Points about Hinkley Point C (HPC)

Assurance of food and energy supplies must be basic concerns for governments of any hue. The fear of loss of public confidence (votes) were the 'lights to go out' has increasingly beset UK governments over at least the last decade.

In August 2003, a persisting oil leak in a poorly maintained transformer in Wimbledon blacked out 500,000 people in South London and Kent for up to two hours. In May 2008 an unfortunate co-incidence of two separate failures within a minute of each other – one at the Longannet coal-fired plant on the Firth of Forth and the other at Sizewell B nuclear power plant in Suffolk which did not involve the nuclear reactor – affected 500,000 people scattered between London and the North of England: the sudden loss of power over-strained the national grid which normally can transport power from one end of the country to another.

The power companies have since worked hard as – barring natural incidents such as floods – there have been no further incidents on such a scale. However, concerns remain about the size and nature of the national grid which in August 2016 was described by the *Energy and Climate Intelligence Unit* (ECIU) as '*old centralised and inflexible kit approaching retirement*'[1]: but due to de-industrialisation and improved efficiency, the UK's electricity demand fell by 13% between 2005 and 2014, so since 2005 the grid has not been so stretched. Nevertheless in June 2013 Ofgem warned that the UK's energy sector faces "unprecedented challenges"[2] and that "*spare electricity power production capacity could fall to 2% by 2015, increasing the risk of blackouts*". To counter this risk, the National Grid has arranged for extra demands to be met by a 'Supplemental Balancing Reserve (SBR)' of about 2 GW capacity (see GW definition below) which provides contracts to electricity generating companies when they commit to making available a power station which would otherwise have been closed or mothballed.[3]

Power plant electricity 'capacity', usually quoted in 'GigaWatts' (GW – 10^9 watts), is the amount of power capable of being produced at any one moment. Supply over a period of time is expressed as TeraWatt hours (TWh or watt-hours $\times 10^{12}$). An electricity generating plant operating at 1 GW throughout the year could in theory generate 8.766 TWh (8,766 GWh) in that year (there are 8,766 hours in a year); but no plants work flat out all the time. Current Nuclear Power Plants (NPPs) do well to work at 85% capacity.

Throughout 2014 electricity demand in the UK was 335 TWh (335,000 GWh), up from 300 TWh in 1990 which was met by a very different mix of sectors as shown in Table 1. In 1990, the only form of renewable energy was hydro-electricity which provided 2.6% of the demand. Coal dominated, while electricity generation from gas was only just beginning. The nuclear contribution seems to have changed but little, but in 1990 was wholly dependent its already ageing 'Magnox' reactors – a British design which never took on elsewhere as it was inferior to the US pressurised water reactors (PWR) (this is the main reason why the UK lost its early lead in lead in nuclear power technology). All the Magnox reactors will be decommissioned by the 2020's, leaving the UK with just one nuclear reactor, the 1.25GW capacity PWR reactor at Sizewell B, commissioned in 1995 and hoped to last until 2055. Since 1990, coal in the UK has largely been replaced by gas and renewables and carbon emissions are now much lower. Most coal is now imported: within a decade or two it should largely be confined to smelting plants and not partake in any electricity generation

Table 1. Fuel sources for UK electricity generating power plants (PP) in 1990 and 2014

	% in 1990 (total 300 TWh)	% in 2014 (total 335 TWh)
Coal	66.4	29.1
Gas	0.05	30.2
Nuclear	19	19
Oil and other	12	2.5
Renewables	2.6	19.2
Wind	0	9.4
Bio-energy	0	6.8
hydro	2.6	1.8
Solar	0	1.2

Based on DECC (Digest of United Kingdom Energy Statistics) 2015 [4]: and UK electricity generation statistics 1920 – 2012 [5]

Had the demand of 335TWh been required evenly throughout 2014 it could have been met by a capacity of 38.2 GW: but in order to meet the widely fluctuating hourly, daily, monthly and seasonal demands, the total generating capacity had to be almost double, at about 72GW. The national grid can only meet such fluctuations if a continuous 'baseload' supply is guaranteed. Somewhat notoriously and unfairly, renewable sources are frequently criticised through their innate variability (the sun isn't always shining and the wind isn't always blowing) so are falsely said to be incapable of providing the baseload which fossil and nuclear-fired PPs can 'guarantee' whatever the weather – a characteristic much vaunted by the nuclear industry. Carbogenic fossil fuel-driven turbines (the electricity-generation of which – be it noted – is only 33% efficient) can easily be boosted or turned down by varying the fuel supply; but in nuclear reactors (which have about one-fifth the carbogenicity of gas[6]) the fuel is always reacting and heat is still generated even if the connection to the turbines (which are also only 33% efficient) is turned off. So to maintain efficiency, a virtue is made of necessity and NPPs are used to generate electricity 'continuously', thus guaranteeing a baseload if all else fail. However, in practice NPP's are inevitably closed down during maintenance and re-fuelling, and can have unplanned outages; so do well if they run 85% of the time, although EDF predict 90% for HPC (which of course is yet untried).

Richard Black, of the not intrinsically anti-nuclear *Energy and Climate Intelligence Un*it wrote on 22 August 2016[7] "*Although there is an additional cost for balancing variable-output wind and solar, the four ways of doing it – demand-side response, interconnection (with overseas generation), storage, and peaking gas-fired generation – are all either achievable right now or developing swiftly.*" So further nuclear developments such as HPC are not needed to maintain baseload. The storage systems envisaged by Black include pumped hydroelectricity, in which hydroelectricity (or any other form of electricity) generated at times of low demand is pumped back uphill, at 70 to 80% efficiency, to be re-released when needed; and '*peaking generation*' from a relatively small number of gas-powered plants fired when needed (see also ref 1). Others argue that supplies can still be secure in the absence of any fossil or nuclear power– this issue is addressed later.

In the meantime, we may note that it is remarkable how overall supplies have been maintained while the output from UK NPPs has not risen and will decline while HPC gets on line which, even if successful, will not take place for up to ten years

Hinkley Point C (HPC)

In January 2008, Gordon Brown's Business Secretary, John Hutton, told MPs they would give a "safe and affordable" way of securing the UK's future energy supplies while fighting climate change. HPC was chosen as the first site the following October, with further sites possible at Sizewell in Suffolk and Bradwell in Essex (already the sites of NPPs), and yet further developments at Moorside (Cumbria) and Wylfa (Anglesey). HPC, Sizewell and Bradwell would have two EPR (defined below) reactors each of 1.6 GW capacity, while for Moorside and Wylfa opportunities could be taken to explore other advanced designs. The two reactors at HPC would supply 7% of the UK's electricity. In October 2013, Ed Davey, the Lib-Dem minister for DECC in the Coalition, announced that the 'strike price' for HPC, which customers would pay, would be £92.50/MWh, such a high quote being justified as the first nuclear deal which factored in the cost of waste disposal, although there has been no decision on the very thorny problem of how the waste, which will leave a multi-millennia-long legacy, will be disposed – a classic case of 'kicking the can down the road'. There would be slight reductions in the strike price if new EPR reactors at Sizewell and/or Bradwell also came on line; all three plus the current Sizewell B reactor would supply about 25% of the UK's electricity – more than ever before. HPC was expected to come on line in 2023. Construction costs for the two EPR reactors at HPC alone are expected to be at least £18 billion and would be very likely to rise substantially.

The controversial chosen design is that of the EPR, formerly the 'European Pressurised Reactor', a 'third generation design' – i.e. an ultramodern 'first-of-a-kind' – developed by the heavily-debt laden French firm Areva now owned by EDF – Electricité de France – which in turn is 85% owned by the French government. Following take-overs, EDF is now the biggest supplier of electricity in the UK, but remains heavily in debt following the 2008 economic recession.

Significantly advanced features claimed for the EPR include

- four independent emergency cooling systems;
- leak-tight containment around the reactor
- ability to use 5% enriched uranium at 17% greater efficiency than the widely used second generation designed pressurised water reactors favoured by the US (and currently at Sizewell B).
- The EPR design can also use 100% MOX - Mixed Plutonium/Uranium oxide fuel, which would be attractive as a means of consuming some of the UK's excess civilian plutonium kept at Sellafield. There is over 120 tonnes of this, a considerable embarrassment which, however, will scarcely be touched by even 100 EPR reactors.
- The EPR also has an extra container and cooling area if a molten core escapes from the reactor, and a two-layer 2.6 m thick concrete wall designed to withstand '9/11' types of

aeroplane impact.

There are two current EPR builds in Europe – at Finland's Olkiluoto plant (under construction since 2005) and at Flamanville, France (under construction since 2007). The Finnish plant has seen several revisions to its start-up date and is now expected by 2018 at the very earliest. The Flamanville EPR in France is also officially expected to start up in late 2018 but this seems very unlikely. There have been considerable cost over-runs at both sites with significant faults, for example in the concrete setting and the steel reactor container vessels. Two further sites at Taishan in southern China have passed initial 'cold testing' and are expected to become operational early next year, which nevertheless will still be at least two years late. Many critics are highly dubious (to say the least) and in view of the unexpected delay to HPC announced on 28 July 2016 (ironically the same day that EDF announced its final investment decision) and the following anger expressed by China, it will be interesting to see how the Chinese development in particular will be handled – not only by the Chinese but by those who criticise the whole EPR concept. One commentator has said that HPC is 'too big to fail, but too big to succeed' – which neatly summarises the dilemma faced by the Government.

Another controversy surrounding the UK's proposal at HPC is the nature of the subsidy, the legality of which in EU law is being challenged by Austria (which 'Brexit' may therefore side-step). The original 'strike-price' deal was claimed not to be a state subsidy as it will be placed on the customers when they buy the electricity: it will, moreover, apply for decades whatever else happens in the energy market from other sources. Others argue that the question of whether the strike price encompasses a state subsidy or not is a very arcane point open to other interpretation.

But powerful as such legal concerns are, the very scale of the costs when compared with the rapid fall of renewable energy costs provides an even stronger case against pursuing the HPC project.

The World Energy Perspective report and its collaborator Bloomberg New Energy Finance[8], take a measured look at the future of renewables in the global energy supply. The mean global prices in $US per MWh and the derived and simplified trends of some of these, are summarised below: note, these are mean values; the ranges are wide and variable.

Table 2. Global average prices for each major fuel sector in 2009, 2013 and 2016

Prices USD /MWh	2009	2013	2016***
Coal	55	80	80
Gas	50	65	82
Biomass	125	120	115
Solar PV	260	120	105
Onshore wind	100	80	90
Offshore wind	150	200	160
Wave	370	500	na
Nuclear	80*	95*	150**

* Second Generation plants which includes Sizewell B

** Third Generation Reactors?
*** Pitta Clark, 2016 – ref 9

Table 2 shows that, due to harsh conditions at sea and the need for very strong foundations on the variable sea-bed conditions, offshore wind (potentially the most contributory) is significantly more expensive than nuclear or onshore wind. These conditions also make the offshore prices significantly more than the costs quoted for second generation nuclear plants, but not more than third generation plants such as that planned for HPC. Neverthe-less, in August 2016 Greg Clark, Secretary of State for Energy, gave a Development Consent Order for 300 turbines with 1.8 GW capacity at 'Hornsea Project Two', 50 miles offshore east of Hull, to be constructed by DONG; the price is yet to be negotiated but is likely at first, to be close to that for nuclear from EPR or other third generation reactors. This is a signific-ant and encouraging advance, especially if offshore prices fall while nuclear prices do not.

Onshore wind and solar, from being much more expensive than nuclear, become substantially cheaper – but in UK, solar farms would require large areas of land. Wind enthusiast predict an even greater fall in offshore wind prices, but for this account I prefer the Bloomberg analysis as even though it (like the ECIU reports) is conservative, even offshore wind stands up well in the analysis. However all these costs are provisional although those for solar and onshore wind will continue to decline. Furthermore, the development of wind power should be endogenous to the UK and provide useful employment. DONG are willing to scale up offshore wind development were HPC to be cancelled: such scaling up would be expected to reduce overall costs further.

There are enthusiastic advocates of wave and tidal power but at present these are generally very expensive although the cheapest options shown in the Bloomberg document do approach those of the mean offshore costs. Unconsidered by these studies is the potential for artificial photosynthesis, a new and exciting 'threshold' technology which needs much more development, and to which Jonathan Porritt in a very informative blog[10] refers somewhat wryly as, although holding great prospects, there are other more established technologies which promise more rapid advances.

The World Energy / Bloomberg study also predicts the following overall changes of global contributions from each of the major electricity generation fuels in 2040 compared with the contributions in 2016 (Table 3).

Table 3. Expected changes in global sector contributions to electricity generation by 2040

Thousand TWh/year	2016	2040
Wind & solar	1.5 (6.7%)	10.5 (30.3%)
Nuclear	2.7 (12%)	3.8 (11%)
Hydro	3.8 (17%)	4.9 (14.2%)
Gas	5.6 (25%)	5.6 (16.2%)
Coal	8.8 (39.3%)	9.8 (28.2%)
Totals for these major sources	22.4 (100%)	34.6 (100%)

Table 4 shows an interesting set of UK price predictions, given in the 'Economist' of August 6th 2016, (derived from data from the National Audit Office) comparing earlier and later predictions of the 2025 prices of UK electricity from nuclear, offshore and onshore wind, solar and natural gas. These give a longer-term and more speculative prediction which is more optimistic about offshore wind prices, indicating that by 2025 offshore wind and nuclear prices will be much the same, and onshore wind and solar much cheaper.

Table 4. UK Prices in 2025 of major non-fossil fuel sectors and gas predicted in the years indicated

Predicted cost for 2025; £ / MWh	Earlier prediction (year)	Later prediction (year)
Nuclear	80 (2012)	105 (2015)
Onshore wind	90 (2010)	60 (2016)
Offshore wind	140 (2010)	105 (2016)
Solar	175 (2010)	60 (2016)
Gas	87 (2012)	85 (2013)

The main 'eye-catching' conclusions of the World Energy Council / Bloomberg report[8] are

- **Coal and gas prices to stay low.**
- **Wind and solar costs fall sharply,** making these two technologies the cheapest ways of producing electricity in most of the world in the 2030s.
- **Fossil fuel power attracts $2.1 trillion.** Some $1.2 trillion will go into new coal-burning capacity, and $892 billion into new gas-fired plants.
- **But renewables take lion's share.** Some $7.8 trillion will be invested in green power.

In addition

- **The 2^{o}C scenario would require much more money.** The world needs to invest another $13.1 trillion in zero-carbon power by 2040 to stop atmospheric CO_2 rising above the IPCC's 450 ppm.
- **Electric car boom supports electricity demand.** Electric vehicles will add 8% to global electricity demand in 2040 and will drive down the cost of lithium-ion batteries for 'behind-the-meter' (i.e. home domestic) storage of electricity leading to a global storage capacity from around 400MWh to nearly 760GWh in 2040 - a major boost.
- **China coal-fired generation will not grow as much as previously projected,** as in 10 years coal-fired generation will be 1,000TWh, or 21% below previous predictions.

- **That makes India the key to the future global emissions trend,** as its electricity demand may grow 3.8 times between 2016 and 2040, despite investing $611bn in renewables in the next 24 years, and $115 billion in nuclear, it will continue to rely heavily on coal power and a trebling of its annual emissions by 2040.
- **Renewables will dominate in Europe and overtake gas in the US.** Wind, solar, hydro and other renewables will generate 70% of Europe's power in 2040, up from 32% in 2015; and in US to 44% in 2040 from 14% in 2015, as gas slips from 33 to 31%.

What is interesting in these predictions is the lack of prominence globally of the nuclear sector which contrasts with the great future predicted for electric road vehicles - much vaunted by nuclear advocates as a reason for continuing the development of nuclear power. But World Energy / Bloomberg also predict a great development of 'behind-the-meter' storage systems ideal for home electricity production from solar panels, domestic windmills, etc. This is a direct challenge to those who criticise renewables on the grounds that the sun is not always shining and the wind not always blowing. Although Bloomberg do not predict the demise of nuclear, its future is unspectacular – far from the frequent cries that it must remain a major factor in the energy supply for the UK, and the world.

Summary so far

I acknowledge the differences in details among the references behind the above analysis, but the general trends are clear.

- Costs of electricity generated from fossil and nuclear fuels are unlikely to decline over the next decades whereas those from renewables – even offshore wind – will fall, making them very cost-competitive.
- The capacity for electricity generated and stored from renewables, in the UK and globally, has huge potential for expansion – enough to replace fossil and nuclear sources completely and to supply the required baseload.
- Such developments would, however, be revolutionary and require significant re-design of supply grids, including the UK National Grid, but are entirely feasible.

HPC and China

Rob Davies, writing in the Guardian of 8th August 2016 [11] explained that the UK is currently running a persistently high current account deficit of about 200 billion $US - 6.9% of the UK's GDP – which precludes the UK government from investing in HPC. Therefore, for a project as big as HPC (projected now to cost up to £24bn to build) outside money is needed. Although Chancellor Osborne announced in September 2015 that the government would guarantee £2bn to finance the project, the next month a 'Strategic Investment Agreement' signed in London, committed EDF to a 66.5% share in Hinkley Point C, and CGN to 33.5%. This allows EDF and CGN to define the contracts with key suppliers.

CGN is a wholly Chinese State-owned Concern – although in 2014 the Chinese government allowed CGN to raise US$3.16 billion in an initial public offering in Hong Kong, allowing a form of public (not 'private') investment. China also has investment interests with EDF for their own versions of the EPR nuclear reactors at Taishan, which CGN and EDF are in a joint venture, of 70-30 respectively, to build. So as the UK State cannot afford to build HPC, the costs are being borne by two predominantly State-owned foreign companies – EDF (85% State-owned) and CGN (100% Chinese State-owned), although the UK public will be subsidising the costs of producing the electricity through the extra-ordinary 'strike price' of £92.5/MWh, in order to allow EDF and CGN to profit from and justify their build-investment to their funders.

China already invests far more in the UK than in France, Germany and Italy combined, in 2012 to the tune of $2.75bn in UK to $1.1bn in the rest, and currently has about $11bn worth of stakes in UK companies – including a 1% stake in BP worth $2bn, a 60% stake in Weetabix worth $1.9bn; and (intriguingly, as many Chinese students come to the UK) a 40% stake in the student accommodation group UPP worth about $850million. Chinese companies already own some big UK businesses outright and are investing in hi-tech, aviation and cars. During the Chinese President's State Visit to the UK in October 2015, £40bn of UK-Chinese partnerships, including HPC, were signed. BP agreed a £6.5bn contract to supply liquefied natural gas to China and Rolls-Royce signed a £1.6bn deal to supply Trent 700 engines to a Chinese aviation company. Also, China Construction Bank agreed to provide up to £6bn of funding to help regenerative medicine and tissue engineering research at Oxford University. This is the political and economic context of Theresa May's very last-minute delay in approving the HPC deal, which has prompted the warning from the Chinese ambassador to the UK, Liu Xiaoming, that relations with Britain were at a "crucial historical juncture".

The implication is that May's concerns are based on threats to cyber-security through Chinese control of IT-sensitive equipment installed at HPC. This may be the unmentionable case but there are many reasons more plausible than Chinese sensitivity to impugned slights on their diplomatic integrity. These should emphasise two main themes – need and costs.

Necessity. Do we need HPC?

The National Grid is close to the heart of many power engineers: it has played a fantastic role, and the outages of a few years ago have been avoided by good management. But now is the time for a careful re-assessment with a view to liberating more local production, tapping better into renewables and allowing greater efficiency while still preserving the 'baseload' concept. As already noted, HPC is unlikely to open within six years – ten may be a more realistic assessment, if at all.

The scenario for a UK demand of 357TWh in 2030 envisaged by the ECIU[1] is deliberately conservative, not involving the newer emerging technologies such as tidal/wave or artificial photosynthesis, and relatively downplaying anticipated price falls in renewables, but still demonstrates that HPC is not needed. The major contributors would be wind (27.7% offshore and 8.3% onshore), international interconnections (19.3%) and gas (11.5%): non-Hinkley nuclear would provide 2.6%: coal or coke would be eliminated from the power supply (but probably used for a limited degree of smelting and vintage railways, etc.). The annual cost savings to energy bills could be as much as £1.2 billion.

In the meantime, rapid advancements in renewable energy will have come to fruition. These will address the frequent taunts about the sun and the wind by advocating, for example, Li-ion or Li-air batteries in 'behind-the-meter' home domestic electricity storage, and overcoming the claims that baseload supplies from nuclear are essential. Other sources, such as biomass (particularly if backed by carbon capture, which some advocate as being the most realistic scenario for this otherwise less promising technology), ground heat, fuel cells, Combined Heat and Power schemes and a host of other 'minor' technologies, make in sum a significant contribution, as would continuing improvements in efficiency of use and of generation. Together with a revolution in smart meters and grid-free home generation, these are all capable of taking up the slack.

Costs

Furthermore, these advances will drive down costs, particularly of solar and on-shore wind. Economy of supply from the potentially huge resources of offshore wind may be met less well, but the costs can be expected to be close to that from the strike-price deal for HPC. But cost-projections are inevitably speculative: for this analysis I have taken the approaches of Bloomberg and the ECIU which are deliberately conservative, thereby leaving room for lower relative falls in costs than other more optimistic estimates predict, although we can safely assume that renewables-based power will become significantly cheaper while fossil- and nuclear-based power will not.

Dealing with China

China may see HPC as a 'loss leader' to its burgeoning nuclear industry which it wants to export. It is committed to expanding nuclear at home, and failure to secure HPC will be very disappointing. Threats arising from their hurt feelings should be countered by soft diplomacy. Close inspection and interrogation of the two points above may allow more coherent and less offensive but still powerfully persuasive arguments that lower the profile of concerns over security and encourage a more diplomatic and favourable advance in Anglo-Chinese relations than was apparent from Liu Xiaoming's first reaction.

China may well feel well disposed to the UK because of our relatively stable politics and well-developed legal system, and will be reluctant to withdraw from the UK altogether. They should be reassured over their other investments.

From the UK's standpoint, withdrawal from HPC will protect all UK Society from the economic consequences of another 'white elephant'. This line should be explained to the UK building industry and Trade Unions who should be reassured that there will be plenty of employment and investment opportunities in the renewables sector. Indeed, although serious considerations will be needed on how to adjust our strategy from a heavy dependence on the current National Grid to a more flexible system of smart grids more attuned to local sensitivities and needs, it may well be possible for the UK to have a nuclear-free energy industry in the second half of the 21st century.

Coda: the 'threat' from fracking.

On the evening of 6th August, government spin doctors sent selected media outlets an email announcement - *Theresa May has re-written Osborne's plans to ensure local people benefit directly from fracking*.

"Communities could receive up to 10% of tax revenues derived from shale exploration in their area to spend on priorities such as local infrastructure and skills training. The new fund could deliver up to £10 million per eligible community."

Medact has recently updated its case against fracking on the bases of environmental pollution and enhanced emission of greenhouse gases[12]. Attempts to popularise hitherto unpopular schemes of fracking for gas or oil are more examples of trying to improve energy security by making available more UK-based fuel sources to generate electricity. Greenpeace[13] has revealed the truth behind this ruse, given without any notice or facility for journalists to check details but, on reflection, turning out to be a sham because any cash handouts would come only after shale exploration and from the tax on the profits from full-on commercial gas extraction.

Hence, this attempt to improve the UK's energy security cannot compare with advances in renewable energy technologies – or even nuclear. It can therefore be discounted. But it is reminiscent of earlier attempts to popularise nuclear power before the Fukushima disaster which – belatedly – woke the world up to significant social disadvantages associated with nuclear technologies. These can be avoided by enhancing the production of electricity from renewable resources in a fossil-fuel-free world.

Health impact

During a safety testing assessment, the US General Accounting Office (GAO, 2003, [14]) described spent nuclear fuel (SNF) as 'one of the most hazardous materials known to man' (repeated in 2012), but went on to re-assure the American public that it posed little danger, as when transported it was in protected containers, and also that SNF is inherently difficult to disperse. The 2003 report did admit, however, that '*widespread harm is possible under certain severe but <u>extremely unlikely conditions</u> involving spent fuel stored in storage pools*' (my underlining) The main problems at Fukushima arose from such 'extremely unlikely' conditions exposing the rods in such pools thereby causing the widespread and continuing dispersal of their SNF.

As described above, the EPR design addresses safety concerns from, for example, a '9/11' attack (considerations which were behind the GAO 2003 report); but the complexity of the design may be at the root of the problems at all four sites currently under construction. Whether the design would protect against a precisely targeted conventional or 'mininuclear' explosion of yields, say, around 1 Kt is not mentioned.

'Low-level' ionising radiation is one of the most studied factors in environmental health, yet still among the most controversial principally because of two powerful antagonistic lobbies – the international pro-nuclear industries with their strong links to nuclear weapons, and the 'nucleo-phobic' public environmental and anti-militarisation groups – although there are several anti-weapons pro-NPP groups, as well as the obverse. Although it cannot be doubted that natural and anthropogenic ionising radiation causes significant adverse effects on peoples' health, the 'grand social effect' combining any overall benefit with adverse effects continues to be debated.

Particular emphasis has been placed on leukaemia, although cancers in general have been explored quite intensely and, to a lesser degree, cardiovascular and psychological effects. Transgenerational (inherited) effects have also been studied – somewhat inconclusively, at least for humans. Leukaemias are particularly poignant as infants and children seem most vulnerable, as found among the Japanese atomic bomb survivors in the 1950's and 1960's.

In 1990, Gardner *et al* [15] reported a significantly high incidence of leukaemia and lymphoma in young people in West Cumbria whose fathers worked at the nuclear factory at Sellafield, implying paternal transmission of a radiation-linked risk factor. Among children born in the nearby village of Seascale over a 35 year period there were 6 cases of leukaemia compared with 0.6 expected, an ERR of 9.36 (95% CI 3.04 to 21.84). The dosimeter badges worn by the fathers of the six children indicated that before conception they had received 100 to 200 mSv more radiation than the background of about 3 mSv a year, and although the fathers of some control cases had received comparable extra doses, most had not. This apparent paternal effect on children born in Seascale has never been replicated. It should be noted that there was no excess of leukaemia among children born outside Seascale while their fathers were working at Sellafield but who subsequently moved into Seascale; and that the absolute numbers are low and various explanations other than radiation have been mooted.

In the first decade of the 21st century, several European studies seemed to confirm earlier impressions that children residing within 5 Km of a NPP were also at significant risk. These reports have been summarised by Ian Fairlie (2013-14)[16] who conducted a meta-analysis of studies in Germany, the UK, France and Switzerland, summarised below, and gives many useful references. All countries had more observed cases than expected, but Germany (where the highest number were observed and expected) was the only country where statistical significance at the 5% level was reached. This may indicate that the numbers in UK, France or Switzerland countries were not enough to reach significance. In its 14th report in 2011, UK's COMARE (Committee on the Medical Aspects of Radiation in the Environment) [17] did not accept these interpretations, but Fairlie's study post-dates that report.

S**tudies of observed (O) and expected (E) leukaemia cases within 5 km of NPPs,** from Fairlie 2014 [16]

Dataset	**O**	**E**	**O/E**	**90% CI**	**-*p*-value**
Germany	34	20.1	1.41	1.04-1.88	0.033
UK	20	15.4	1.3	0.86-1.89	0.15
Switzerland	11	7.9	1.4	0.78-2.31	0.17
France	14	10.2	1.37	0.83-2.15	0.15
Pooled	79	57.5	1.37	1.13-1.66	0.004

No radiation readings were taken during these studies, nor could any be. Official annual average dose estimates of the radiation coming from the radioactive discharges vented via the stacks at each NPP were given, but seem much too low to explain the observations. Fairlie suggests several possible extra confoundables which would greatly amplify the risk, such as the annual periodicity of the discharge venting, with relatively large doses vented each time producing sudden short-lived but high contamination of air and people. Fairlie also claims – feasibly – that tritium in the discharges is much more dangerous than conventional scientific opinion allows; that embryos and foetuses are particularly vulnerable to radiation, and their haemopoietic stem cells even more so.

Fairlie tends to discount other possibilities including the so-called Kinlen hypothesis of 'population mixing', which he says does not fit the strong association of proximity to NPPs. Kinlen[18] suggested that when small and long-settled populations in rural settings experience an influx of new people (when for example building a NPP) 'new' infectious agents which might be leukaemogenic are imported. Such agents need not be specifically leukaemogenic, just immunogenic. This is of added significance to infants and children as the world-wide epidemiology of acute lymphoblastic leukaemia (ALL) is unique. Typically, in UK there are about 500 new ALL cases each year – about 100 are in adults, 400 in children under 15 (including 300 in children under 5): the peak age is 2 – 3 years old.

Fairlie (and others) are justified in assuming that during early childhood haemopoietic stem cells may be particularly radiosensitive, as they undergo very rapid cell-division during this period. What has not been previously appreciated by any commentator is that this particularly applies to lymphocytes, as at this stage of the infant's life the lymphocytes' genes for B and T-cell immunoglobulins are undergoing vigorous and random DNA recombinations during mitoses. Furthermore, immediately after birth infants start breathing and swallowing environmentally-carried foreign macromolecules and organisms which further stimulate their lymphocyte clones into yet more rounds of vigorous genetic recombinations. These contribute vitally to the infinite potential of immune diversity, enabling immunoglobulins (antibodies) to develop against virtually any 'foreign' macro-molecule, especially infectious agents, as successful recombinations code for the relevant antibody to the foreign macromolecules to which the neonate has been exposed. Nevertheless, even though the genes are programmed to try recombining repeatedly ("try, try, and try again") most attempts are unfruitful.

Proportionately, only very few cells recombine successfully and reach maturity with functional immunoglobulin genes producing active antibodies. The vast majority of cells apoptose (die) and their materials are re-cycled for the next generation of lymphocytes: but a very small number may not apoptose because a mismatch during mitosis elsewhere in their DNA has coded for a mutated 'preleukaemic' gene which allows avoidance of apoptosis. (Very few of the mutations affect the recombined immunoglobulin genes directly, although this is occasionally observed.) The upshot is that the vigorously mitosing lymphocytes of prenatal and early post-natal babies may be very open to multiple shots of 'preleukaemic' mutations due to faults in the somatic recombinations in any part of their DNA. Greaves[19] suggests, in a 'Darwinian' model, that these mutations enhance clonal survival even though the clone has 'gone wrong'. It may be noted that the genes found in the clones of childhood lymphoid leukaemia show a wide variety of very complex mutations, implying ongoing further mutations after the first 'hit': these can affect their pathogenicity and the options for treatment.

This fits in well with the 'two-hit' hypothesis (or indeed multiple-hit hypothesis) of leukaemogenesis first postulated by Greaves and supported by Fairlie – whereby a pre-leukaemic mutation in a haemopoietic cell line in an embryo is followed in early post-natal life by further 'hits', so that eventually a fully leukaemic clone emerges. Such a mechanism does not require the initiating event to be from a specific oncogenic infection but merely an oxidising event whether arising from effects of oxidative metabolism straying outside the mitochondria (the usual cause of DNA damage requiring repair) or due to ionising radiation which effectively turns water into hydrogen peroxide which then damages DNA. Fairlie may be correct with his hypothesis but other non-radiation risk factors, such as new immunogens brought in by migrant populations, could add to the DNA damage.

(Note, I am preparing the above points in this section for a peer-reviewed publication in the near future)

Findings among nuclear industry workers

Statistically powerful cohort studies have confirmed the oncogenicity of radiation experienced by workers under 'normal' working conditions at NPPs. Klervi Leurau *et al* ('Lancet Haematology' 2015)[20] followed up, as part of an 'INWORKS' study, 308,297 people who worked in the US, France and UK between 1945 and the mid 2000's for a total of 8.22 million person-years and monitored for up to 60 years after exposure. They found a clear positive association between protracted low-dose red bone marrow exposure (up to many hundred milliGrays (mGys) over decades – normal 'background' whole-body radiation being about 2 mGy a year) and leukaemias, especially chronic myeloid leukaemia (which has a very different pathogenicity to ALL but is still a very serious condition). Overall, the mean extra yearly dose was 1·1 mGy (SD 2·6) but averaged about 0.5 mGy early on, rising to about 3 mGy in the later stages. The mean cumulative red marrow dose of all 308,297 people in the study was 16 mGy and ranged from zero to 1,217.5 mGy (i.e. high); but the distribution was very skewed as the median dose was 2·1 mGy (IQR 0·3–11·7), with a tenth percentile of 0·0 mGy and a 90th percentile of 40·8 mGy. The extra relative risk (ERR) for all-leukaemia mortality was **2.96 per Gy**, 90% CI being 1.17 to 5.21. These somewhat arcane expressions can be interpreted as showing that comparing an unexposed population in which 'normally' 100 people would be expected to die of leukaemia, the extra deaths in an otherwise identical population exposed cumulatively to an extra Gy would be **296** (i.e. 296 extra deaths caused by the workplace exposure). This circumstance would be very exceptional although they would not die immediately but maybe years or even decades later. But if that otherwise identical population were exposed cumulatively to the much lower mean dose of an extra 16 mGy, an extra ten people (110 instead of 100) would die from leukaemia at some stage of their life. It may be noted that the total number of leukaemic deaths in this study was 531 out of 308,297 participants.

The same INWORKS group was followed up for other cancers when a lower but still positive association with radiation was found (Richardson *et* al 2015 [21]).

Problems of a different order are presented by Fukushima and Chernobyl where shorter lived and biologically dangerous isotopes such as Sr-90, I-131, Cs-134 and Cs -137 were released to contaminate the air and soil. At Chernobyl, acute radiation syndrome affected 237 people of whom 31 died in the first three months. The 'LD50' for acute radiation syndrome is about 5Gy. Most affected people were fire and rescue workers not fully aware of the dangers. The 'Chernobyl Forum' of the IAEA, other UN organizations and Belarus, Russia and Ukraine, published a report on the radiological environmental and health consequences saying that 15 people have died from thyroid cancer and speculate that over 80 years the final cancer death toll may reach 4,000 among the general population of 5 million or so living in the contaminated areas. These figures are much lower than other estimates. Cardis (2011 [22], 2015 [23]), while indicating profound methodological difficulties, reported that by 2065 there could be between 11,000 and 59,000 extra cancer cases (mean about 25,000). Nevertheless, against the expected background of cancer incidence in that region over those nine or so decades, it will be impossible to pick out the individuals directly affected by the Chernobyl disaster even among those very increased extra numbers.

In Fukushima there have officially been no deaths due to radiation although at least six workers exceeded lifetime legal limits for radiation and more than 300 got significant radiation doses. Although in April 2012 the WHO claimed that workers mitigating the accident's effects would face only 'minimally higher risks' for some cancers, this is highly contentious. Unexpectedly high rates of thyroid cancers in local children have been found. IPPNW Germany predicts very significant rises in cancer rates and there is little doubt that the Japanese authorities, in hoc to commerce, have missed a golden opportunity to conduct - out of the Fukushima tragedy - a set of well-designed powerful, ethical and consented studies on the long term effects of ionising radiation (see my 2011 Medact blog (Boulton[24]).

As Tilman Ruff (2016 [25]) says "The most important lesson from Fukushima is that sustaining global health demands a renewable energy future, not a radioactive one."

Are there nuclear alternatives to HPC?

Many pro-nuclear advocates criticise HPC, often focussing on the 'Small Modular Reactor' (SMR) principle, giving as examples the design of reactors for submarines (a purely military objective). Rolls-Royce, for example, have decades of experience of building such small reactors which typically now have a capacity of about a tenth of HPC (165 MWe), and use enriched uranium in vessels primed with 'burnable poisons' which allow the reactors to continue working for 30 to 40 years, thus avoiding re-fuelling (a considerable technical advance). An appealing application would be to fix, say, five such SMRs in tandem in one location to generate civil electricity (Clegg and El-Shanawany [26]).

However, in 2013 Edwin Lyman of the Union of Concerned Scientists[27] expressed concerns about the safety, security and costs of SMRs. A few years earlier, Makhijani and Boyd [28]argued that SMRs offered no real advantage over current NPPs, not least due to managing the nuclear waste from more widely dispersed sites. In any case it would still take ten years to go through all the licensing applications and building works, and possibly longer – hardly a solution for an urgent problem. It seems therefore that SMRs offer no solution to the current problem (a point with which the ECIU agree – ref 1), and indeed would aggravate the extremely important environmental and potential health concerns surrounding the issue of nuclear waste.

Other options, such as thorium-based reactors, have even longer timescale problems for development and approval. Geologically-rich deposits of Th-232, the relevant isotope with a 14 billion year half-life, are found in India: although this is not fissile (like U-235 or Pu-239) neutron bombardment can turn Th-232 into U-233 (half-life 160,000 years) which is fissile. There are considerable technical hurdles to overcome before these properties make power generation from Th-232 feasible.

Conclusion.

The ongoing fiasco surrounding Hinkley Point C and the practical difficulties of developing alternative nuclear technologies in the UK draws attention to the fact that the UK could survive without any further development of nuclear-based systems for generating electricity. The final phase-out of generation from Sizewell B in 2035 or, if extended to 2055 could and should be the final curtain for civil nuclear power in the UK until and unless nuclear fusion based on plasma-confining technology and free of the risks of contamination from the products of nuclear fission comes along. The embryonic plans to extend a UK nuclear build to Moorside and Wilfa [29] should be abandoned.

If a convincing case could be made that for global survival it would be essential to generate electricity from nuclear fission, the writer would be persuaded: however this seems very unlikely and as yet I favour the rapid development on a global industrial scale of a low-carbon nuclear-free renewable technology, as envisaged by Arjun Makhijani of the US PSR-affiliated Institute for Energy and Environmental Research, a pathway which an increasing number of private investors in new energy-generation projects, including a substantial minority of the Tory-inclined and not-anti-nuclear UK Institute of Directors (IoD)[30], seem to be following. Although over half the IoD are misguided enough to support fracking, it is evenly split on the future of HPC, less than half thinking that it would make the UK more competitive. As a whole, the IoD support all forms of mainstream renewables and agree that Theresa May is right to reconsider the future of HPC. It is encouraging to note that a significant minority lack confidence in HPC and in fracking – and more may be persuadable when reliably informed about the economic and safety issues surrounding the UK's hitherto proposed 'new nuclear build'.

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Frank Boulton: August 2016

Addendum: 30 September 2016

Well, the small ray of hope which followed Theresa May's postponement of the HPC deal has all but been extinguished. She has now approved it, the contracts have been updated and the Department for Business will confirm the formal signing on social media yesterday (September 29th) – ushering in the bulldozers.

As the above piece makes abundantly clear, there is a powerful case for the UK not entering a new phase of nuclear power: we simply don't need it as all our needs can be supplied by renewables which can be phased in 100% without recourse to a nuclear 'baseload'. Furthermore, such a system would be substantially cheaper than the Strike Price agreed for HPC and our already very significant problem of handling nuclear waste would not be compounded by a new nuclear build – that is, assuming that such a programme succeeds, as overruns and technical problems seem very likely.

Common sense has been thwarted by 'power-politics' of the old sort being played by new players – particularly China. Beyond HPC is the prospect of more EPRs being built by solely by Chinese companies at Bradwell, while at Sizewell an alternative Generation III design is before the Office of Nuclear Regulation. With an active and passive cooling component known originally as ACC-1000, now known as 'Hualong 1' and intellectual property-transferred wholly to China. Not far beyond them – as a sort of second string – is the prospect of another consortium 'NuGen', a Franco-Japanese affair with HQ in Manchester, building yet another 'Generation III' NPP based on a Westinghouse-based design – the 1,100 GWe capacity AP 1,000. Westinghouse is now owned by Toshiba, Japan. This is also being assessed by the UK Office for Nuclear Regulation for a build of three reactors at Moorside, near Sellafield. Larger versions – AP 1,300 and AP 1700 are on the drawing board, and being developed in China and the US.

China in particular seems determined to develop its nuclear industry and sell it to the world as part of its own 'destiny'. As the West becomes more and more by-passed in the power-politics of the world, we should become more cautious in depending on outside sources for our energy supplies. We should, nevertheless, encourage positive trade deals such as some of those mentioned above. But UK investment in renewables and their associated employment opportunities must expand: the Department of Business should not slacken its programme of renewables development, and we must continue to hold it to account for such developments.

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