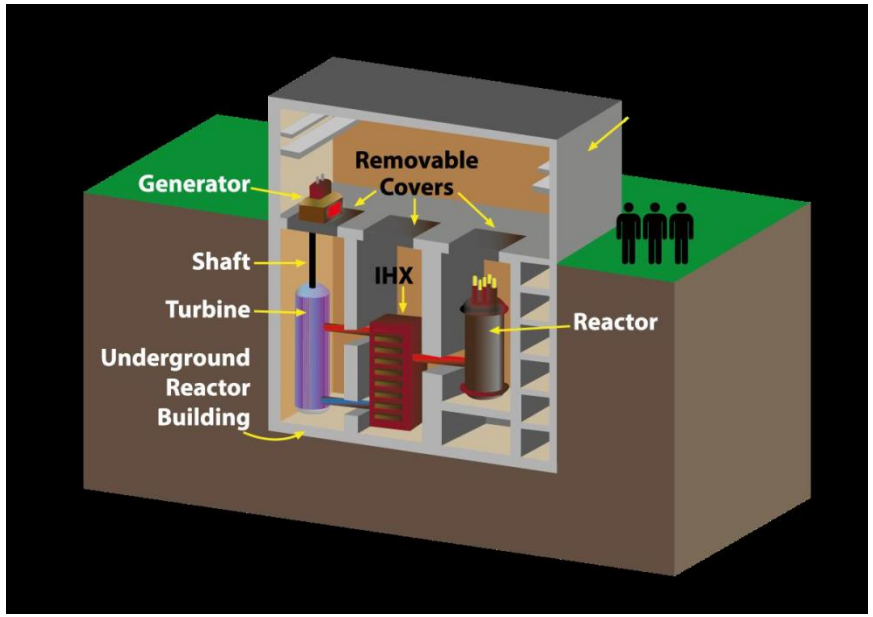
Urenco U-Battery

Jacobs, Atkins, Urenco collaboration

Micro reactor concept targeting industrial power units and remote off-grid applications

Target applications include: enrichment facilities, back-up power for large NPPs, embedded power and heat for heavy industry, desalination and transport

Twin unit 2×10MWth, 2×4 MWe, helium cooled, TRISO fuel, 800℃ process heat



https://urenco.com/news/global/u-battery-advancing-toward-siting-a-first-of-a-kind-smr-in-canada
29 July, 2019

U-Battery Micro Reactor,
SMR in UK : UK in SMR
MANCHESTER, 25 September 2014

NuScale SMR

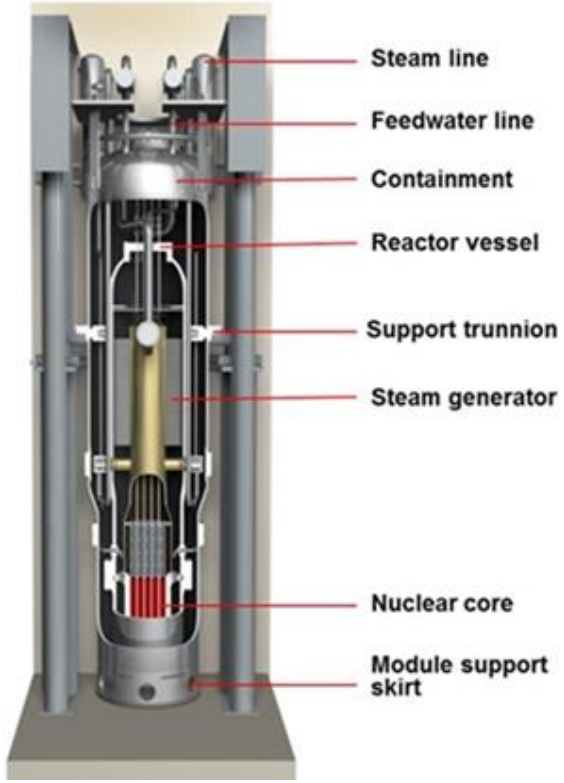
NuScale Power LLC designed modular PWR plant with up to 12 units each of 45MWe

Entirely natural circulation

24 month operating cycle

Extensive USNRC engagement and programmes of work supported by Fluor and Dec 2013 USDoE award

https://www.nuscalepower.com/newsletter/nucleus-spring-2019/powering-the-next-generation-of-nuclear



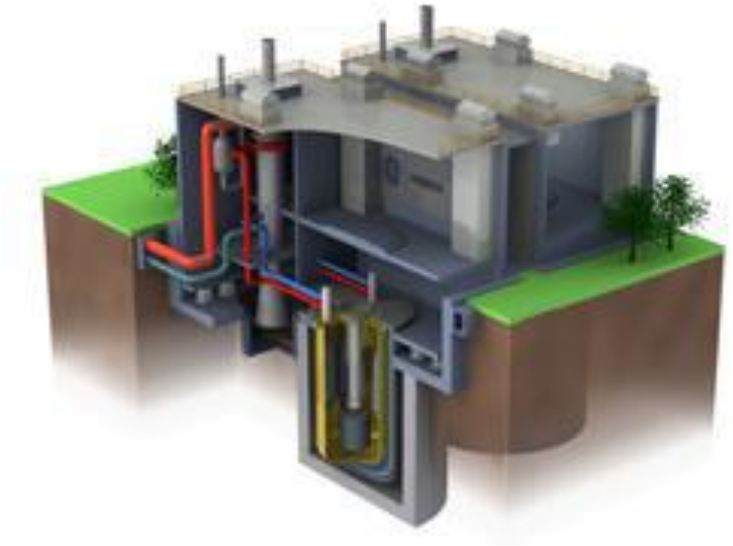
www.nrc.gov/reactors/advanced/nuscale.html

PRISM

GE Hitachi has proposed its PRISM (Power Reactor Innovative Small Module) for disposition of the UK's stockpile of plutonium .

Compact modular pool-type sodium cooled fast reactor with passive cooling for decay heat removal.

Each PRISM power block consists of two modules of 311 MWe (840 MWt) each, operating at high temperature over 500°C.



https://nuclear.gepower.com/build-a-plant/products/nuclear-power-plants-overview/prism1

Summary

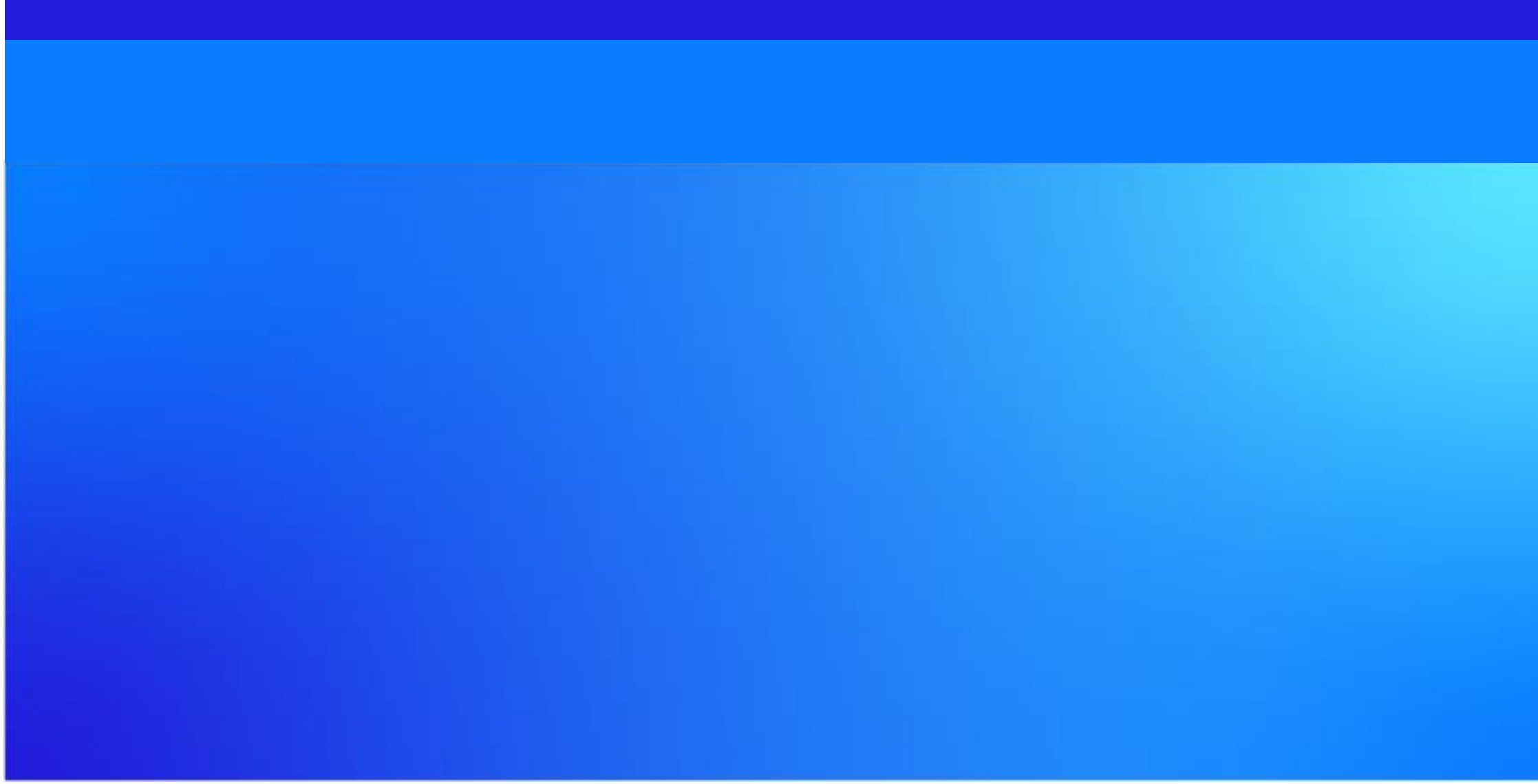
Key points:

- UK Government Advanced Reactor (AR) R&D programmes on-going in the UK
- Participation in international Gen IV Forum activities
- Keen interest and UK Government support for Small Modular Reactors in general
- Potential safety features and economic benefits of SMRs recognised
- BEIS Nuclear Innovation Programme and Nuclear Sector Deal out to 2030 and beyond (2050?) being implemented

Copyright Notice

Important

The material in this presentation has been prepared by Jacobs®.



Jacobs

Challenging today.
Reinventing tomorrow.