Abstract

- *The global demand for electricity is increasing. Both developed and developing nations have an increasing demand from a growing population for access to low cost electricity. Activists are creating societal disruption to highlight that CO_2 emissions are causing climate change. Governments are committing to reduce emissions, but progress is slow and difficult. Renewable electricity sources are unreliable for the electrical baseload required by national grids. Nuclear is seen as an elitist, expensive solution that only a few nations can afford or access.*
- *This paper will review the role that Small Modular Reactors (SMR) have to potentially be part of the solution. However, at the present time each nuclear nation is focused on the technical details and the optimum design through their industrial base. Their presumption is that the optimum design will result in international sales and huge orders.*
- *Being small these modular reactors would be nationally distributed to become regional power providers. In addition to a source of electricity for a region, the heat generated can be used commercially (e.g. in chemical plants to produce hydrogen) or domestically (e.g. to heat homes and offices). There are a number of non-nuclear nations with aspirations of joining the nuclear community, but the entry barriers are high in terms of investment and regulations.*
- *This paper will explore factory built, low cost, mass produced nuclear reactors, not by focusing on the technology, but the acquisition process. It will consider lessons learnt from satellite and fighter aircraft programmes which led to the formation of consortiums of nations with a common aim. It will consider a consortium of nations that are engaged in nuclear power generation or have the aspiration to become a nuclear nation.*
- *To become zero emitters of greenhouse gases the world needs to stop burning fossil fuels, but electricity demand is increasing globally. Global procurement of Joint Small Modular Reactors (JSMR) will help achieve these two opposing requirements.*

Dale Shermon

- QinetiQ Fellow | Head of Planning, Monitoring and Controls
- BA Degree in Technology, Open University
- Chartered Engineer with Institution of Engineering and Technology (IET)
- ACCA Diploma in Accounting and Finance (C Dip (A&F))
- ICEAA Certified Cost Estimator / Analyst with the Parametric Specialism (CCEA-P)
- Past Chairman (7 years) current member of the board of the Society for Cost Analysis and Forecasting (SCAF)
- Council member and Fellow of the Association of Cost Engineers (FACostE)
- UK and Europe Regional Director, life member of International Cost Estimating and Analysis Association (ICEAA) and recipient of the Frank Freiman award
- Fellow of Association of Project Managers (FAPM)
- Co-author of the '*Association for Project Management (APM) Body of Knowledge (BoK) issue 7*'
- Co-author of "*Cost Engineering Health Check: How good are those numbers?*", 2017, ISBN: 978-1-4724-8407-9
- Editor and major contributor of "*Systems Cost Engineering*" , July 2009. ISBN: 978-0-566-08861-2

Solving the climate crisis with satellites, fighter aircraft and nuclear reactors.

Dale Shermon – QinetiQ Fellow

Head of Planning, Monitoring and Control, Performance Excellence

ICEAA Workshop, Pittsburgh

17 to 19 May 2022

QINETIQ/22/00798

QINETIQ

Agenda

Presentation aim: highlight the plight of mankind due to greenhouse gases and the need to work globally to solve the problem.

5

5 fundamental mobile phone technologies including Touch Screen and Liquid Crystal Displays (LCD) developed by QinetiQ experts

12

12 Empire Test Pilot School students have become astronauts including Major Tim Peake

3 secs

Every 3 seconds a Boeing aircraft takes off or lands that has been tested in QinetiQ's low speed Wind Tunnel

40

40 organisations, including the Royal Navy involved in 6 weeks of operations during the Unmanned Warrior Exercise

50+

including 50+ unmanned vehicles operating in the air, land and sea

Joint Small Modular Reactor (JSMR) | May 2022 | © QinetiQ QINETIQ/22/00798

85+

locations woldwide

1,300+

patents (including 300+ pending)

We are QinetiQ

£1,278m

FY2021 revenue

7,000+

People with unique science and engineering expertise

1,850km

1,850km of the TANAP pipeline will be protected by OptaSense®

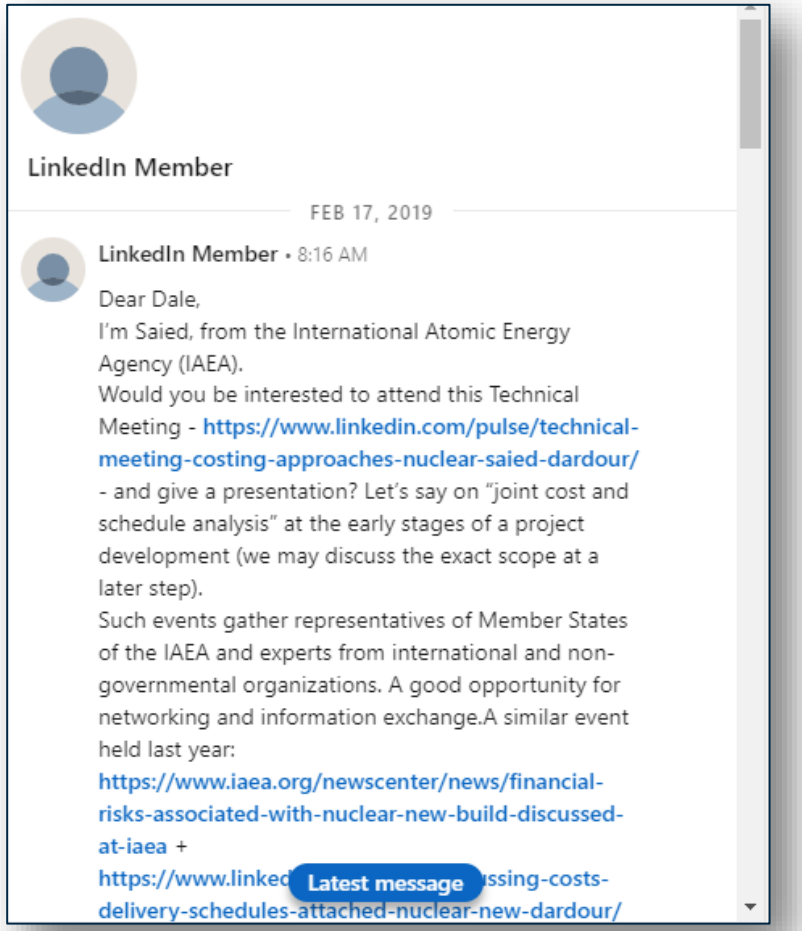
16

Our Ocean Basin in Gosport, UK contains enough water to fill 16 Olympic swimming pools

QINETIQ

International Atomic Energy Agency presentation

- Feb 2017 – invitation to speak at the International Atomic Energy Agency (IAEA) technical meeting on “joint cost and schedule analysis”
- The International Atomic Energy Agency is an international organization that seeks to promote the peaceful use of nuclear energy, and to inhibit its use for any military purpose, including nuclear weapons.
- The IAEA was established as an autonomous organisation on 29 July 1957. Headquarters: Vienna, Austria
- The objectives of the IAEA’s dual mission – to promote and control the Atom – are defined in Article II of the IAEA Statute.
  - “The Agency shall seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world. It shall ensure, so far as it is able, that assistance provided by it or at its request or under its supervision or control is not used in such a way as to further any military purpose.”



IAEA workshop at Idaho National Laboratory (INL)

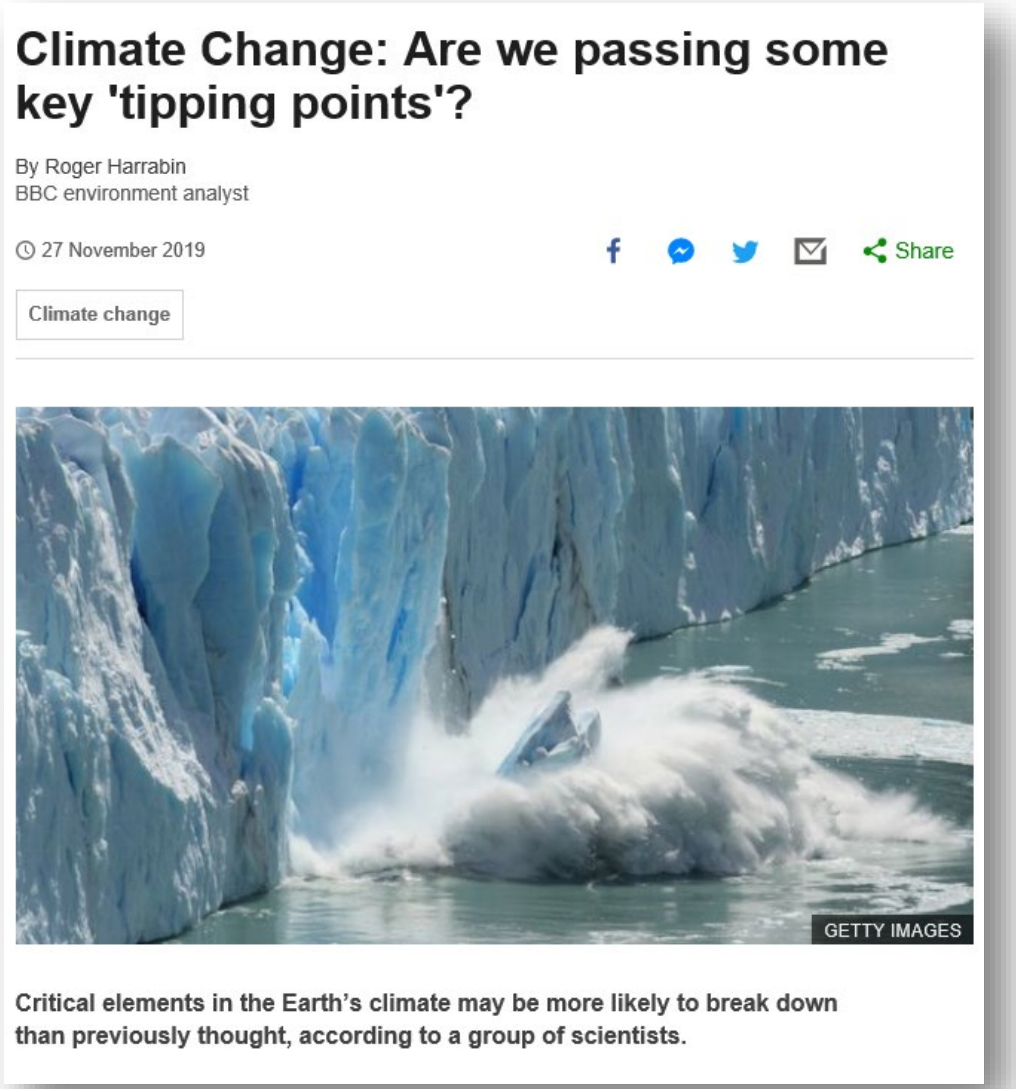
- Presented at the IAEA workshop at Idaho National Laboratory (INL)
- 30 Sept to 3 Oct 2019
- Presented two papers:
  - Considering the cost of vulnerability in Critical National Infrastructure (CNI)
  - Parametric cost modelling at the early stage of projects
- Good exchange of ideas and knowledge from both sides.

The problem

The Problem

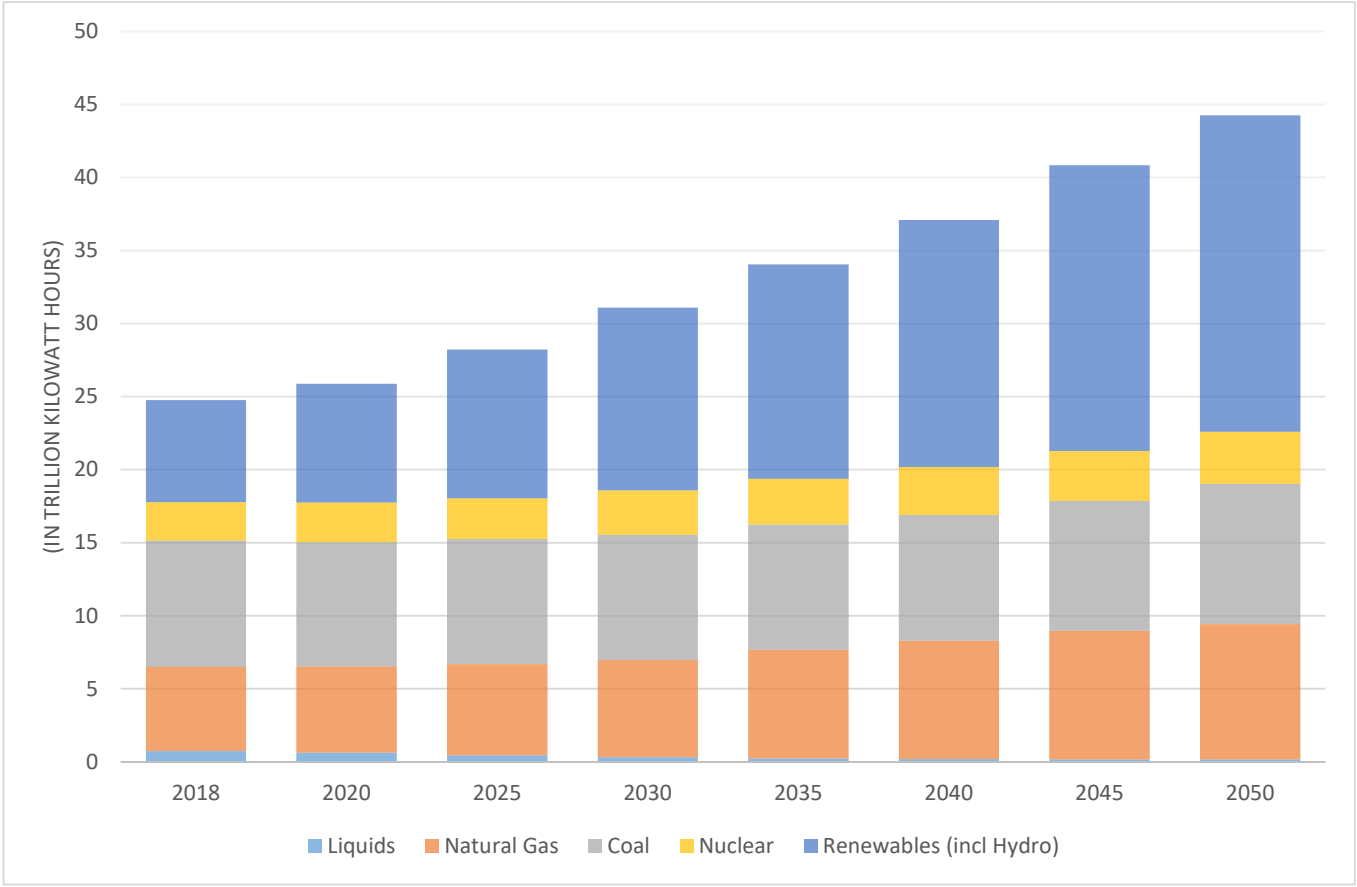
Countries will have to increase their carbon-cutting ambitions five fold if the world is to avoid warming by more than 1.5°C (34.7°F), the UN says.

https://www.bbc.co.uk/news/science-environment-50547073



Projected electricity generation worldwide by energy source

- The global demand for electricity is increasing.
- Both developed and developing nations have an increasing demand from a growing population for access to low cost electricity.



https://www.statista.com/statistics/238610/projected-world-electricity-generation-by-energy-source/

The Problem

- Activists are creating societal disruption to highlight that CO_2 emissions are causing climate change.
- Governments are committing to reduce emissions, but progress is slow and difficult.
- Renewable electricity sources are unreliable for the electrical baseload required by national grids.
- Nuclear is seen as an elitist, expensive solution that only a few nations can afford or access.

https://www.theguardian.com/environment/2020/jan/07/save-the-planet-guide-fighting-climate-crisis-veganism-flying-earth-emergency-action

https://www.bbc.co.uk/newsround/49766020

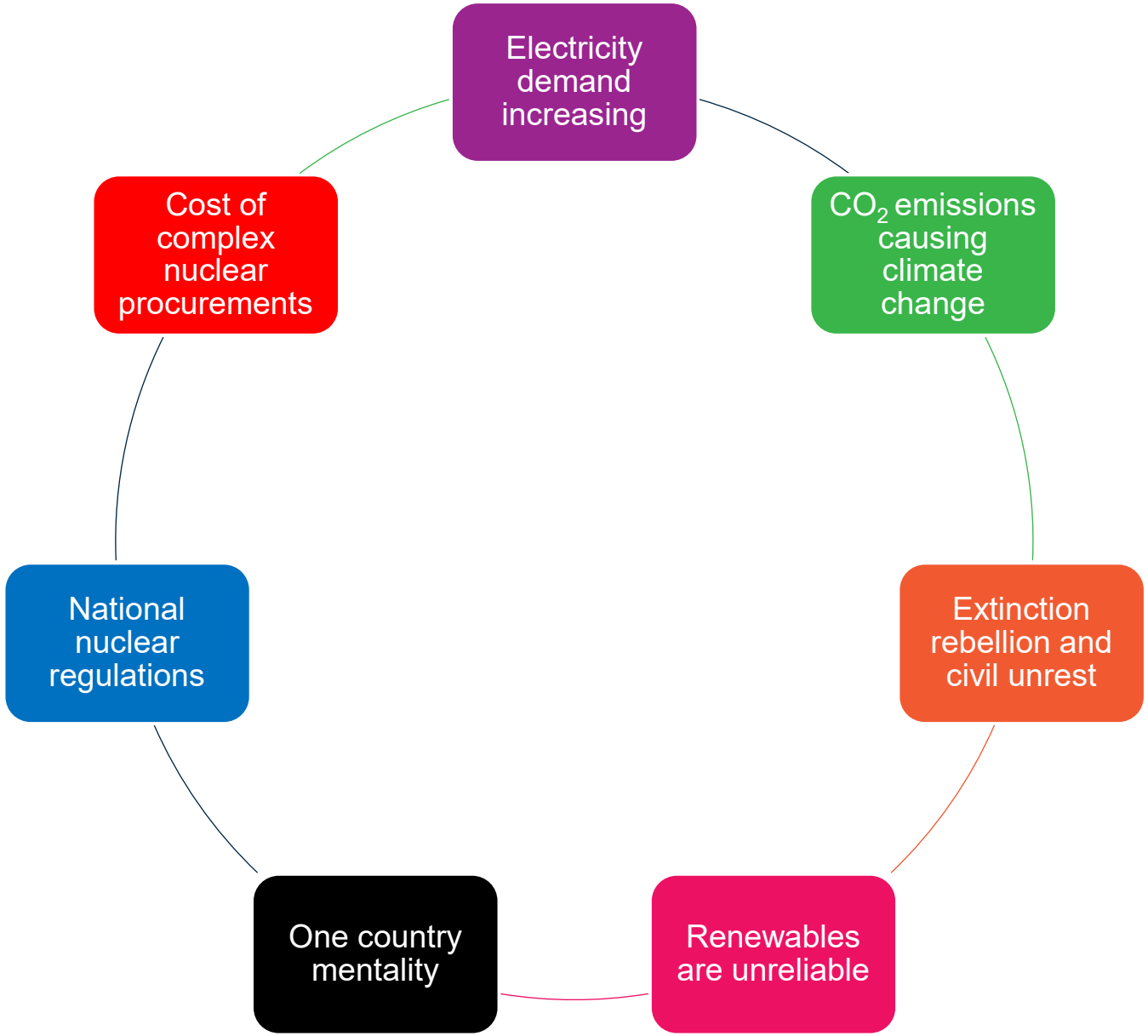
https://www.thenation.com/article/archive/postcards-from-the-global-climate-strike/

https://www.kairoscanada.org/event/week-for-future

Age: 4.5 billion years
Earth orbits the Sun at an average distance of 93 million miles
Average temperature of the earth is 15°C
Sphere with a roughly 8,000 mile diameter
Earth's atmosphere is an extremely thin sheet of air extending from the surface of the Earth to the edge of space; about 60 miles thickness.
Population: 7.7 billion (2020)
Population: 0.000 billion (Future)

The Problem

- As an independent observer of the IAEA workshop there were some common themes which are captured here.
- The attendees at the workshop were mainly from the nuclear domain.
- Are there lessons that can be learnt from outside the nuclear domain?



Small Modular Reactors

Conventional nuclear power stations

- Hinkley Point C nuclear power station is a project to construct a 3,200 MWe nuclear power station with two EPR[1] reactors in Somerset, England.
- The site was one of eight announced by the British government in 2010, and in November 2012 a nuclear site licence was granted.
- Construction cost**: £22 billion to £23 billion**
- Construction began: 11 December 2018
- Hinkley Point C will be the first in a new generation of nuclear power stations in the UK. The planned twin unit UK EPR is capable of generating 3,200MW of secure, low carbon electricity for 60 years.

https://www.edfenergy.com/

1. EPRs – originally known as European Pressurised Water Reactors – are a type of Pressurised Water Reactor (PWR).

Small Modular Reactors (SMR)

- Small modular reactors (SMRs) are nuclear fission reactors that are smaller than conventional nuclear reactors and typically have an electrical power output of less than 300 MW or a thermal power output of less than 1000 MW
- They are designed to be manufactured at a plant and transported to a site to be installed.
- The greater safety should come via the use of passive safety features that operate without human intervention, a concept already implemented in some conventional nuclear reactor types.
- SMRs also reduce staffing versus conventional nuclear reactors. SMRs are claimed to cross financial and safety barriers that inhibit the construction of conventional reactors.

https://en.wikipedia.org/wiki/Small_modular_reactor

- One hindrance to commercial use may be licensing, since current regulatory regimes are adapted to conventional designs. SMRs differ in terms of staffing, security and deployment time. US government studies to evaluate SMR-associated risks have slowed licensing.

Source: “Small Modular Reactors - once in a lifetime opportunity for the UK”, Copyright Rolls-Royce 2017

Observation – too many designs; too few orders

Small Modular Reactors (SMR)

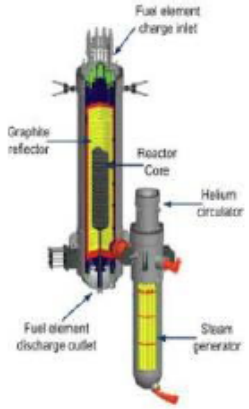
- The floating nuclear power plant Akademik Lomonosov, operating in Pevek in [illegible] end of 2019 the first and only completed working prototype in the world connected to the grid. [illegible] based on the design of nuclear icebreakers.
- The construction of the world's first commercial land-based SMR started in July 2021 with the Chinese power plant Linglong One. The operation of this prototype is due to start by the end of 2026.

ACP-100

Chinese **iPWR**

- 125MWe/ module
- 0.3 g seismicity
- 2 passive safety trains
- 24 month refueling cycle

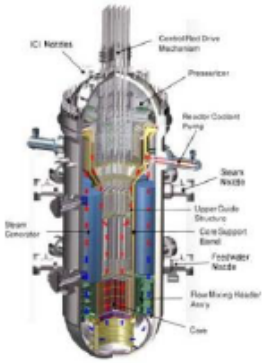
HTR-PM



Chinese **HTR**

- 105MWe/ module
- 0.3 g seismicity
- Passive (inherent) and active safety trains
- Online refueling

SMART



South Korean **iPWR**

- 110MWe/ module
- 0.3 g seismicity
- 4 passive safety trains
- 24 month refueling cycle

RITM-200

Russian **iPWR**

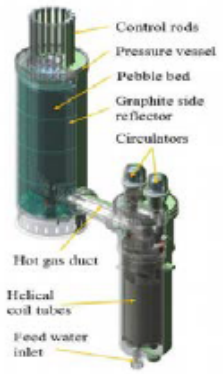
- 52MWe/ module
- 0.3 g seismicity
- 2 safety trains (passive and active)
- 24 month refueling cycle

NuScale

American **iPWR**

- 60MWe/ module
- 0.5 g seismicity
- 2 passive safety trains
- 24 month refueling cycle

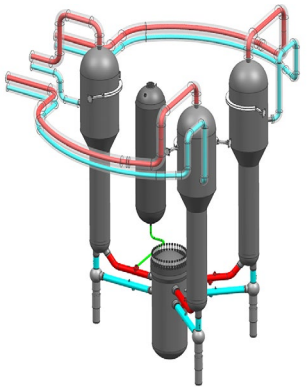
Xe-100



American **HTR**

- 75MWe/ module
- 0.3 g seismicity
- 4 passive (inherent) safety trains
- Online refueling

Rolls-Royce

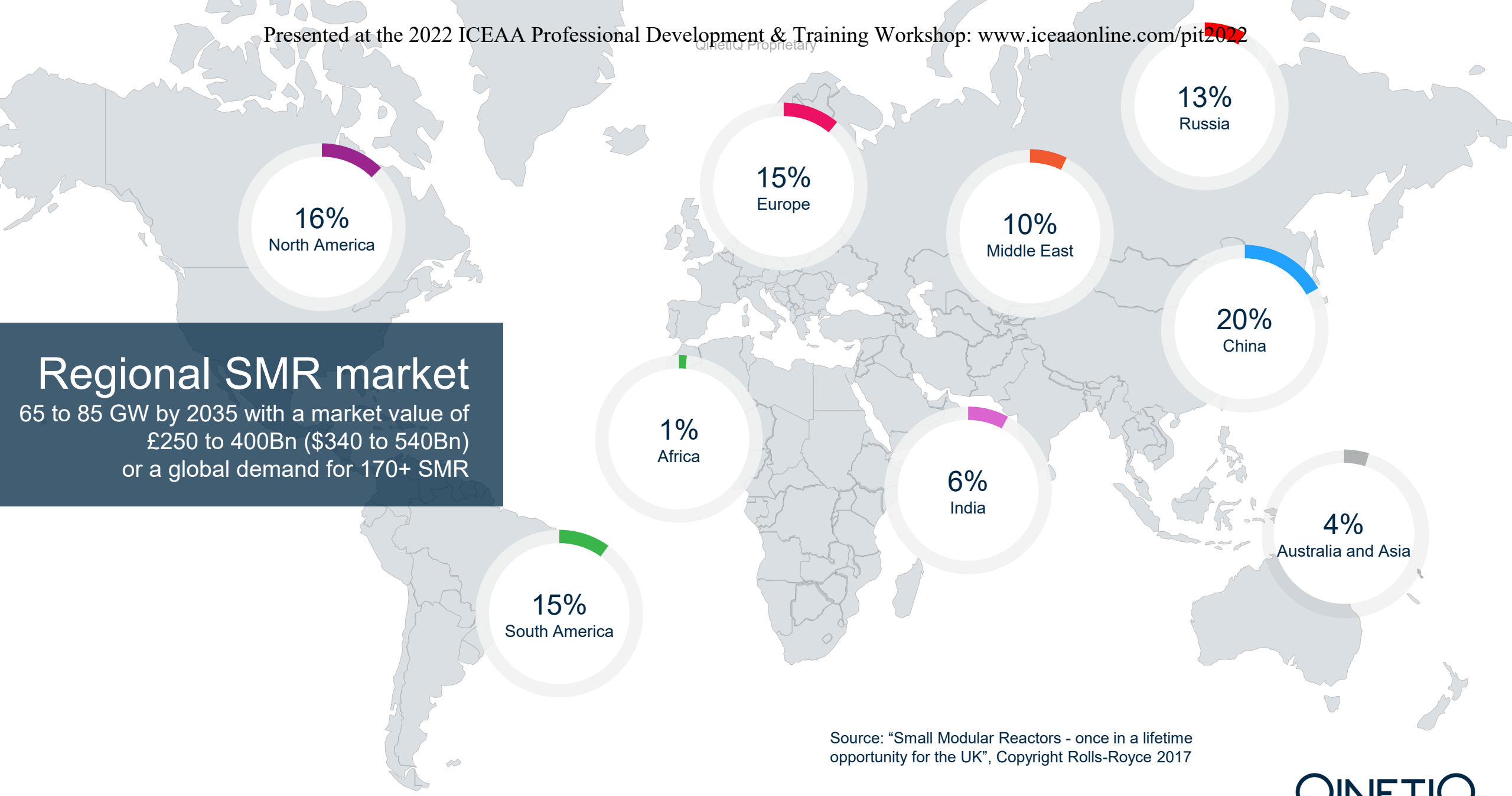


UK PWR

- 400-450 MWe/ module
- 0.3 g seismicity
- Passive
- 18 days refuelling outage

Regional SMR market

65 to 85 GW by 2035 with a market value of £250 to 400Bn ($340 to 540Bn) or a global demand for 170+ SMR



Source: “Small Modular Reactors - once in a lifetime opportunity for the UK”, Copyright Rolls-Royce 2017

The Solution

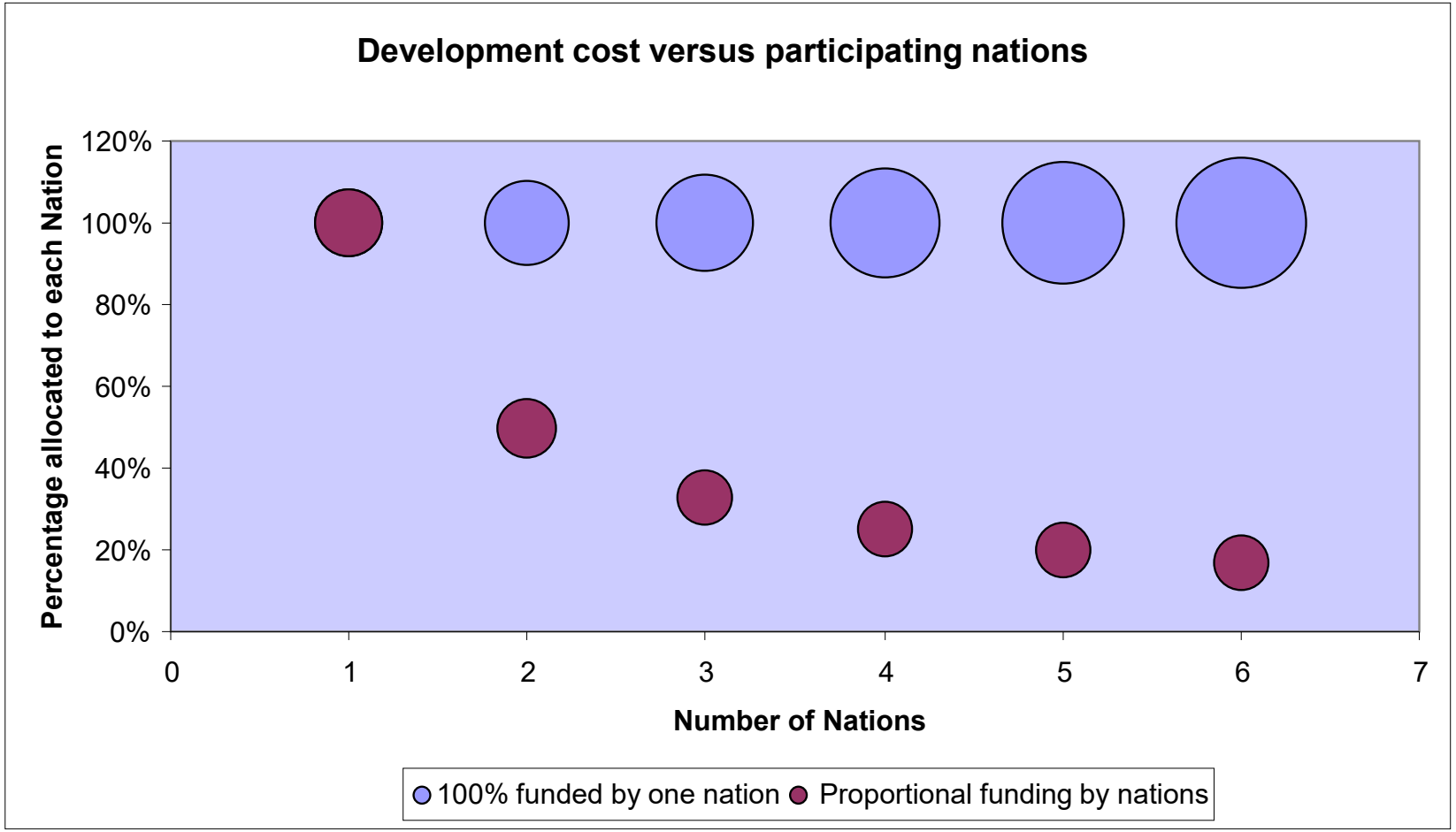
Collaboration

- Many nations are pursuing a SMR design. Each nation believes it will capture the SMR market; if only they had the right solution
- The Convention for the establishment of a European Space Agency (ESA) starts with the paragraph:
  - *'Considering that the magnitude of the human, technical and financial resources required for activities in the space field is such that these resources lie beyond the means of any single European country,…..'*
- It then establishes an international cooperative framework to resolve the problem.

- The same approach is needed for Climate Change. It can't be solved by individual nations or governments. But there is no focus at the present time, there is no ESA for nuclear power generation.

Development cost economics

- Small Modular Reactors (SMR) have the potential to be part of the solution.
- Share the development cost to bring the right design to the global market.
- Share the knowledge, upskill the partners, appreciate the capabilities.



Learning curve theory

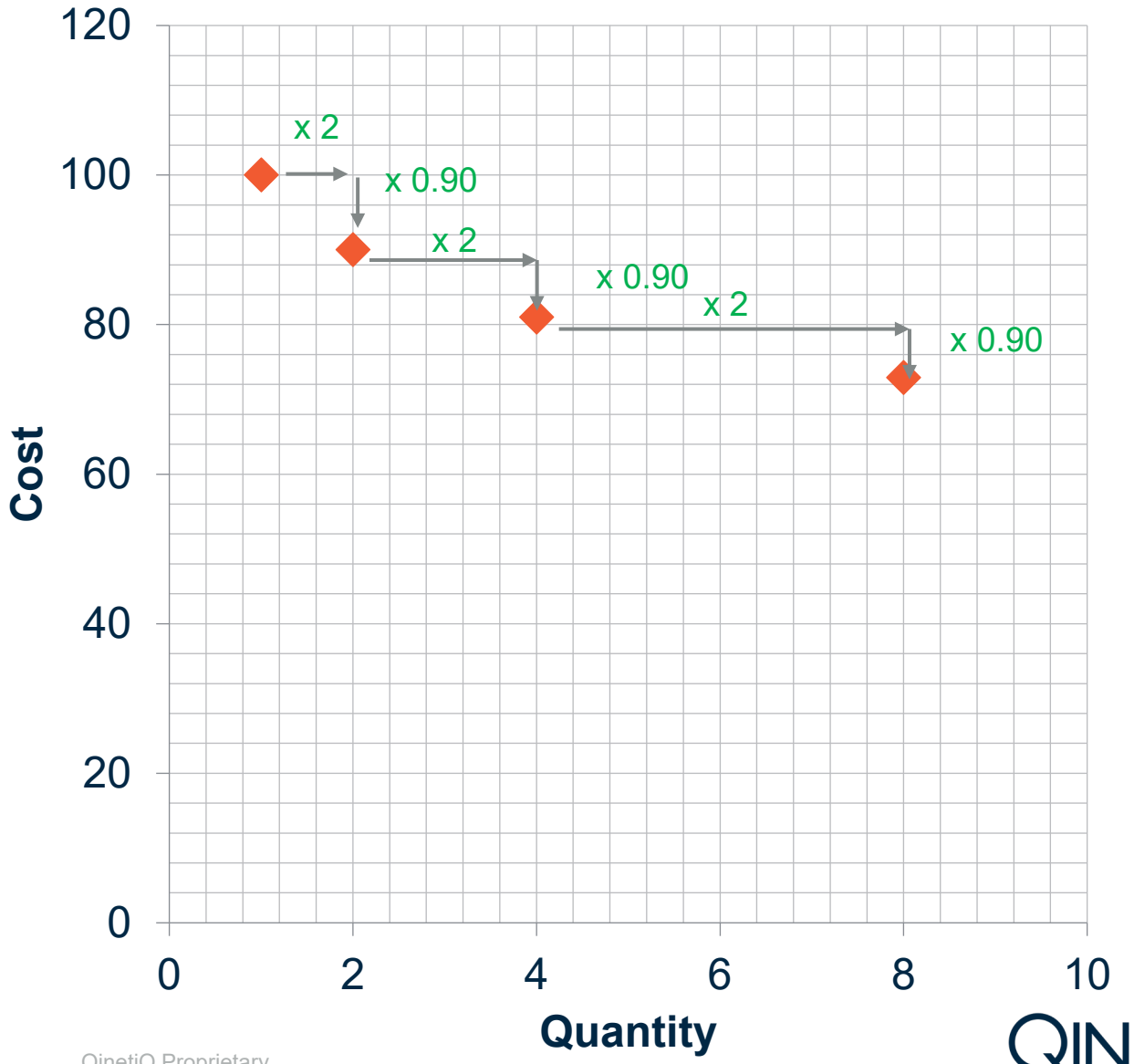
Global total demand is only 170 production units. Hardly mass production!

But this is highly skilled, high quality, valuable manufacturing

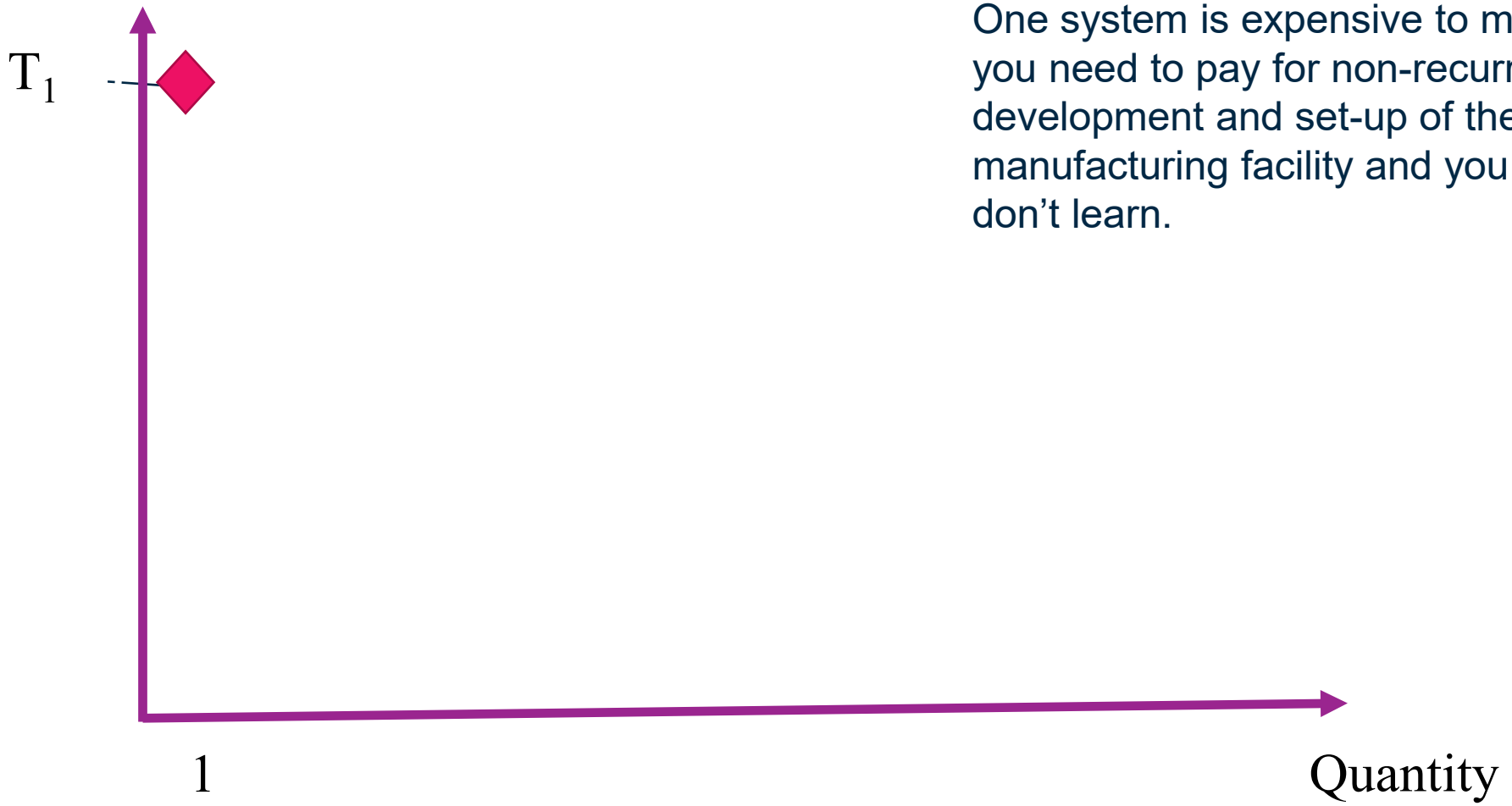
Manufacturing learning curve theory:

'As the quantity doubles the effort reduces by a constant factor'

For example, a learning factor of 90%

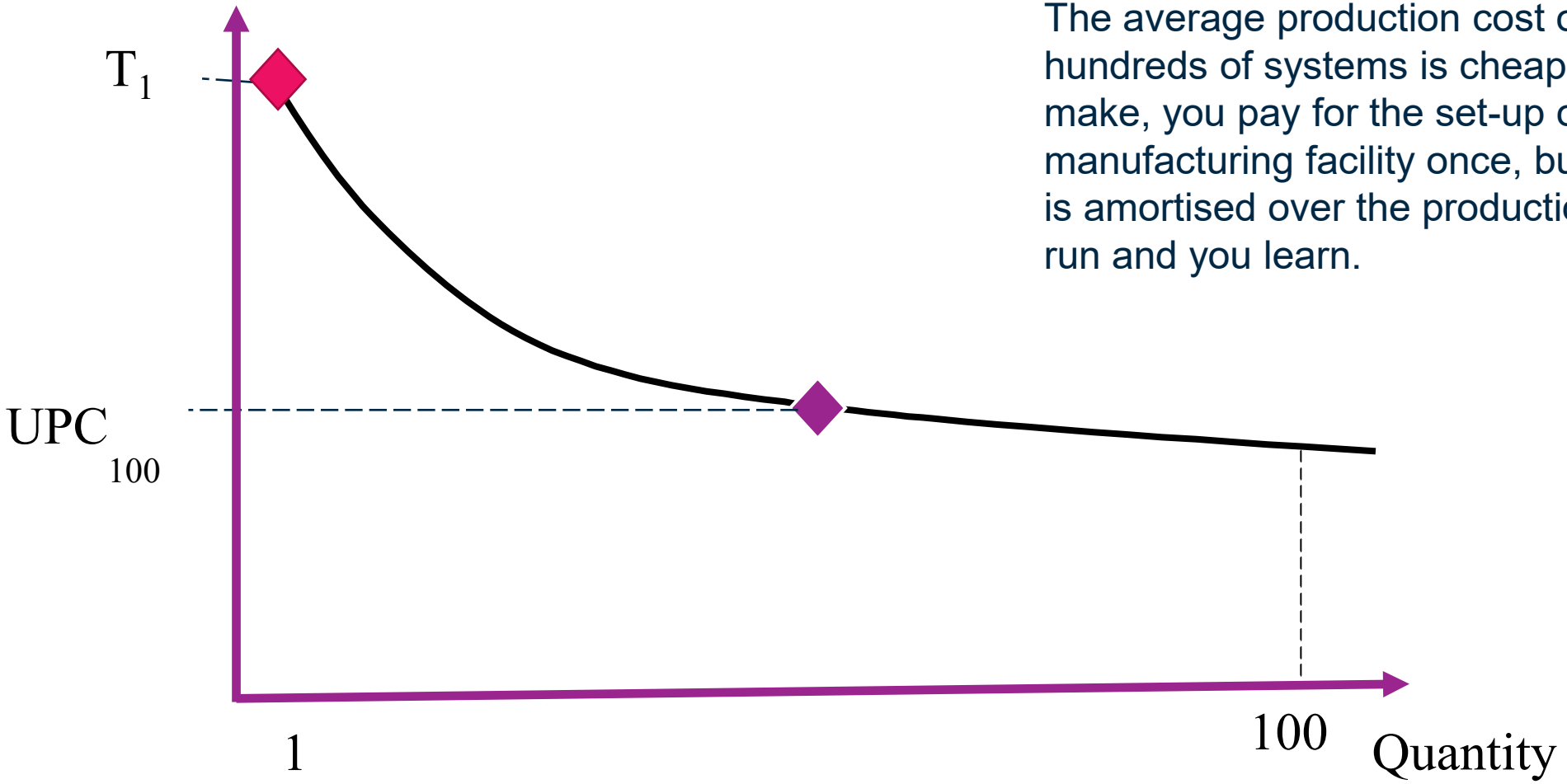


Production cost economics



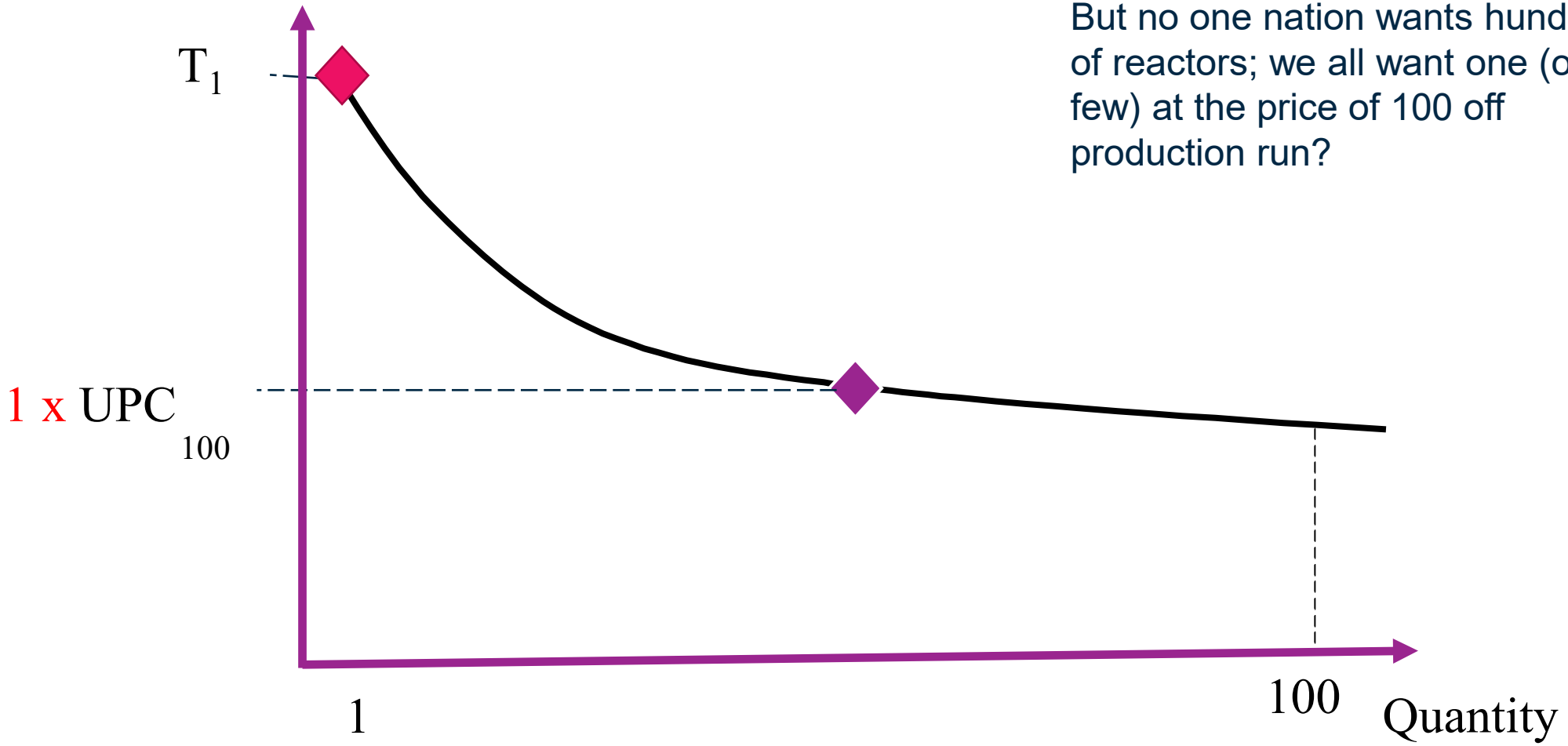
One system is expensive to make, you need to pay for non-recurring development and set-up of the manufacturing facility and you don't learn.

Production cost economics



The average production cost of hundreds of systems is cheaper to make, you pay for the set-up of the manufacturing facility once, but it is amortised over the production run and you learn.

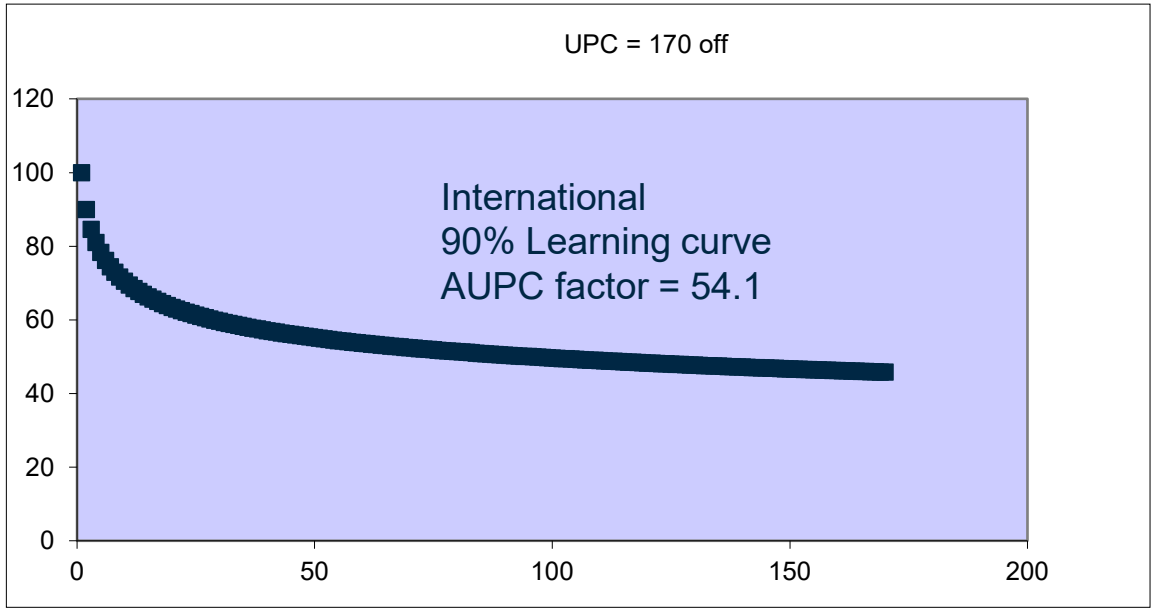
Production cost economics

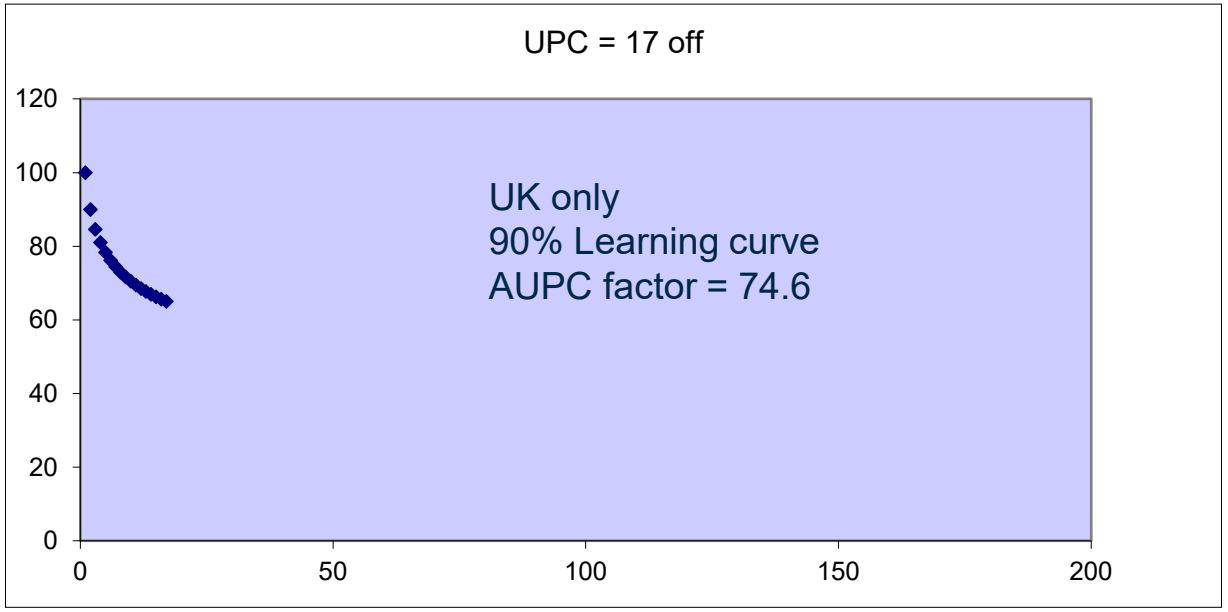


But no one nation wants hundreds of reactors; we all want one (or a few) at the price of 100 off production run?

Production cost economics

- Small Modular Reactors (SMR) have the potential to be part of the solution.
- However, each nation is focused on the technical details and the optimum design through their industrial base.
- Their presumption is that the optimum design will result in international sales and huge orders.
- If the same design is mass produced the saving will be (74.6 – 54.1) / 74.6 x 100 = 27%

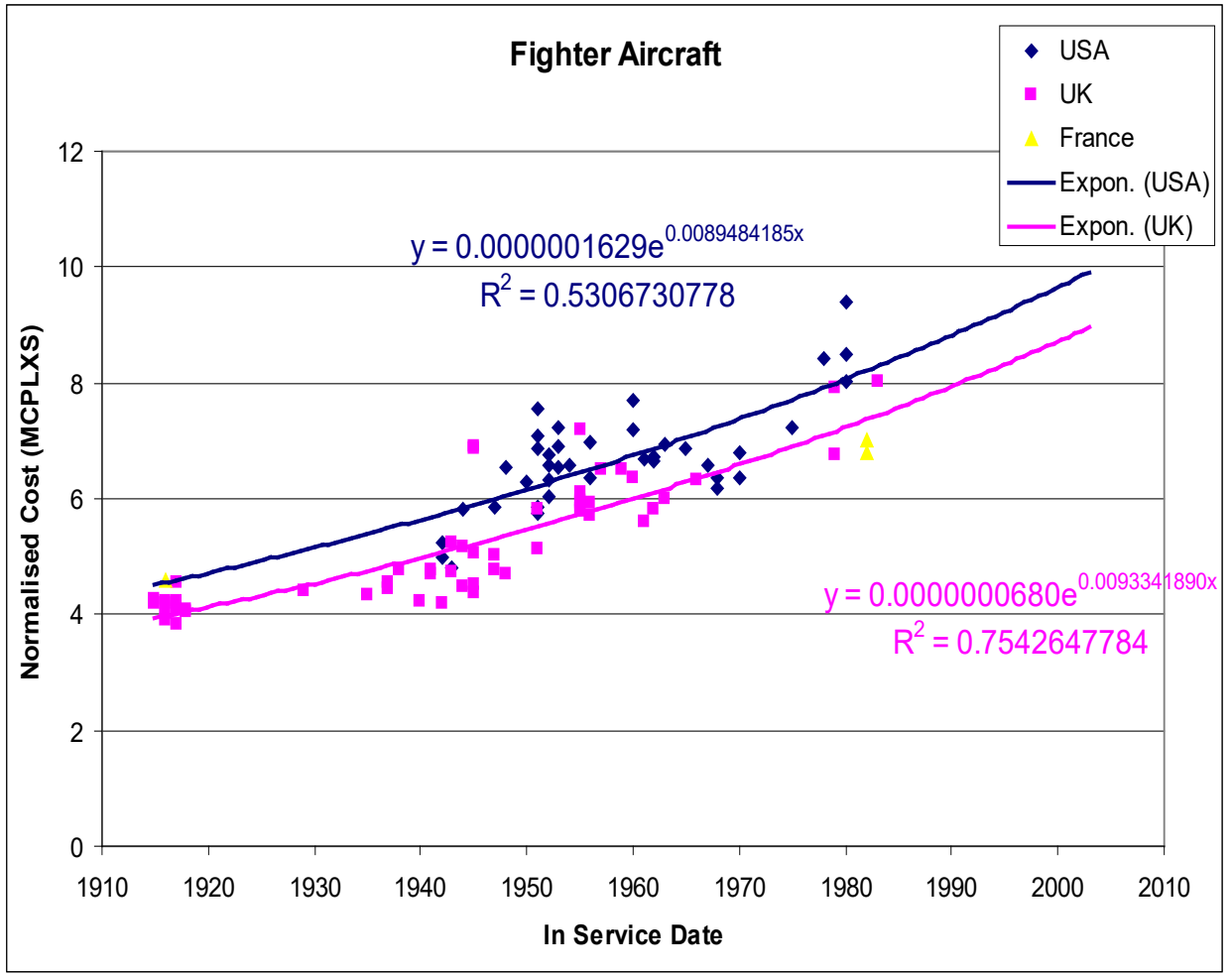




Proposal: the Joint small modular reactor (JSMR)

The F-35 story

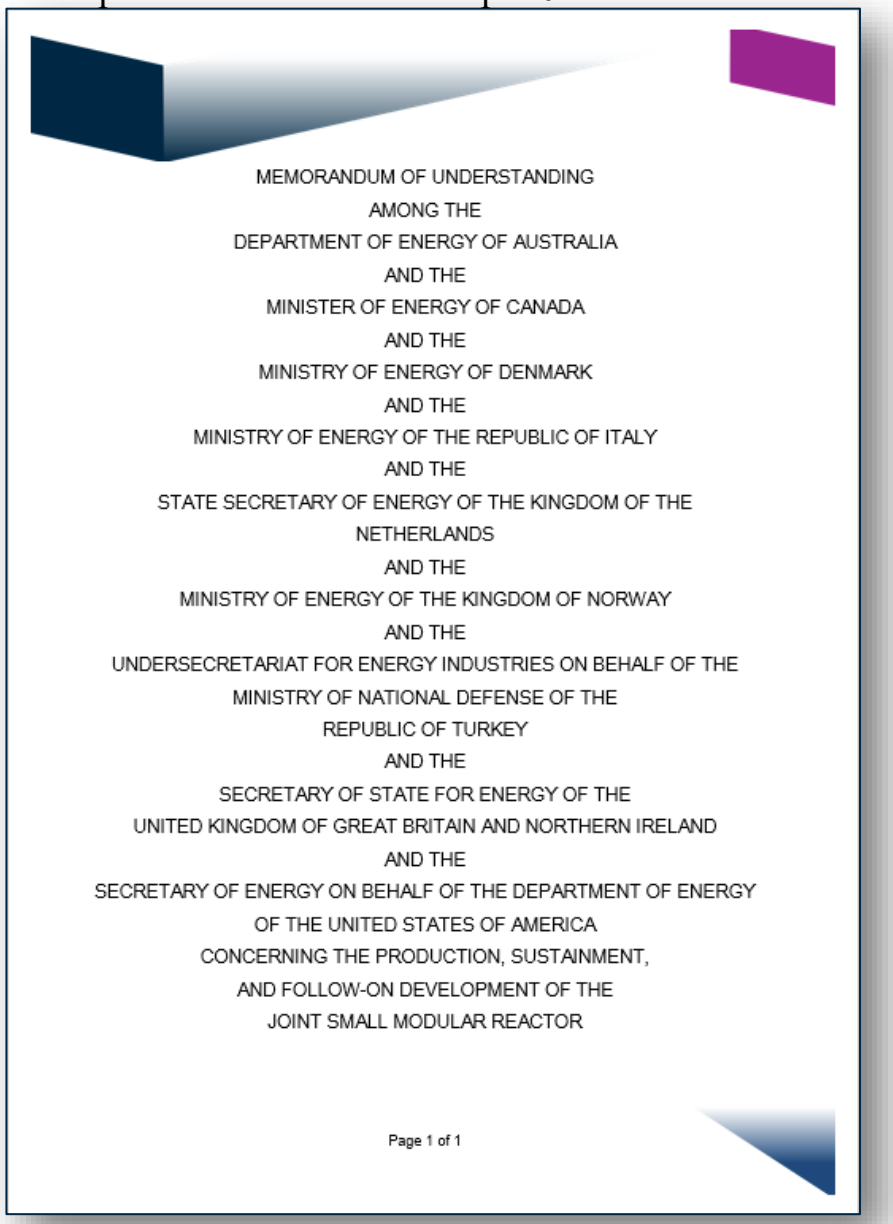
- The Joint Strike Fighter (JSF) or F-35 is the largest ($1,502.8 Bn) defence contract in the world.
- Core to this acquisition philosophy is; all government partner nations commit to the purchase of a number of aircraft and in return, those nations industries receive orders to mass produce components or assemblies of the aircraft for final assembly in America and delivered globally.
- The Average Normalised cost density for Fighter aircraft in 2000 in USA was 9.647 while UK was 8.711
- The USA had a Normalised cost density of 8.711 for Fighter aircraft in middle of 1988.
- Through the JSF programme the UK jumped 11.5 years of technology gap (stealth, material, etc.) regarding Fighter Aircraft
- The application of the same JSF procurement approach to SMRs would accelerate the development and production of SMRs to both nuclear and non-nuclear nations.



JSMR Programme Management Office (PMO)

The Programme Management Office:

- Governments controlled with Industry advisors
- Physical presence in the JSMR PMO
- Colocation of Prime contractor and lead systems integrator (LSI)
- Planning and oversight of all Nuclear regulation negotiations
- Planning and oversight of all infrastructure
- Technical oversight and assurance
- Single integration facility of international supply chain

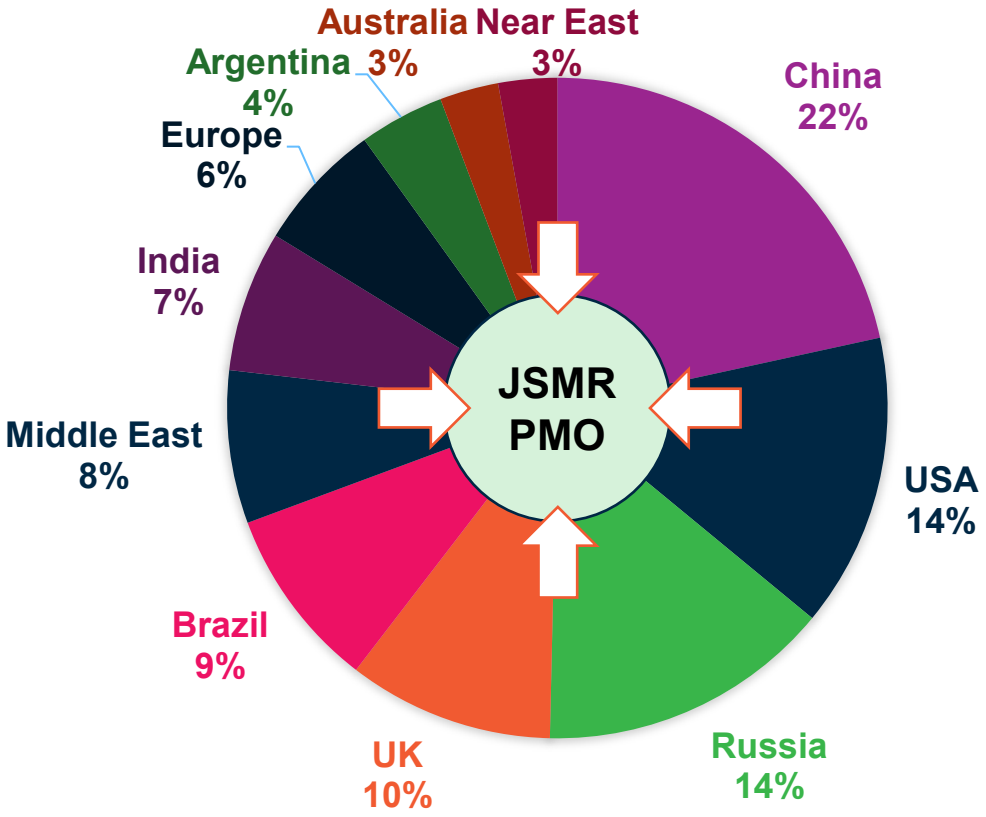


MEMORANDUM OF UNDERSTANDING
AMONG THE
DEPARTMENT OF ENERGY OF AUSTRALIA
AND THE
MINISTER OF ENERGY OF CANADA
AND THE
MINISTRY OF ENERGY OF DENMARK
AND THE
MINISTRY OF ENERGY OF THE REPUBLIC OF ITALY
AND THE
STATE SECRETARY OF ENERGY OF THE KINGDOM OF THE NETHERLANDS
AND THE
MINISTRY OF ENERGY OF THE KINGDOM OF NORWAY
AND THE
UNDERSECRETARIAT FOR ENERGY INDUSTRIES ON BEHALF OF THE MINISTRY OF NATIONAL DEFENSE OF THE REPUBLIC OF TURKEY
AND THE
SECRETARY OF STATE FOR ENERGY OF THE UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
AND THE
SECRETARY OF ENERGY ON BEHALF OF THE DEPARTMENT OF ENERGY OF THE UNITED STATES OF AMERICA
CONCERNING THE PRODUCTION, SUSTAINMENT, AND FOLLOW-ON DEVELOPMENT OF THE JOINT SMALL MODULAR REACTOR

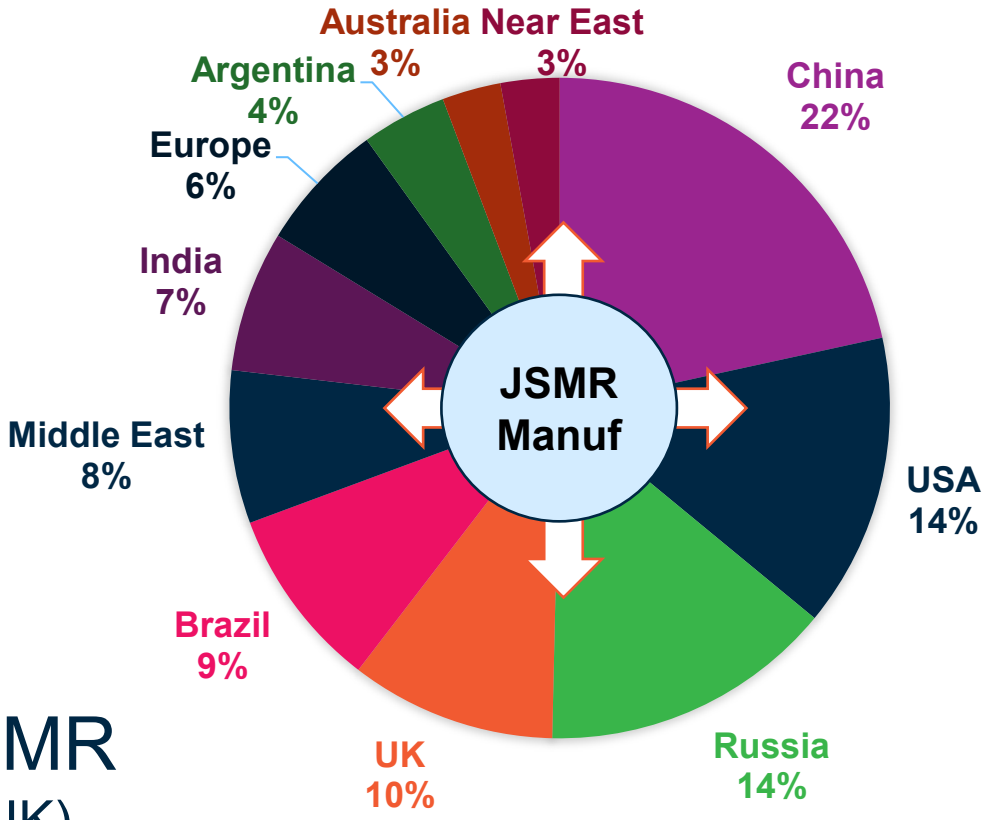
Page 1 of 1

National Joint SMR strategy

INPUT – Number of SMR commitment and funding flow to PMO



OUTPUT - Workshare and SMR deliveries flow to partners



170+ SMR
(17 for UK)

Solution

1. Joint SMR (JSMR) programme established by partner governments
2. International governments sign a JSMR MOU with commitment to:
   - Number of SMR required
   - Funding
   - Workshare agreement

The F-35 story

3. PMO instigate international competition to design SMR fully compliant with JSMR needs:
   - Capable of mass production with internationally supply chain;
   - Compatible with international workshare;
   - Commitment to mass production and average price;
   - Compatible with JSMR nuclear regulations;
   - Disposal 'as a battery'

4. Down selection to two designs to be built as prototypes to demonstrate capability and industrial strategy; winner takes all!

5. Down selection of winning design; partner governments lead international partner nations to fund full scale production

6. Delivery of cheap SMRs to international partner nations. Work share for all nations proportional to the value of the JSMR required.

Joint SMR initiative – SWOT – Strengths, Weaknesses, Opportunities and Threats

	Helpful	Harmful
Internal focus	Strengths: • Cheaper production due to economies of scale • CO_2 initiative; quell extinction rebellion • Cheaper baseload electricity	Weaknesses: • Increased Nuclear waste • Winning design only assembles reactors; no manufacture of the whole reactor
External focus	Opportunities: • Solve world energy problem • All signatories receive workshare • Tackles greenhouse gas problem • IAEA led international Green initiative	Threats: • Another country (not IAEA) proposes JSMR concept • Low-end nuclear technology knowledge shared with non-nuclear nations

Summary

- IAEA recognised globally as the solutions architect for the JSMR initiative
- International collaboration through Project Management Office (PMO) and IAEA leadership of global supply chain with workshare in established and emerging nuclear partners
- Factory built, mass production of small modular reactors to benefits from economies of scale
- Small modular reactors delivered 25% cheaper than independent national production.
- CO_2 initiative to actively reduce greenhouse gas emissions
- Harmonised international regulations
- Nations with an aspiration to join this JSMR programme and become nuclear nations through a lower investment route; would wish to join the programme.

Any questions?

QINETIQ

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