Review

The siting of UK nuclear reactors

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Abstract
Choosing a suitable site for a nuclear power station requires the consideration and balancing of several factors. Some ‘physical’ site characteristics, such as the local climate and the potential for seismic activity, will be generic to all reactors designs, while others, such as the availability of cooling water, the area of land required and geological conditions capable of sustaining the weight of the reactor and other buildings will to an extent be dependent on the particular design of reactor chosen (or alternatively the reactor design chosen may to an extent be dependent on the characteristics of an available site). However, one particularly interesting tension is a human and demographic one. On the one hand it is beneficial to place nuclear stations close to centres of population, to reduce transmission losses and other costs (including to the local environment) of transporting electricity over large distances from generator to consumer. On the other it is advantageous to place nuclear stations some distance away from such population centres in order to minimise the potential human consequences of a major release of radioactive materials in the (extremely unlikely) event of a major nuclear accident, not only in terms of direct exposure but also concerning the management of emergency planning, notably evacuation.

This paper considers the emergence of policies aimed at managing this tension in the UK. In the first phase of nuclear development (roughly speaking...
1945–1965) there was a highly cautious attitude, with installations being placed in remote rural locations with very low population density. The second phase (1965–1985) saw a more relaxed approach, allowing the development of AGR nuclear power stations (which with concrete pressure vessels were regarded as significantly safer) closer to population centres (in ‘semi-urban’ locations, notably at Hartlepool and Heysham). In the third phase (1985–2005) there was very little new nuclear development, Sizewell B (the first and so far only PWR power reactor in the UK) being colocated with an early Magnox station on the rural Suffolk coast. Renewed interest in nuclear new build from 2005 onward led to a number of sites being identified for new reactors before 2025, all having previously hosted nuclear stations and including the semi-urban locations of the 1960s and 1970s. Finally, some speculative comments are made as to what a ‘fifth phase’ starting in 2025 might look like.

Keywords: nuclear installations, siting, safety, history, economics

(Some figures may appear in colour only in the online journal)

1. Introduction

The accident affecting four units of the Fukushima Dai-ichi nuclear power plant in Japan, following the Tohoku earthquake and tsunami in March 2011, has had a profound effect on the development of, and attitudes towards, nuclear energy in many countries. Subsequently there has been a great deal of attention paid to learning the lessons of the event.

Fukushima emphasised that severe nuclear accidents, especially in areas with relatively high population densities and land values, are not just an issue for human health and environmental protection; they also have profound implications for issues such as industrial production and the value of real estate assets. Such considerations have motivated the research project Management of nuclear risk issues: environmental factors and safety (NREFS) of which this work forms a part.

The siting of any large-scale industrial project will inevitably involve compromise among a range of desired features. In the case of nuclear power stations and other installations, these factors will include:

- radiological and safety factors—distance from major population centres; ease of evacuation in a major accident scenario; local issues such as seismic stability and vulnerability to flooding (either from short-term extreme weather events or long-term, climate change, e.g. sea level rise);
- economic factors—cost of land and labour; tax regimes; proximity to the market for the electricity; ease of delivering fuel and removing waste; provision of cooling water; access to the site for construction and maintenance etc;
- technical factors, e.g. the ability of the geology to withstand the very high weight of a nuclear power reactor and to build or expand connections to the transmission grid;
- social factors—levels of local public and political support; availability of skilled workforce; history of positive engagement in the area;
- environmental factors—quality of the local environment; level of disruption associated with construction, operation and decommissioning; ease of remediation;
• ‘political’ factors—the imperative to develop a nuclear weapons programme very rapidly had a profound effect on the development and siting of nuclear installations in the 1940s and 1950s.

This paper will explore how the relative importance of these factors evolves and has evolved over the last seven decades. Similar factors affect other forms of electricity generation, though to differing degrees. For example, the cost of transporting fuel to the site is much higher for a coal-fired power station than for a nuclear power plant, there being a difference of a factor of several thousand in the mass of fuel required in the two cases. So for coal plant, proximity to the mineral resource or importation port is a much greater factor than for nuclear power stations. Clearly the quality of wind, wave or tides is a crucial factor when it comes to siting renewable plants. By contrast, perceptions of the threat and consequences of a major accident are more important factors in the decisions around planning nuclear power stations, although the extent to which this has been influenced siting decisions has varied from time to time.

The debate on siting of nuclear power stations (and other facilities) in the UK, and in particular how to manage considerations of safety with regard to nearby residents, can be divided into four phases:

• the early days (roughly 1945–1965), comprising the early research and production establishments (military and civil including two small power-generating reactors at Windscale and Dounreay) and the Magnox power station programme—a period which included the Windscale fire of 1957;

• the second phase (roughly 1965–1985), comprising the last Magnoxes, the second nuclear programme in the UK, the advanced gas-cooled reactors (AGRs) and the commissioning of two larger prototype power reactors, at Winfrith and Dounreay—a period which included the major accident at Three Mile Island, USA in 1979, though this occurred after all the AGR sites had been identified;

• the third phase (1985–2005)—the introduction of a new reactor design requiring siting in low-population areas (Sizewell B and Hinkley Point C, though the latter was not built), followed by a period when there was no prospect of new reactor build and such focus on siting as there was involved the search for a location for waste repository—a period which included the accident at Chernobyl, Ukraine in 1986;

• the fourth phase (2005–date) when a growing interest in nuclear new build reawakened interest in siting issues, alongside ongoing debate around waste disposal—a period which included the accident at Fukushima, Japan in 2011.

The four phases can, very crudely, be characterised as:

• early days—considerable caution, with distance from populations being a key driver of siting policy;

• second phase—growing belief that the safety and reliability of reactors had been significantly improved so siting could be more relaxed with regard to the density of local population;

• third phase—return to caution as a new power reactor system (pressurised water reactor, PWR) was chosen (it had been decreed that any power reactor type new to the UK would require a conservative siting regime until its safety was proven), followed by a national loss of interest in nuclear power new build and growing frustration over the ability to site anything anywhere, as option after option for waste disposal met with insuperable local objection, coupled with greater public awareness of the potential for and consequences of major reactor accidents;
• fourth phase—much greater public and political support for nuclear new build (even after Fukushima), especially in areas with a long association with the industry, leading to a relatively positive debate on developing new facilities alongside existing stations (operating or being decommissioned).

The Magnox power stations—the nine power stations that represented the UK’s, and indeed the world’s, first major foray into civil nuclear power (plus two military stations at Calder Hall and Chapelcross which also generated electricity)—were located at remote, isolated sites. These were generally on the coast or on river estuaries (with the exception of Trawsfynydd, situated on a large lake in Snowdonia), in order to minimise the costs and environmental effects of extracting cooling water, required predominately for condensing steam during turbine operations. Since Magnox plants produced steam at a relatively low pressure and temperature compared with contemporary fossil fuel powered stations (and were therefore less thermally efficient), they required about twice as much cooling water per unit of electricity generated. It was therefore sensible to allocate the limited inland sites with sufficient water supplies to coal-fired plants (Haire and Usher 1975).

The earliest nuclear plants—including production and research facilities such as Dounreay in Caithness, Windscale in West Cumberland and the ‘military’ Magnox reactors at Calder Hall (Windscale) and Chapelcross—were placed in areas of low population density, with an eye on minimising the radiological effects of a major accident.

Such isolated areas often present challenges regarding, for example:

• access to the site for construction and maintenance;
• providing and accommodating a workforce;
• the quality of the local environment
• in some case, the distance from the centres of power demand.

The first reactors of the AGR programme (decisions on construction being taken between 1965 and the late 1970s) were built alongside the existing Magnox stations at Dungeness in Kent, Hinkley Point in Somerset and Hunterston in Strathclyde. However, the later stations included new sites closer to centres of population, namely at Hartlepool in County Durham and Heysham in Lancashire (as well as a new remote site at Torness in Lothian). Sizewell B, the UK’s only PWR power reactor (at least until the onset of a potential new build programme twenty years later), sits next to a Magnox station in Suffolk which is now in the process of being decommissioned (see figure 1).

From 2005 onwards the prospects of a programme of new nuclear power stations have improved and the focus has been on developing new nuclear plants alongside existing ones. The National Policy Statement (NPS) on nuclear power (DECC 2011a) identified eight sites for potential new build before 2025, all adjacent to existing nuclear plants (either operating or being decommissioned). Among the arguments for this approach were the existence of infrastructure including transmission connections to the National Grid, the degree of local public and political support and the presence of a skilled workforce. While the number of stations which will come into operation before 2025 is uncertain, it does appear that siting issues for such plants have been settled.

Clearly any developments in a ‘Phase 5’, which one might arbitrarily define as commencing in 2025, will be heavily dependent on how ‘Phase 4’ turns out. However, already it is possible to identify some issues which might be heavily influential on shaping the medium-term future of nuclear power and the siting of nuclear installations. Post-Fukushima, two opposing arguments may be emerging. One has it that the absence of any clear signs of radiobiological consequences of the accident, coupled with clear evidence of psychological
consequences which may be associated with the response to the event (e.g. widespread compulsory evacuation), should result in a downward reassessment both of the potential hazards of releases of radioactive materials and of the appropriate response to such a release.

Figure 1. UK nuclear sites (NIA 2013).
The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has announced a review of the ‘Linear No-Threshold Model’ of radiation hazard, which assumes that radiation exposure remains proportionally harmful in the long term at all dose levels, saying that it ‘does not recommend multiplying low doses by large numbers of individuals to estimate numbers of radiation-induced health effects within a population exposed to incremental doses at levels equivalent to or below natural background levels’ (UNSCEAR 2012). Similar discussions have been initiated in the European Union through the MELODI project, the High Level and Expert Group noting: ‘Any over-estimation of the risks (of low level radiation exposure) could lead to unnecessary restriction’ (MELODI 2009).

This would imply a relaxation of emergency measures—such proposals have been put forward in the USA (Guarino 2013)—and perhaps also of siting criteria. However, at the same time, others are arguing that the effects of Fukushima could have been more severe had the wind been blowing in a different direction at the time of the accident and that this should be taken into account by tightening the restrictions on plant siting and emergency arrangements.

2. Phase 1—the early days, 1945–1965

The nuclear programme after the Second World War was established with remarkable speed. In 1946 research and production facilities were established at Harwell (Oxfordshire), Risley (now in Cheshire), Springfields (Lancashire) and Windscale (Cumbria). Motivations included the desire to create an independent UK deterrent nuclear weapons system and a wish to develop a new way of making electricity which would not suffer from some of the problems associated with coal (e.g. air quality and the power of the mining unions). An important factor in site selection for these first facilities, then, was the speed with which they could be developed, leading to the choice of government-owned land, usually defence establishments which were becoming available after the end of hostilities.

The first nuclear reactors in the UK were built at what was then the Atomic Energy Research Establishment (AERE) at Harwell in Oxfordshire. GLEEP—the 3 kW Graphite Low Energy Experimental Pile—was commissioned in 1946, with the 6 MW BEPO (British Experimental Pile 0) following in 1948. Sir John Cockcroft, the first Director of AERE and later a founding Board Member of the United Kingdom Atomic Energy Authority (UKAEA), described the siting criteria for AERE, and hence indirectly for the first of the UK’s research reactors, as follows.

‘We considered the desirable conditions for the future establishment. It should not be too far from London; there should be easy access to a University; there should be some degree of isolation and lastly the countryside should be pleasant to live in. It was also thought necessary to start with a prepared site with roads, services and some permanent buildings, and Lord Cherwell suggested that we should look for a suitable RAF Airfield. So, in a hurried visit to England in the autumn of 1945, Professor Oliphant and I looked at airfields. In the end we were given Harwell’ (Cockcroft 1948).

Although Harwell was selected mainly for its existing infrastructure and relative ease of access to London, a more remote site would be needed for a plutonium production factory, once the British government had decided to pursue an independent nuclear weapons programme.

The debate around the site to be used for this facility was heavily influenced by the parallel discussion in the USA. The Americans were using water-cooled piles for the purpose. Some 30 million gallons of water a day were required for cooling, water which had to be extremely pure to prevent corrosion of metal components. Any interruption of the flow would result not only in rapid overheating but also a simultaneous increase in the level of radioactive fission occurring...
in the pile, as water is a strong absorber of neutrons. Unless ‘control rods’ could be inserted immediately to stop the fission processes, the risk of widespread radioactive release would be high. Although it was felt such an accident would be very unlikely to occur, nonetheless the US scientists determined that the piles should be built five miles apart and should be 50 miles from any town of 50,000 inhabitants, 25 miles from one of 10,000 and five miles from one of 1,000. A 30 mile four-lane highway was built to evacuate the area rapidly in an emergency. General Groves, head of the wartime US/UK Manhattan Project which had developed the atomic bomb, told the British in 1946 that he ‘would not be surprised to hear the news that one of the piles had gone up’ (Arnold 1992).

To apply the US criteria strictly would have eliminated almost all sites in the UK, with the exception of some in north and west Scotland. Initially two sites were considered, in Harlech, Snowdonia, Wales, and between Arisaig and Morar on the northwest coast of Scotland. Christopher Hinton, the first Director of the atomic production facility founded in 1946 and based at Risley in Cheshire, eliminated Harlech on the grounds of its historic importance and population density.

A panel set up to review the criteria concluded that the plutonium production piles must be at least 40 miles (rather than 50) from large centres of population. Even so, Arisaig remained the only apparently acceptable location—a greenfield site plagued by unsuitable foundation conditions, poor communications and presenting an enormous challenge to the establishment of a labour supply. Hinton strongly doubted that there were sufficient resources available to develop the site, which would in any case have taken several years. As he later wrote: ‘from 1946 to 1954 atomic energy was a defence industry, hence speed was vitally necessary and great risk of failure had to be accepted’ (Hall 1986).

The problem was sidestepped by pursuing gas-cooling for the piles rather than water-cooling. The ‘gas’ in question was to be normal air, blown over the graphite pile containing the uranium fuel elements. Since gases generally play little part in the absorption of neutrons, this approach eliminated the risk of a runaway nuclear reaction (as well as the need for a huge and reliable supply of water).

This safety advantage meant that, although a remote site was still required, the radiological criteria could be relaxed a little. In 1947 an ex-Royal Ordnance factory at Sellafield in what was then Cumberland (now Cumbria), was chosen for construction of Britain’s military reactors. The site was renamed ‘Windscale’ to avoid confusion with the uranium manufacturing establishment at Springfields near Preston, though it remained known as Sellafield locally. Windscale Pile No. 1 became operational in October 1950 and Windscale Pile No. 2 in June 1951 (Bolter 1996).

Safety was also a key consideration in the choice of Dounreay, formerly the HMS Tern II airfield, 9 miles from Thurso in Caithness, for the UK’s fast reactor research programme. The potential dangers of the facility were explicitly accepted by Christopher Hinton when he addressed local residents at Thurso Town Hall in 1955 (Cashmore 1998). The dome housing the reactor was designed to implode in case of accident and the remote site chosen to minimise the impact in the event the worst did happen. Jonathon Kirk, who worked as an operations manager during construction of DFR, recalled that ‘on the night we went critical (i.e. started up) many of the plant managers asked to leave the site’ (Nuclear Engineering International 2009).

By contrast, facilities like the nuclear fuel fabrication plant at Springfields (1946), which did not include any nuclear reactors, could be established closer to centres of population, in that case within 5 miles of Preston, a town of some 100,000 people.

By the mid-1950s a shortage of space at the Harwell site led to a search for another research location to site the ongoing research and test reactor programme, some eight reactors eventually being constructed there (NDA 2010). Some 70 sites were considered but eventually
Winfrith Heath in Dorset was chosen. In contrast to the earlier research establishment, this was largely a greenfield site (though based around former Admiralty land at West Howe) and involved the compulsory purchase of considerable areas of land from local owners. At the Public Inquiry held in 1957 the reasons for choosing the site were listed as: a degree of remoteness from large population centres; reasonably good road and rail links; a potential source of labour from the Poole, Bournemouth and Weymouth areas; a large underground water supply for cooling purposes; and proximity to the sea (some 5 miles) for discharge of effluent (Miller 2009).

The debate around Windscale in particular established a number of principles which have continued to guide siting policy in the UK, designed to ensure that the population density around a nuclear facility throughout its lifecycle will not exceed certain limits. As the HSE (Health and Safety Executive, responsible inter alia for nuclear safety) has put it: ‘Since the start of the civil nuclear power programme in the 1960s, the government has applied a policy of siting new nuclear power plants in areas where the population density does not exceed certain thresholds and where the growth of that population can be monitored and controlled. This is done by means of land use planning policies which require local councils to carefully consider the impact of new developments within ‘consultation zones’ around each nuclear site. The aim was to avoid the population around the station steadily rising to an undesirable level’ (HSE 2008). These themes will be considered in more detail below.

2.1. The first power programme—Magnox

The UK government’s 1955 White Paper A Programme of Nuclear Power (Ministry of Fuel and Power 1955) set out a 10-year programme for construction of a fleet of Magnox civil nuclear power stations intended to supply between 1500 and 2000 MW of electricity to the national grid. The Magnox programme was intended to provide 25% of UK electricity needs at a total cost of £300 million (£6.5 billion in 2013 prices). The first three orders were placed in 1956 for Berkeley (Gloucestershire), Bradwell (Essex) and Hunterston (Strathclyde), loosely based on the design of the Calder Hall reactors.

The 1955 White Paper addressed the issue of siting and safety as follows:

‘The history of the development of nuclear energy has made everyone aware of its destructive possibilities and it would be natural to ask whether there were any special dangers associated with nuclear power installations. The first important thing to recognise is that it is impossible for an ‘atomic explosion’ to take place in a power reactor. If nuclear power facilities are properly designed any accidents that may occur will be no more dangerous than accidents in many other industries.

‘The main hazards in a nuclear power station are caused by the concentration of highly radioactive materials. But these are known dangers which can be guarded against, both by precautions in the design of the reactor itself and if necessary by enclosing some or all of it in a gas-tight container. The reactors that will be built for the commercial production of electricity will present no more danger to people living nearby than many existing industrial works that are sited within built-up areas. Nevertheless the first stations, even though they will be of inherently safe design, will not be built in heavily built-up areas’.

By the mid-1950s there was growing concern about the potential effects of atmospheric atom bomb tests. However, the month after the 1955 White Paper was published, Minister of Works Nigel Birch was dismissive of any similar dangers involving civil nuclear power. In a Parliamentary debate on fallout from atomic weapons testing he stated: ‘I am advised that there is no danger at all associated with radioactivity from the use of atomic power for civil purposes. Such radioactive materials as are emitted are very weak and their effect is not cumulative. Their
radioactivity ceases almost at once. I want to dispose of any suggestion that the use of atomic energy for civil purposes raises any danger’ (Hansard 1954).

Nevertheless, based on work by T M Fry at the UK Atomic Energy Research Establishment at Harwell, acceptable population densities near nuclear reactor sites were characterised. Fry’s principles, as described in a key paper written with Greg Marley in 1955, were as follows.

- Very few people should be exposed to extreme risk (plans should be prepared for the urgent evacuation of nearby people in the downwind direction).
- Protracted evacuation or severe restriction on normal living should not be imposed on any but small population centres.
- Temporary evacuation or restriction should not be necessary for more than 10 000 people in any but exceptional weather conditions.
- If an accident were to coincide with exceptional weather conditions not more than 100 000 people should ultimately be affected.

In any 10° sector around the plant the population would have to be less than 500 within 1.5 miles, less than 10 000 within 5 miles and less than 100 000 within 10 miles. Population limits all around the site would have to be less than six times the 10° limits (Marley and Fry 1955).

The Windscale fire in October 1957, in Plutonium Pile No. 1, had an effect on public perceptions and on the legislation governing the nuclear industry, notably influencing the establishment of the independent Inspectorate of Nuclear Installations (INI, later renamed the Nuclear Installations Inspectorate, NII). This was created as a result of the 1959 Nuclear Installations Act to take over responsibility for the regulation of safety from the UKAEA’s own Health and Safety Branch (Fishlock 2008). However, its technical relevance to the Magnox stations then being constructed (and in the case of Calder Hall, operated) was limited. Magnox operated at a higher temperature than the Piles, thereby reducing the build-up of Wigner energy in the graphite moderator (the key cause of the fire), while instead of air, pressurised carbon dioxide was used as the circulating coolant, practically eliminating the possibility of the core catching fire. The official view of the radioactive releases caused by the fire was a reassuring one: ‘We (the Medical Research Council) are satisfied that it is in the highest degree unlikely that any harm has been done to the health of anybody, whether a worker in the Windscale plant or a member of the general public’ (Ministry of Fuel and Power 1957). As a result the fire did not affect siting criteria for the Magnox programme then being planned or under construction.

A contemporary report on the establishment of the Sizewell A Magnox station (Electrical Times 1960) listed a number of reasons for the choice of the site, including its suitable geology, proximity to the sea as a source of cooling water for the turbines, position near to a source of high electricity demand and a sufficiently large site to allow for further nuclear stations at later dates. Low population density was not specifically cited, though it was noted that Sizewell itself was a very small fishing village while Leiston (a mile and a half inland) was a small town with few more than 4000 inhabitants.

3. Phase 2—the second nuclear programme, AGR, 1965–1985

As the Magnox programme started to develop, thought was turning both to the reactor design of the programme which would succeed it and to where such plants should be located. As W S Gronow noted, even as the first sites were adopted it was recognised that it would only be a few years before sites of that particular degree of remoteness would be difficult to find (Gronow 1969). A growing sentiment was: ‘As we move into an era of increasing demand...
for nuclear power, it is clear that less reliance must be placed on protection of the public through siting and that greater emphasis must be placed on the design, testing and long-term maintenance of the safety features of reactors. The ultimate aim of this development must be the specification of design requirements for reactors having no siting restrictions (Charlesworth and Gronow 1967). Further, as AGR would require only about half as much cooling water per unit of electricity produced as did Magnox (since it would operate at higher steam pressure and temperature), it would be easier to locate AGR stations away from the coast and nearer to demand centres (Haire and Usher 1975).

Marley and Fry’s initial approach to acceptable population levels near nuclear facilities was modified to permit a more flexible assessment of population distribution. The final development of the criteria was reported in 1963 (Bell and Charlesworth 1963). In this iteration, the population around the reactor in question was examined in relation to a system of weighting factors derived from the dispersal of iodine in stable air conditions in downwind directions. (For example, the weighting factor for 1–1.25 miles from the site was 671; for 2–2.25 miles 84; for 3–4 miles 18; for 9–10 miles 1.1.) The product of population numbers and weighting factors was summed out to a range of 10–15 miles for various 30° sectors subtended from the reactor, the sector with the highest product being designated as the ‘site rating factor’. Sites were then classified according to their site rating factors and, by independent evaluation, a particular reactor type was designated as suitable for a given class of site.

In 1964 the UK government published a White Paper, The Second Nuclear Power Programme (Department of State and Official Bodies and Ministry of Power 1964), which set out a programme for construction of the second generation of British nuclear power stations, to be based on the advanced gas-cooled reactor (AGR) concept. The AGR programme was intended to provide some 5000–8000 MW of capacity.

The first AGRs to be ordered (Dungeness B in 1965, Hinkley Point B and Hunterston B in 1967) were built alongside existing Magnox plants and therefore de facto adhered broadly to the same siting criteria as their predecessors. However, the debate was changing as the technology developed. In March 1967 the International Atomic Energy Agency held a symposium entitled, The containment and siting of nuclear power plants (IAEA 1967). The meeting noted the tension between wishing to build nuclear power stations close to the cities where most of their output is to be used (including, potentially, the use of waste heat from the turbine halls for district heating systems) and the requirements of meeting safety practices which dictated that the stations must in most cases be built away from heavily populated areas. At that stage, however, it was believed that a resolution to the challenge was emerging as experience of new plant projects accumulated.

3.1. A changing international debate

The prevailing opinion of the 250 scientists from 28 countries who attended the seminar was that, against a background of rapidly rising estimates of the capacity to be installed within the following twenty years, the attention being paid to safety considerations was reducing serious hazards and bringing about changes in siting decisions.

It was recognised that heavily populated countries which had already used remote sites for their first nuclear reactors, the UK being an obvious example, might have different perspectives from those countries where there were still sites distant from centres of population. F R (Reg) Farmer, sometime Director of the UK Atomic Energy Authority’s Safety and Reliability Directorate, argued as follows: ‘Until now the sites that have been selected for nuclear power stations have reflected the best available judgement of the balance between the safety of a particular reactor and the size of the population theoretically at risk. This was good enough
to get nuclear power programmes started with relatively few stations and consequently a fair degree of freedom in choosing where they had to be. By now, however, many countries, some of which have high population densities, have accepted the major role of nuclear power. This implies the need to site nuclear power stations strategically in relation to the demand for electricity if their full economics are to be realised. In order, therefore, to derive full advantage from the development of nuclear power it is now necessary to identify and adopt quantitative safety standards to which siting considerations can be related.’ Farmer went on argue that in the UK it was already clear that reactors would have to be designed to standards of safety which would permit complete freedom in siting, and the same situation would soon be reached in other countries. When this goal was reached, site categorisation would disappear and all reactors would need to meet a single high standard if they were to play a significant part in a power network. Less populated sites might be reserved for development of new types of reactor (Farmer 1967).

In the final panel discussion, F de Vathaire said that his impression of the meeting was that justification for site selection was influenced by the practical conditions in each country and that, put simply, countries of low population density were attracted by the concept of safety based on the concept of maximum accident and distance and were more concerned with the maximum individual dose in the event of an accident. By contrast, in more densely populated countries there was more interest in probabilistic approaches and the effects of collective dose, i.e. the probable number of cancers, as this method enabled quantitative justification for the risks involved in siting in urban areas. (De Vathaire expressed his personal view that siting would remain to a considerable extent a matter of faith however good the probabilistic data seemed to be.)

3.2. A more relaxed approach

De Vathaire’s summary well described the shift in the stance of the UK regulators between the first and second nuclear programmes (i.e. the Magnoxes and the AGRs). The nuclear siting criteria adopted in the UK in the mid 1960s (and reaffirmed in the 1970s) were based on Farmer’s work. Farmer developed a series of probability curves (F–N curves or Farmer curves) seeking to quantify the risk to members of the public from accidental releases of the fission product iodine-131 during a severe reactor accident. Iodine-131 is an especially important isotope in such circumstances, being easily absorbed by the body (into the thyroid gland) and highly radioactive, although with a half-life of about 8 days it effectively decays away entirely within about three months of release so does not represent a long-term threat. As was seen after the Chernobyl accident in 1986, where the illness has been the main off-site radiological health effect of the accident, iodine-131 exposure can result in raised rates of thyroid cancer, although fortunately the condition is readily treatable and is rarely fatal.

Farmer’s three risk curves referred to reactor accident scenarios taking place in ‘urban city’, ‘semi-urban’ and ‘remote rural’ environments. The characteristics of the three categories came to be defined as follows:

- remote site—some villages totalling 10 000 people or so at 4–5 miles and a few large towns totalling 50 000 people or so at 9 to 10 miles, with a background population of 150 people per square mile in the populated rural areas inland of the coastal site;
- semi-urban site—a coastal site on the fringe of a highly populated country, the nearby population including a city of 200 000 people at 3–5 miles and a conurbation of about 1000 000 people lying at 20–30 miles, with subgroups of 10 000–50 000 people in the range 5–20 miles and background population of 300 people per square mile;
(hypothetical) city site—an exclusion zone of half-mile radius around the reactor and a uniform population density of 12,800 people per square mile in all directions from 1/2 to 10 miles, typical of wide suburban areas around large cities in the UK (Beattie 1975).

Farmer’s work suggested that choosing a semi-urban site for locating a nuclear power station would increase the total radiological accident risk to members of the public by about a factor of 10, with a further factor of 10 increase if the reactor were sited in an urban city centre. This is largely accounted for by the different population densities between rural and urban environments, which are of the order of 1–100. Farmer concluded that site selection could reduce risk to members of the public from accidental releases of radioactivity by only about a factor of 100. This was regarded as representing a relatively small safety advantage for siting nuclear reactors in remote locations. In his 1967 Vienna paper Farmer had said: ‘it is no use gaining a factor of 3 or 5 in safety by siting and losing a factor of 10 or 100 through lack of attention in reactor engineering’. John Dunster (HSE) and Roger Clarke (National Radiological Protection Board) later said: ‘a reactor siting policy which favoured remote sites would not increase the safety of reactors—it might marginally decrease that safety’, arguing that the longer transmission, lines to remote sites may result in a greater frequency of unplanned grid disconnections. ‘The reactor systems are designed to sustain such unplanned disconnections and emergency power sources are available. Nevertheless, any unscheduled event stresses the safety systems and if other failures occur simultaneously, may be the initiating cause of an accident’ (Dunster and Clarke 1980).

As noted earlier, the government had taken a deliberately cautious approach to the siting of the first (steel pressure vessel) Magnox nuclear power stations, locating them in comparatively remote or rural areas to minimise the numbers of people at risk in the event of an escape of radioactivity. (The final two Magnox stations, at Oldbury-on-Severn in Gloucestershire and Wylfa on the Isle of Anglesey, had concrete pressure vessels, like the AGRs.) In line with changing international perceptions and Farmer’s work, this approach was reviewed by the Nuclear Safety Advisory Committee in 1968. In February of that year, Minister of Power Richard Marsh told the House of Commons: ‘the safety of a gas-cooled reactor in a prestressed concrete pressure vessel is such that it may be constructed and operated much nearer built-up areas than we have so far permitted’ (Hansard 1968a), although the following month, in response to question about the maximum density of population near to which he would permit a nuclear power station to be built he said, ‘I cannot lay down precise figures but I do not yet contemplate licensing stations within a mile or two of developments of full urban density’ (Hansard 1968b). As a result, AGRs were allowed to be built in near-urban environments at Heysham and Hartlepool (which is only 5 miles from Middlesbrough and was in the heartland of the Durham coalmining industry, an issue which caused considerable opposition from the National Coal Board at the time) (Tromans and Fitzgerald 1997). The Central Electricity Generating Board (CEGB) felt able to reassure Durham County Council’s Planning Committee that ‘the latest design of building, plant and equipment were such that there was no possibility of harmful effects being brought upon local people’ (Durham County Council 1968).

The population weighting factors used, distilled from the work by Bell and Charlesworth discussed earlier, were derived from a consideration of the dispersion characteristics of what was known as the generalised Gaussian Plume Model for a prolonged release of radioactive material, based on exposure to iodine-131 downwind of the site (Clarke 1979).

The Royal Commission on Environmental Pollution (RCEP) examined siting policy for reactors in its Sixth Report, chaired by Brian (later Lord) Flowers (Flowers et al 1976). RCEP supported the government’s policy of near-urban siting for commercial nuclear power stations for a variety of reasons. Safety of the public was considered to derive more from high
standards in the design, construction and operation of nuclear power stations than from remote siting—siting within 30 km of an urban centre of demand was thought to be ideal. The need for electricity transmission cables would be reduced, thereby improving the aesthetics of the nuclear power station and reducing transmission losses. It was thought feasible that waste heat from station cooling water could be captured as an energy efficiency measure for use in local district heating or for industry. Reg Farmer served as a technical consultant to the report. One of RCEP’s conclusions was that the relatively small safety advantage in siting nuclear reactors in remote locations, as calculated by Farmer, might be outweighed by other more practical factors in favour of siting reactors closer to industrial and population centres that actually consume the majority of electricity.

In fact, the new AGR site at Torness in Lothian would have met the Magnox siting criteria in terms of population density and some commentators subsequently argued that there was no shortage of isolated coastal sites which could in principle have been used for nuclear plants, though not all would have been ideal in other respects (e.g. distance from major demand centres) (Openshaw 1980).

4. Phase 3—Sizewell B, waste and stagnation, 1985–2005

As early as 1974, Sir Christopher Hinton, the former board member of the UKAEA who had subsequently become the first Chairman of the CEGB, was expressing concerns about the proposal that the UK should develop the US-style pressurised water reactor (PWR) for its projected third nuclear programme. He told the Parliamentary Science and Technology Select Committee: ‘The important question (about light water reactors) is whether, in our crowded island, they are safe. Many Americans are doubtful about their safety. The effectiveness of the emergency cooling arrangements is questioned. Light water reactors use very large welded vessels with many welded branches. But it is only three years ago the Generating Board attributed outage of many of its modern high pressure boilers to defective stub welding of branch pipes. It seems to me that in the last ten years the size and rating of the light water reactors has been pushed forward so daringly as to involve the possibility of hazard. All plants (even conventional plants) involve some measure of risk but it seems to me that of all the nuclear plants at present on the market the ones whose safety should be most strongly questioned are the light water reactors’ (Patterson 1985).

Around the same time (and before the Three Mile Island accident in 1979), the US Nuclear Regulatory Commission tightened, or at least formalised, its guidelines on plant siting (NRC 1975). Under the new guidelines, reactors would have to be located away from very densely populated centres, with areas of low population density generally to be preferred. In determining the acceptability of a particular site located away from a very densely populated centre but not in an area of low density, consideration would be given to safety, environmental, economic or other factors that may result in the site being found acceptable. ‘Locating reactors away from densely populated centres is part of the NRC’s defence-in-depth philosophy and facilitates emergency planning and preparedness as well as reducing potential dose and property damage in the event of a severe accident.’ The Burlington site in Pennsylvania was abandoned and Indian Point in New York State in effect became the upper boundary for population density surrounding a nuclear power stations.

4.1. Growing unease

In the event it would be nearly another decade before the UK was to order its first PWR power reactor. The UK did have some experience of the PWR concept from its nuclear submarine programme (Chumbley 1996). However, the reactors had a reported thermal output of about
70 MW, around one fiftieth that of a 1 GW(e)+ power reactor such as Sizewell B (Bellona 1996). For the beginnings of a PWR power reactor programme it was deemed appropriate to return to the conservative siting criteria which had been applied to the Magnox programme until such a time as the design could be regarded as tried and tested and therefore suitable for building in semi-urban environments like Hartlepool or Heysham.

This theme was emphasised in the Public Inquiries into the construction of Sizewell B and Hinkley Point C in the mid- to late 1980s. Ron Anthony, Chief Inspector of Nuclear Installations, told the Sizewell B Inquiry: ‘If a reactor system new to commercial operation in the UK, such as a PWR, is put forward for licensing, it is government policy that initially it would be located only on a remote site until appropriate experience had been gained’ (Anthony 1983). Similarly at the Hinkley Point C Inquiry, Anthony’s successor Eddie Ryder reiterated that it was policy ‘... to require PWR stations, which are new to this country, to be sited in remote areas, at least until satisfactory operating experience is obtained’ (Ryder 1989).

While the population constraints concerning the first UK PWRs would be as strict as those which had been applied to the Magnox programme, following the Sizewell B public inquiry more relaxed siting criteria were proposed and presented to the Advisory Committee on the Safety of Nuclear Installations for later PWRs. They were based on a population density of 900–1800 persons per square kilometre in the most populated 30° sector, falling between the ‘remote site’ criteria and the ‘semi-urban’ criteria which had been applied to the later AGRs.

The Three Mile Island accident in the USA in 1979, in a PWR reactor which had been operating for less than a year, further exacerbated concerns over the use of the technology in the UK, although no significant release of radioactivity had resulted. In the USA, in particular, the accident had a profound effect on plants then under construction.

In the UK the NII published its first set of Safety Assessment Principles (SAPs) for Nuclear Power Reactors in 1979, which were amended in 1988 following a recommendation from the Sizewell B PWR public inquiry and again in 1992 and 2006 (HSE 1992). The 1992 SAPs were of central importance to the siting of new nuclear power stations because they specified a number of key siting principles including:

- the first plant of a new type should be built on a remote site;
- all nuclear plants are required to have an emergency plan;
- the site topography, as it affects possible dispersal of radioactive releases and movement of the population, will be characterised;
- information on natural and man-made hazards in the area will be provided;
- it would be possible to evacuate all persons from an affected area of up to 1 km around the site in about two hours.

However, as far as nuclear power new build was concerned these documents were of limited significance, as there was no realistic prospect of anyone considering constructing such plants.

5. Phase 4—renaissance, 2005 to date

By 2005, attitudes to nuclear power, in government and in the public, were changing rapidly. The UK’s decade as a gas exporter had ended and imports were rising (BP 2012). Gas and coal prices had risen on the back of an increase in global oil prices and the fall in carbon dioxide emissions through the first half of the 1990s had largely stalled as coal reasserted itself as a fuel for electricity (DECC 2013). Nuclear power began to look much more attractive to many commentators.
In 2001 the HSE had published the Radiation (Emergency Preparedness and Public Information) Requirements (REPPIR) (HM Government 2001). These regulations put a duty on local authorities to ‘prepare, review, revise and test off-site emergency plans for fixed sites and test carrier’s emergency plans’, one aim being to increase awareness of such plans among the local population. The SAPs were revised in 2006 (HSE 2008) to apply lessons learned since the previous iteration (1992), benchmark with international standards and respond to the rising profile of decommissioning of civil nuclear liabilities in the UK.

The Nuclear White Paper of 2008 (BERR 2008) included a foreword from the then Prime Minister, Gordon Brown (Labour Party), saying, ‘The Government has today concluded that nuclear should have a role to play in the generation of electricity, alongside other low-carbon technologies. . . Nuclear power is a tried and tested technology. It has provided the UK with secure supplies of safe, low-carbon electricity for half a century. New nuclear power stations will be better designed and more efficient than those they will replace. More than ever before, nuclear power has a key role to play as part of the UK’s energy mix. I am confident that nuclear power can and will make a real contribution to meeting our commitments to limit damaging climate change.’ However, any new plants would not be built with government money but by commercial concerns.

From a business point of view, private sector companies decide on where to locate new facilities by balancing such key factors as proximity to markets and materials, availability of skilled and trained labour, well developed infrastructure, good transportation networks, connections to electricity and water utilities and low land and development costs (Gerrard 1994). These factors are also relevant when such decisions are taken by state-owned bodies. However, it is likely that financial considerations will be relatively more important (and social considerations less so) to commercial entities than to effectively social ones such as governments. As previously noted, siting power stations close to centres of demand reduces the need for building and operating long-distance power transmission, reduces losses from the electricity grid, improves the efficiency of the network and reduces costs, and may also have advantages during the construction phase and with regard to the provision of a workforce. There have been many protests over the last decade and more over proposals for new overground transmission lines, often associated with needs to connect new windfarms, and gaining planning permission is becoming increasingly challenging (BBC 2005). This has resulted in powerful social pressure to put such transmission lines underground, at much greater cost (CPRE 2012).

These considerations should also be viewed against the background of a UK population which had grown by some 25% between 1951 and 2011 (Census Reports 2013). Although the degree of urbanisation increased marginally over this period (from 78.4% in 1960 to 79.6% in 2011) (Index Mundi 2013), the national population growth inevitably led to an expansion in the population density of some rural areas.

In practice, at least for the first phase of any proposed large-scale new build programme in the UK, reuse of existing nuclear sites delivers on many of these requirements (e.g. the pre-existence of grid connections and other infrastructure although significant strengthening may be required, availability of skilled workers and cooling water supplies) while also tending in general to be in relatively isolated areas for the historical reasons discussed earlier. A ‘hierarchy’ of site characteristics desirable for new build was developed (Jackson and Jackson 2006):

(1) existing nuclear power sites (14);
(2) other existing nuclear sites (5);
(3) conventional power sites (about 80);
(4) greenfield sites.
In a 2008 paper for the Nuclear Safety Advisory Committee (Highton and Senior 2008), the HSE argued that ‘The improvement in safety which can be achieved solely by a choice of nuclear sites is limited and needs to be considered against the social, economic and amenity advantages that may arise. In this sense the selection of sites for nuclear power plants in the United Kingdom involves some judgement of the balance between safety, economics and amenity.’

Under the 2004 justification of practices involving ionising radiation regulations (Defra 2004) the Secretary of State must decide whether a new class or type of practice resulting in exposure to ionising radiation is justified by its economic, social or other benefits in relation to the health detriment it may cause. This decision was published in 2010 with regard to the EPR design under consideration for new build at Hinkley Point C (DECC 2010a).

The NPS outlined the conclusion of the Strategic Siting Assessment (SSA) process, initiated in 2009 and designed to identify sites in England and Wales that were ‘potentially suitable’ for nuclear new build, ‘based on the information available to the government at the time’. (Although energy was nominally an issue which was governed at UK level, the Scottish Government had made clear its opposition to nuclear new build north of the Border; as the planning authority it had an effective veto on such development.) Potential plant owners were invited to ‘nominate’ sites for new build, which would be assessed by the Infrastructure Planning Commission (IPC), an independent body established in March 2010 to take development consent decisions on nationally significant infrastructure projects. (The IPC was subsequently abolished, its duties transferring to the Infrastructure Planning Unit within the Planning Inspectorate.) A site licence under the 1965 Nuclear Installations Act would have to be granted before a new reactor could be installed and operated on a specific site. Before the ONR granted a licence it would ensure that the site was suitable for the particular design and that the potential operator could adequately control construction, operation and maintenance of the plant to ensure safety (ONR 2012a). EDF applied for a site licence for Hinkley Point in mid-2012 and the licence for Hinkley Point C was granted by the ONR in November 2012 (ONR 2012b).

In April 2009 the government had published for consultation the list of sites which were to be included in the SSA process for stations to come into operation before 2025. At that stage 11 such sites were included, all but two alongside existing nuclear power facilities (operating or being decommissioned). A series of ‘SSA criteria’ were published, against which the IPC would make its decision as to whether or not to grant development consent at any of the listed sites (DECC 2011b). These criteria spanned a wide range of considerations:

1. demographics;
2. proximity to military activities;
3. flooding, tsunami and storm surge;
4. coastal processes;
5. proximity to hazardous industrial facilities and operations;
6. proximity to civil aircraft movements;
7. internationally designated sites of ecological importance;
8. nationally designated sites of ecological importance;
9. areas of amenity, cultural heritage and landscape value;
10. size of site to accommodate operation;
11. access to suitable sources of cooling;
12. capability of the site to store spent fuel and intermediate level waste.
Under the heading of ‘demographics’, the government’s position was that it was no longer necessary to apply the remote siting criteria which were applied to both the first generation (Magnox) reactors and proposals to build PWRs at Sizewell and Hinkley Point in the 1980s. As noted above, because the PWR was a new design to Britain at that time a precautionary approach was taken. The designs of reactors being assessed through the Generic Design Assessment (GDA)—at that stage EPR and AP1000—were considered ‘modern’ designs which did not require such a precautionary policy to be applied. Instead the semi-urban criteria, which were applied to the later AGRs, were to be used. The nomination process did not require bodies nominating sites to submit demographic information at that stage because of the complexity of the calculation required to decide whether a site met the ‘semi-urban’ siting criterion—it was noted, for example, that Heysham did not appear to do so but that further advice from the regulators had been sought to see whether the site remained viable.

In 2011 the government announced that, having considered all of the sites nominated and those identified in the alternative sites study, eight sites were potentially suitable for the deployment of new nuclear power stations in England and Wales by the end of 2025, namely:

- Bradwell;
- Hartlepool;
- Heysham;
- Hinkley Point;
- Oldbury;
- Sizewell;
- Sellafield;
- Wylfa.

Three sites from the original 11 were excluded—Dungeness in Kent, owing to local environmental considerations, and Braystones and Kirksanton in Cumbria (2 and 20 miles respectively from Sellafield), both greenfield sites.

It was not considered reasonable to expect nominators to have established detailed layouts for the whole of their proposed developments, including for example any additional land needed for construction or decommissioning, at the time of making their nomination. The SSA could therefore only conclude that sites were ‘potentially’ suitable at a strategic level. There are several other requirements which must be satisfied before a company can begin to construct a nuclear power facility at a particular site. Planning decisions fall to the relevant local and national planning authorities—planning permission for Hinkley Point C was granted in 2013 (National Infrastructure Planning 2013). Assessing the adequacy of the operator’s nuclear liability insurance, financial standing and funded decommissioning programme is the province of the Department of Energy and Climate Change. The EA must grant licences with regard to such activities as:

- radioactive waste discharges and disposals;
- discharge of non-radioactive effluent, including cooling water used in the turbine condenser;
- operation of large diesel generators to act as back-up for safety systems should the site lose off-site power.

These licences were granted with respect to Hinkley Point C in 2013 (Environment Agency 2013).

In March 2011, almost exactly twenty five years after Chernobyl, the Great East Japan Earthquake and Tsunami caused a major event at the Fukushima Dai-ichi nuclear complex.
Three of the six reactors on the site underwent partial meltdown, with a release of radioactive materials second only to Chernobyl. A report requested from the UK’s Chief Inspector of Nuclear Installations, Dr Mike Weightman, concluded that there was no reason to revise the strategic advice given by the regulators on which the Nuclear National Policy Statement was based nor any need to change siting strategies for new nuclear power stations in the UK (Weightman 2011).

6. Towards a fifth phase?

Any predictions about a ‘fifth phase’, from 2025 onwards, are by nature highly speculative at this stage. However, post-Fukushima two diametrically opposed arguments may be emerging.

There has been an absence of any observable radiation-related health damage as a result of that accident. Calculations of doses received by local people suggest that there will be no statistically significant increase in such health effects over the next decades, though the possibility of some health effects undetectable against background levels of the diseases in question cannot be entirely ruled out. However there is clearly observed psychological illness, over and above the trauma caused by the earthquake and tsunami (Nippon 2011). Psychological effects also dominated the health consequences of Three Mile Island (Kemeny et al. 1979) and, arguably, Chernobyl: more than a decade after the accident mothers of young children who were evacuated from the Chernobyl area had twice the rate of post-traumatic disorders found among the general population (Bromet and Havenaar 2007). In the region around Fukushima levels of stress are clearly affecting the confidence of residents to return to their homes even outside the evacuation zone, and presumably this will be more so when the zone itself is delimited. Relocation arguably can make the stress of living with the consequences of a nuclear (or other) accident worse, taking people away from their familiar homes and communities and breaking social links which have built up within those communities. A health questionnaire sent to Fukushima residents by Fukushima Medical University showed that about 15% of 67 500 respondents indicated high levels of stress on the Kessler Psychological Distress Scale, against normal rates of about 3%, while 21% scored highly on a checklist used to screen for post-traumatic stress disorder. It is therefore at least arguable that the countermeasures introduced to respond to these accidents have caused as much, if not more, detriment to the quality of lives of those affected than did radioactive releases during the accident itself. This would seem to contravene one of the basic principles of radiological protection, that of ‘justification’, i.e. that countermeasures should only be introduced if they are expected to achieve more good than harm.

This was leading to some US researchers questioning whether the US Environmental Protection Agency ‘action levels’ for long-term evacuation following a nuclear incident should be reviewed and possibly relaxed (National Council on Radiation Protection and Measurements 2013). While not directly relevant to siting criteria, such a change in approach would be unlikely to lead to stricter population restriction standards.

By contrast, the issue of the potential consequences of Fukushima had the wind direction been less favourable has led for calls to tighten the siting regulations, especially with regard to population densities downwind of nuclear plants. In a 2012 report Greenpeace said: ‘Governmental data released only later revealed that in a worst-case—but possible—scenario, evacuation would have included the megapolis of Tokyo and other settlements up to 250 km away. Clearly, evacuation planning based on circles with diameters of several kilometres is too rigid and hopelessly inadequate in the case of nuclear power plants’ (Greenpeace International 2012). (As noted earlier, the UK approach has been based on 30° sectors rather than circles.)
Some commentators have argued that the panic among people living more than 10 miles from the reactor in the early stages of a major accident may hamper evacuation efforts and called for this to be taken into account when siting of any new facilities is considered (Donn 2013). There may also be calls for giving countries more powers over siting decisions involving nuclear plants in neighbouring countries near their own borders, an issue which is already subject for example to European Union protocols (EU 2012).

7. Conclusions

Several factors are relevant to decisions over siting of nuclear facilities. However, the IAEA does lay special stress on site evaluation aimed at ensuring adequate protection of site personnel, the public and the environment from the effects of ionising radiation, in line with IAEA Safety Standards (IAEA 2003).

In the UK, the way that radiological protection has been incorporated into siting considerations has evolved over time, although the fundamental principle—that there should be an appropriate limit on the population density in the areas around a proposed nuclear plant, both when it is built and in subsequent years—has endured throughout.

In the immediate post-war period many of the facilities established in the UK were in effect one-offs. In view of the small numbers of such facilities it was feasible to place them in highly isolated areas. Much the same could be said of the first power reactors—despite some rather complacent statements about the very low probability of any threat to people on- or off-site in the case of an accident, in practice isolated sites were chosen rather than locations closer to the centres of power demand. Parallels can be drawn with the development of fossil fuel-fired generating plant in the UK. Desires to locate facilities close to centres of demand led to power stations such as Battersea (coal) and Bankside (oil) being built in central London in the inter-War and immediately post-War period. The London ‘pea souper’ fogs, a feature of the capital since the early 19th century, were increasingly being regarded as an unacceptable health and economic hazard, especially following the December 1952 example which killed at least 4000 people, disrupted travel for several days and led to the Clean Air Act of 1956 (Met Office Education 2013). Subsequent coal-fired power stations such as Drax and Didcot were built away from centres of population, with tall chimneys to remove acid emissions from the area.

From time to time it has been assumed that the UK will need a large programme of nuclear reactors, to respond to projections of rapidly growing demand for electricity and/or supply and cost problems with its alternatives. For example, in 1973 CEGB Chairman Arthur Hawkins told the Parliamentary Science and Technology Select Committee that peak electricity demand was expected to grow to 62 GW in 1980/81, 80 GW in 1985/86 and 103 GW in 1990/91. On that basis CEGB saw the need to commission about 36 GW of new nuclear capacity during the 1980s, equivalent to 30 Sizewell Bs (Hansard 1974).

These projections were not unreasonable based on the growth rates which had been seen in the period between the end of the war and the early 1970s. Peak metered demand increased almost five-fold between 1947/48 and 1972/73, representing an annual growth rate of over 6%. In the event, however, the projected growth was not to materialise. Peak metered demand in those three years (1980/81, 1985/86 and 1990/91) in England and Wales was to be 43 GW, 45 GW and 47 GW respectively, against 41 GW in 1972/73 (figure 2).

However, it would be challenging to create a future programme of anything like the size envisaged by Hawkins based on the isolated siting proposals which had characterised the Magnox programme. The much expanded output of modern reactors compared to Magnox, and the possibility of developing several units on one site, mitigate the difficulties to an extent,
but it is important also to consider the other detrimental effects of building reactors so far from centres of demand. These include the disruption to considerable swathes of relatively untouched British countryside, the cost of transmission connections (especially if the new lines have to be put underground to protect the local environment), the higher danger of interruption to connections owing to technical failure (again especially if the wires are underground, making it much more difficult and costly to identify faults) and power losses (although these are modest in the high voltage portion of the grid). By the early 1960s thinking had turned towards relaxing the demographic criteria to allow nuclear plants to be built in ‘semi-urban’ locations, with a hope that in due course demonstrable improvements in plant safety would allow construction in or very near major cities. The AGR programme of reactors was developed with this new approach in mind, with new sites being deployed at Hartlepool and Heysham in much more heavily populated areas than those hosting the Magnox plants, though still by no means in major cities.

In the event, nuclear power developed far more slowly than had been assumed (partly because projected peak power demand was only around 60 GW even by 2013) and the number of new sites required proved to be small. When it came to planning for a third programme of nuclear reactors, based on the PWR design, there was a return to caution, in part prompted by the Three Mile Island accident of 1979. The first two plants of the new fleet were to be built in low-density rural locations, with land alongside the Sizewell (Suffolk) and Hinkley Point (Somerset) Magnox reactors being chosen. But the UK nuclear programme had lost impetus by the mid to late 1980s, for reasons not directly connected with siting problems.

When the UK government became convinced of the need for nuclear new build in the middle of the first decade of the new century, steps were taken to reduce the regulatory and licensing risk for potential investors by providing a pre-licensing assessment of the design. This would shorten the time expended in a Public Inquiry, which for example would not need to consider issues of justification and plant safety for every application, and reduce the danger of significant regulatory changes being introduced between licensing and the start of construction. As part of this process, a series of sites were identified by name (through the Strategic Site Assessment) for new build to be operating before 2025. All of these sites had already hosted

Figure 2. Peak metered demand, England and Wales (MW)—total gross system demand is typically some 10–15% higher (National Grid 2013).
Magnox or AGR reactors (or both) and the list included the semi-urban areas of Heysham and Hartlepool.

At this point the size of any new programme of nuclear power stations is difficult to assess. The government’s aspirations for 16 GW of new capacity to replace AGR capacity (DECC 2010b) could easily be accommodated on the eight sites identified in the SSA, so de facto the same demographic siting criteria as had been used in the AGR programme (which included several sites which were also appropriate for Magnoxes) will apply to these plants.

Should the UK ultimately embark on a programme significantly surpassing the 16 GW presently envisaged, new sites might eventually be required. The hierarchy of sites suggested by Jackson and Jackson would imply that, once the existing nuclear establishment sites have been used (with the exceptions presumably of Trawsfynydd and Berkeley, with limited water supplies, and Hunterston and Torness, owing to political objections from the Scottish Government), attention might turn to sites which have hosted other types of power station. A ‘fifth phase’, commencing around 2025, might be based on more relaxed siting criteria, influenced by a need for several new sites and a reappraisal of the radiological health consequences of a major accident such as Fukushima and a desire to put radiation into a more accurate perspective, thereby reducing the psychological damage caused by such incidents. Or it might be based on tighter population criteria, driven by much lower demand for new build, more restrictions for population densities downwind of the site and more pressure from the European Union or elsewhere to pay more attention to cross-border consequences of nuclear plant location.

At present, however, it is not possible to forecast how a ‘fifth phase’ might develop. A range of factors, such as public perceptions and the political stance of the governments of the day (including local authorities), will be crucial factors which are at present unpredictable. For the time being the issue of siting of the next generation of new build, up to 2025 or perhaps 2030—however large that programme might be—seems to be settled.

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