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

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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 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 achieve these two opposing requirements.

Keywords: Climate, Small Modular Reactors, Collaboration.

Introduction

This paper will consider how factory built, low cost, mass produced nuclear reactors are achievable, not by focusing on the technology, but the acquisition process. The global climate crisis is the biggest challenge mankind has faced and we are only going to solve part of the problem by working together in an international consortium of nations that are engaged in nuclear power generation.

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 achieve these two opposing requirements. This paper will propose the problem and some of the solution.

QinetiQ was formed in July 2001, when the UK Ministry of Defence (MOD) split its Defence Evaluation and Research Agency (DERA) in two. The smaller portion of DERA was rebranded Dstl (Defence Science & Technology Laboratory) and this remains part of the MOD. The larger part of DERA, including most of the non-nuclear testing and evaluation establishments, was renamed QinetiQ and prepared for privatisation. QinetiQ became a public private partnership in 2002 [1.].

The Problem

QinetiQ was invited [2.] to attend an International Atomic Energy Agency (IAEA) cost workshop in 2019 in Idaho, USA. The IAEA was keen to improve the attendee's appreciation of cost and schedule analysis at the early stages of a project, when its design was under development, and the information was limited. The IAEA was formed in July 1957, has its headquarters in Vienna, Austria and has the objective to accelerate and enlarge the contribution of atomic energy for peaceful purposes in such a way as not to further any military purpose.

The workshop was attended mainly by representatives of the member states of the IAEA and experts from international and non-governments organisations. QinetiQ presented two papers and contributed to a good exchange of ideas and knowledge:

1. Considering the cost of vulnerability in Critical National Infrastructure (CNI)
2. Parametric cost modelling at the early stage of projects

Contrary to expectations, the workshop had little focus on nuclear waste, but the destruction of the planet due to global warming caused by the burning of fossil fuels resulting in carbon dioxide (CO_2) and greenhouse gas emissions. The nuclear industry is a low carbon solution to our energy needs.

Climate change requires global governments to reduce greenhouse gases. However, with an increasing demand for electricity [3.] there is a demand for more power stations, see Figure 1. Both developed and developing nations have an increasing demand from a growing population for access to low cost electricity.

Renewable energy sources are unreliable as a source of baseload electricity. Nuclear power provides a solution which produces zero-greenhouse gas.

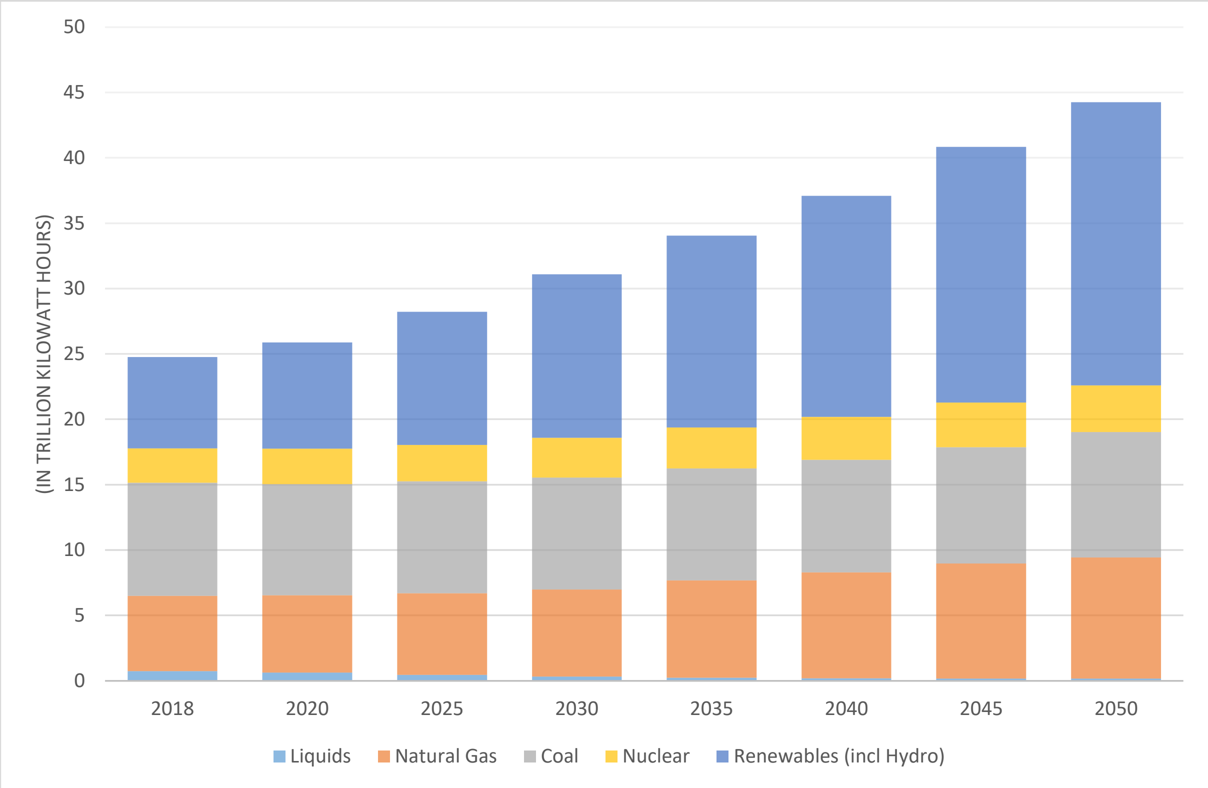

Figure 1: Projected electricity generation worldwide by energy source

Our planet Earth has been orbiting the Sun at an average distance of 93 million miles for approximately 4.5 billion years. The Earth is roughly spherical is shape with a diameter of approximately 8,000 miles. It is a unique planet that has an atmosphere that sustains plants, animals and humankind. This atmosphere is a relatively thin sheet of air extending from the surface of the Earth to the edge of space; only about 60 miles in thickness. The average temperature of the earth is 15°C, the perfect temperature for the balance of life.

This delicate ecosystem currently sustains all life on the planet including a human population of 7.7 billion in 2020. However, as we burn fossil fuel we create CO_2 and this has a correlation with the temperature of the Earth rising and more unpredictable weather.

Climate change activists seek to 'save the planet', but Mother Nature will ensure that the planet is okay. The planet Earth will be orbiting around the Sun in another 4.5 billion years, but it maybe uninhabited due to the climate changes that we have created. The problem is not saving the planet, its saving humankind. The future population of the Earth could be 0.0 billion.

Governments are increasingly sensitive to activists and their disruption to society. 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. The technology is held in secrecy and the entry cost is very high leaving only a few nuclear nations. There are a number of developing nations seeking to enter the nuclear age and seek understanding of the peaceful application of nuclear energy.

At the IAEA workshop the problem could be summarised as shown in Figure 2

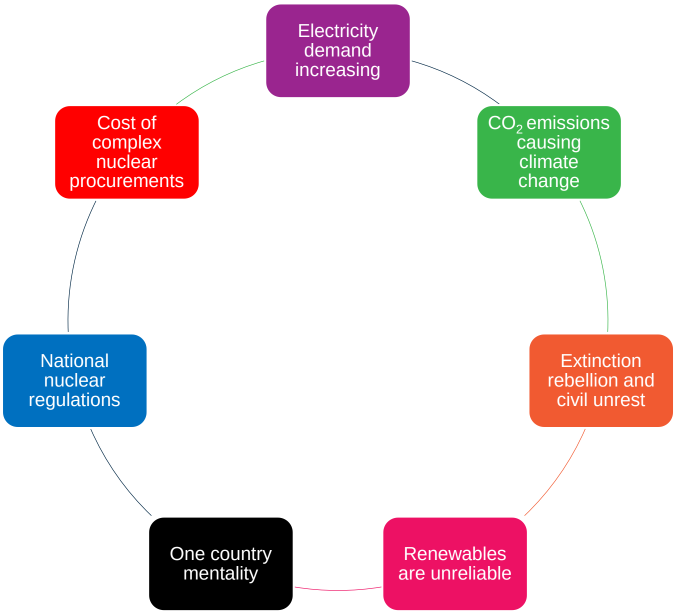

Figure 2: the problem

As an independent observer of the IAEA workshop there were some common themes which are captured above. there was really stalemate, trying to make any progress as 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 commercial nuclear reactors are big projects. For example, Hinkley Point C nuclear power station is a project to construct a 3,200 MW nuclear power station with two EPR 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. The construction cost is estimated at completion to be £22 billion to £23 billion [4.]. Its construction began on 11 December 2018 and will take 8 years to complete. Hinkley Point C will be the first in a new generation of nuclear power stations in the UK capable of generating 3,200MW of secure, low carbon electricity for 60 years.

By contrast, 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.

They are designed to be manufactured at a plant and transported to a site to be installed. These modular reactors will reduce on-site construction and claim to enhance safety due to 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 [5.].

The term SMR refers to the size, capacity and modular construction only, not to the reactor type and the nuclear process which is applied. Designs range from scaled down versions of existing designs to new designs.

One hindrance to their commercial use may be licensing. SMR licensing regulation regimes are adapted to conventional designs, but SMRs differ in terms of staffing, security and deployment time. Another concern with SMRs is preventing nuclear proliferation.

At the IAEA workshop there were also a considerable number of non-nuclear nations with aspiration of joining the nuclear community, but the entry barriers associated with conventional commercial nuclear reactors are high in terms of investment and regulations.

At this IAEA workshop a number of government representatives presented their demand for energy, their power generation mix and their national initiatives for the development of SMR, see Figure 3.

Figure 3: Examples of international SMR designs

These presentations all focused upon their own national requirements for SMR with aspirations for international sales to increase the production numbers and reduce their acquisition cost.

The global SMR market is estimated to be more than 170 units which has a lucrative market value of £250Bn to £400Bn (or $340Bn to $540Bn) by 2035 [6.]. This market is evenly spread around the globe and includes both countries with a developed nuclear industry and those without any nuclear experience, see Figure 4.

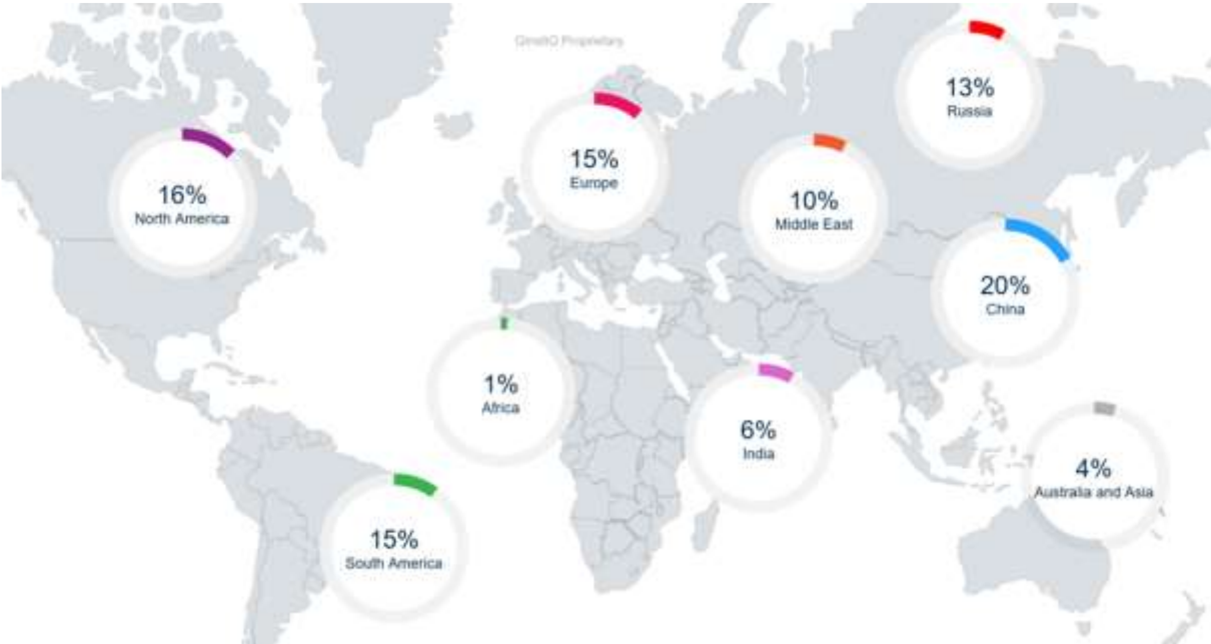

Figure 4: Global SMR market

The development of SMR makes a good case regarding the issue of nuclear waste disposal; as this is more manageable as well. In the case of a SMR their disposal is analogous to the disposal of a battery.

The solution

IAEA is an independent organisation that could bring together the governments of the world for the development of a joint SMR. The development cost of reactors is significant and the entry cost of this industry is out of reach of many nations. But this has been an issue for other human endeavours, for example the space race and defence. In these cases the nations have joined together to spread the non-recurring development costs.

In Europe, the desire to fund space activities was met through the establishment of the European Space Agency or ESA. The convention for the establishment of 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 continues to establish an international cooperative framework to solve the problem. The cost principles that govern this approach are the amortisation of the increased complexity involved in multiple countries working together then being divided by the number of contributing nations. As shown in Figure 5, the addition of nations to the development project is likely to increase the total cost due to different time zones, cultures, languages all adding to the complexity of the project management and communications.

This is offset by the ability to divide this enhanced cost equally by the number of contributing nations. Providing the cost to the individual nation is less than the cost required to conduct the development work alone, the economics are worthy of investment.

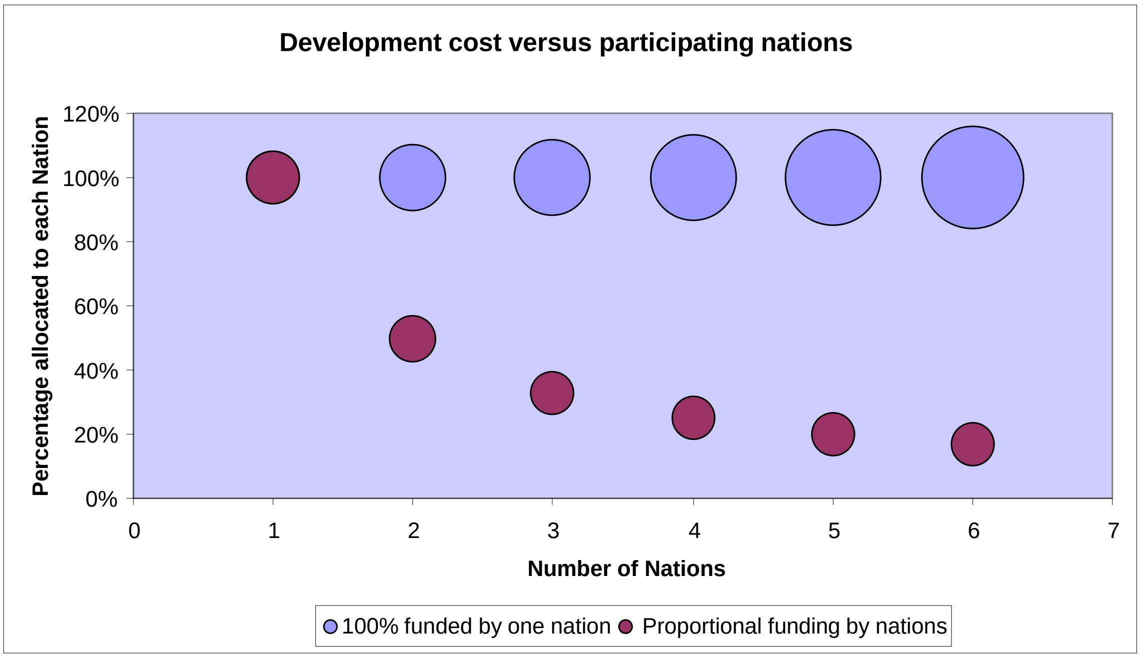

Figure 5: International Collaboration - sharing the development cost

The same approach is needed for Climate Change, this phenomena was created by multiple industrial nations. It can't be solved by individual nations or government's. However, there is no multinational focus at the present time; there is no equivalent to ESA.

When considering the recurring production cost, then economies of scale are achieved through large scale production, rather than multiple countries. The problem with breaking the production units into small batches is the lack of learning. It needs large numbers of production units to make the investment in tooling and robots worthwhile. Large production runs can be achieved through commonality of parts. What does it achieve?

Learning curve theory states [7.] that, providing the design does not change, there is no break in the manufacturing, no changes to the manufacturing process, no breaks in production and the labour force is consistent:

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

For example, applying a learning factor of 90%, the impact is shown in the diagram in Figure 6. The production cost is reduced quickly, but the impact decays, such that the cost is not zero.

This effect can be achieved, not by each country manufacturing its own design as this would result in multiple small batches and never realising the full learning effect. But by each nation manufacturing all of one particular assembly or part of one design. Each country's workshare would be equal to the production cost of the SMRs that the nation required.

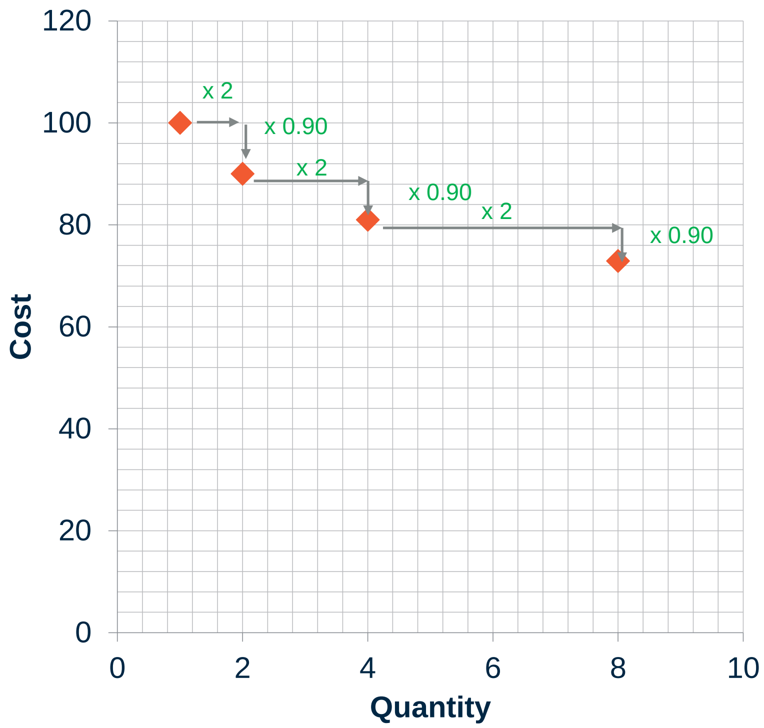

Figure 6: Learning curve theory

This would mean that one nation would be responsible for all of the pipes, while another nation would produce all of the pressure vessels, another the control room and so forth. As a result nations would specialise in particular manufacturing and invest in those skills, for example, electronics, construction, machining, fabrication and so forth.

This means that even the non-nuclear nations could be given highly skilled, high quality valuable manufacturing work, without the need for nuclear proliferation.

Regardless of the design and the cleverness of the SMR solution this effect will always provide a further cost reduction. Setting the cost of the first SMR to an index of 100 it is possible to see the effect of learning in Figure 7.

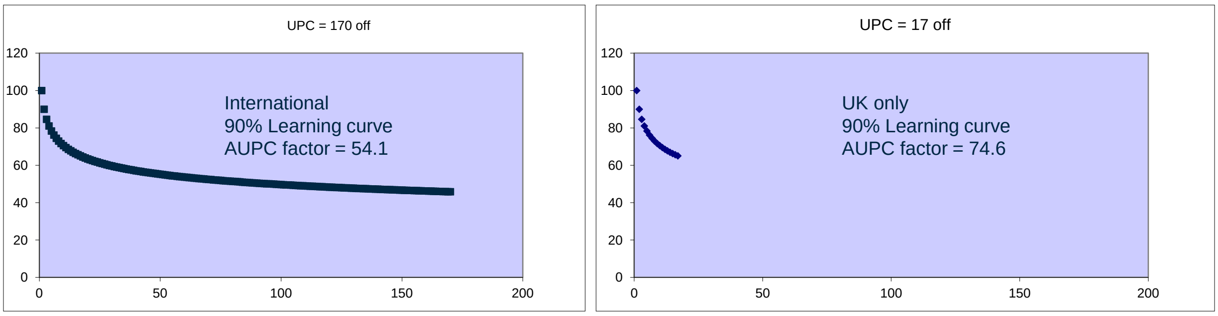

Figure 7: SMR large volume production – the implications of scale

The outcome for the UK, which only requires about 17 SMRs, would result in an average index value of 74.6. However, if the same design is manufactured in large volumes that index is reduced to 54.1. This represents a saving of more than 25% which results from all the parts being manufactured at the same time. If commonality of parts in the design is achieved, such that 170 off becomes 340 off or more then the opportunities to invest in automated, robotic production would influence the savings even further.

The conventional commercial nuclear reactor is experiencing a negative learning curve [9.]. These giant construction sites are increasing in cost. Electrical Power Generation has a typical learning curve of 95%, while aircraft assembly can achieve 80% and nuclear submarines 85% [7.]. The target for the SMR would be 90% or greater.

In addition to electricity these SMRs generate a significant quantity of heat. In the case of conventional nuclear reactors this heat is generally wasted as its not convenient. However, in the case of SMRs their abundance, potentially 17 in the United Kingdom, would lend them to be located nearer to urban areas where the heat energy could also be used for domestic or commercial heating of homes or buildings. Alternatively, the heat could be used for industrial applications such as chemical plants or the generation of Hydrogen. This heat by-product increases the economic case for SMRs.

Proposal: the joint small modular reactor (JSMR) project

The Joint Strike Fighter (JSF) or F-35 is the largest ($1,502.8 Bn) defence contract in the world. This programme has strengthened the USA position regarding design and manufacture of fighter aircraft and reduced the competitive threat amongst its partners. 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.

This acquisition approach also gave nations access to new technology. In a study considering the trend in fighter aircraft technology [8.], the normalised cost density in Figure 8 was produced. This demonstrated a trend of technology improvement for fighter aircraft types over a period of years.

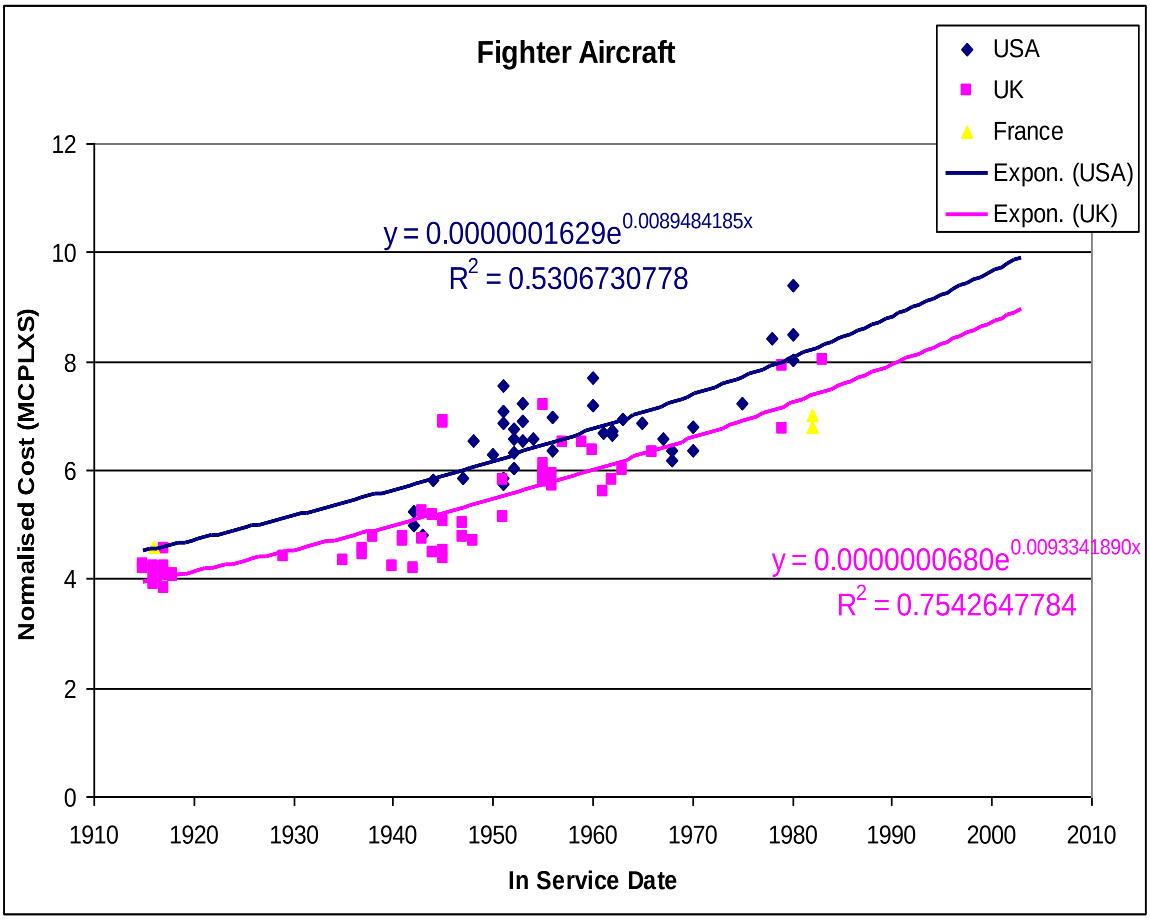

Figure 8: the F-35 story - how the UK jumped the technology gap

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, 11.5 years earlier. Through the JSF programme the UK jumped 11.5 years of technology gap (stealth, material, etc.) 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 while avoiding nuclear proliferation by selecting which component and assemblies of the SMR are produced in different countries; nuclear element need only be produced in nuclear nations.

There is a unique opportunity for the IAEA to become the focal point for SMR provision to global partner nations. Using a memorandum of understanding (MOU) between governments, the IAEA would publish a JSMR roadmap and lead a joint project management office (JPMO) with multi-national representatives. The JPMO would hold an international government to government conference to formalise a more detailed MOU and for signatories to commit to acquiring a number of SMRs for their nation, potentially aligned to Figure 9. The conference would need to agree an international regulatory framework for a single SMR design to be accepted.

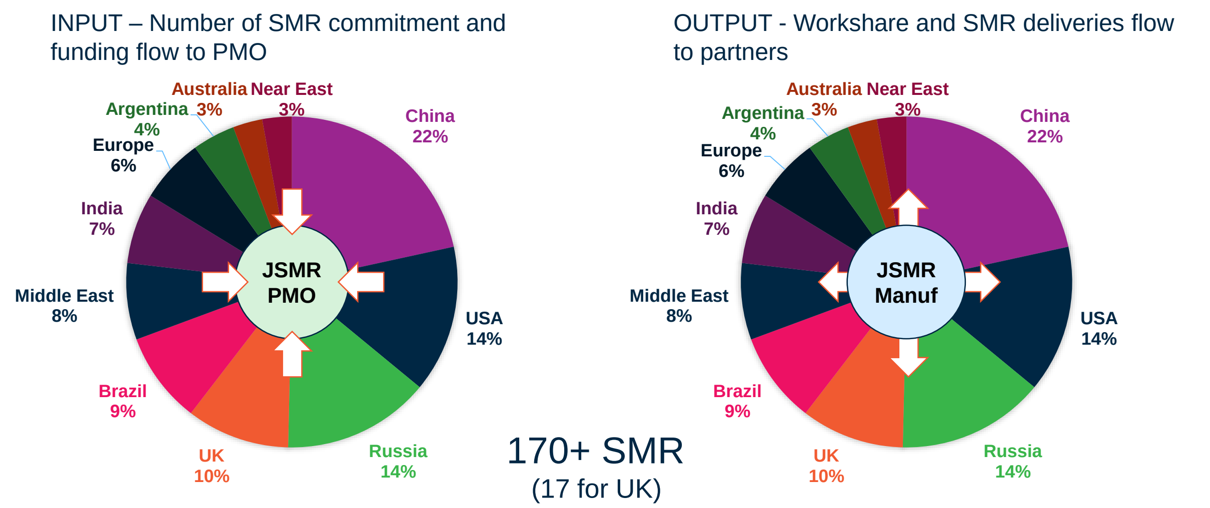

Figure 9: Input and output - the funding commitment and resulting workshare for nations

The JPMO would hold a design, develop and prototype (DDP) competition between partner nations industries where the winner takes all. This design would need to demonstrate regulatory compliance, the SMR full life cycle, low cost through mass production techniques and its ability to be manufactured through a global supply chain.

The winner of the DDP competition would be awarded a production contract to source international elements of their SMR design from the MOU partner nations, assemble, commission and deliver all of the SMRs globally. Their low cost would reflect the mandated mass production of SMRs. Figure 10 provides a diagrammatic representation of the SMR designs being filtered to establish the optimum JSMR design, leading to the international sourcing of the production units.

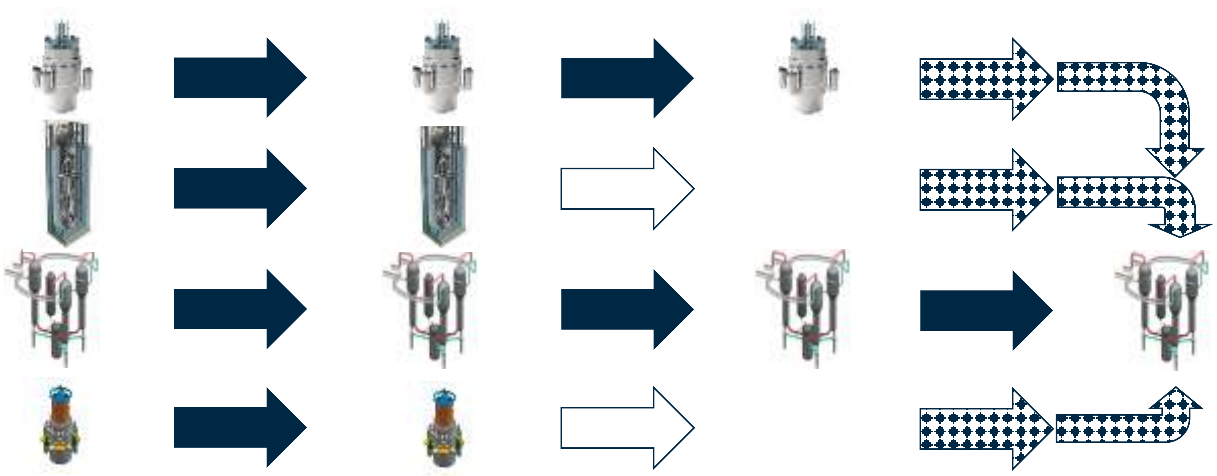

Figure 10: Completion - the F-35 procurement process in action

It is acknowledged that this paper is advocating the generation of more nuclear waste which future generations will need to deal with. But this is being traded against reducing the production of greenhouse gases. Without a radical solution, such as the JSMR project, we will not need to worry about nuclear waste disposal as the rising temperature of the earth with result in an unsustainable atmosphere for life and mankind.

Summary

The benefits of JSMR to participating governments would be:

1. The participating governments would provide the source of SMRs globally.
2. The participating governments would be recognised as a significant contributor to the issue of climate change and reduction of greenhouse gases, not just nationally, but globally.
3. The production of a single SMR design delivered 25% cheaper than independent national production.
4. Participating governments industries would benefit from being at the centre of this global initiative; the winning business would be the lead system integrator (LSI).
5. Nations with an aspiration to join this JSMR programme and become nuclear nations through a lower investment route; would wish to join the programme.

The benefit of JSMR to IAEA:

1. IAEA is completely independent with no stake in SMR development, manufacture or operations. IAEA would be recognised as the architect of this multi-billion dollar programme.
2. IAEA would seek to be the partner nations advisor to the JSMR programme. IAEA would be in a strong position to advise the global partner governments.
3. IAEA would be the independent mediator to the partner nations and steer the discussions regarding the MOU.
4. Ideally, IAEA would provide a significant number of staff for the partner nations in the JSMO at senior levels.

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