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Abstract
Choosing a suitable site for a nuclear installation requires the consideration and balancing of several factors which are sometimes in tension with one another.. 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 to 1965) there was a highly cautious attitude, with installations being placed in remote rural locations with very low population density. The second phase (1965 to 1985) saw a more relaxed approach allowing Advanced Gas-Cooled Reactor construction closer to population centres (in 'semi-urban' locations, notably at Hartlepool and Heysham). In the third phase (1985 to 2005) there was very little new nuclear development, Sizewell B (the first and so far only pressurised water power reactor in the UK) being co-located with an early Magnox station on the rural Suffolk coast. However, there was considerable effort expended on trying to find a site for disposal of radioactive wastes. Renewed interest in nuclear new build grew from 2005 onwards and 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 Power, Safety, Planning, Environmental Protection

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THE SITING OF UK NUCLEAR POWER INSTALLATIONS

M.C. Grimston[1] and W.J. Nuttall[2]

Extended Abstract

Choosing a suitable site for a nuclear installation requires the consideration and balancing of several factors. Some 'physical' site characteristics, such as local weather conditions 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 to 1965) there was a highly cautious attitude, with installations being placed in remote rural locations with very low population density. The second phase (1965 to 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 to 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. However, there was considerable effort expended on trying to find a site for disposal of radioactive wastes. 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.

Introduction

The accident affecting four units of the Fukushima Dai-ichi nuclear power plant in Japan, following the Tohuku 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.

Some of the issues were already apparent after the Three Mile Island accident in the USA in 1979, including the consequences of loss of coolant accidents in light water reactors and the importance of decay heat management in such circumstances. The Chernobyl accident in Ukraine in 1986 also

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resulted in some lessons being learned, notably concerning measures to protect the local population during and after a major crisis and regarding the importance of cross-border issues, especially where nuclear plants are located close to national borders.

Policies concerning the reduction of exposure to nearby residents, e.g. through precautionary evacuation, in the event of a severe offsite radioactive release had been considered before Fukushima. As early as 1977 in the UK, 'Emergency Reference Levels' (ERLs), expressed in terms of the dose to an individual that could be averted in the case of an emergency by taking countermeasures, had been specified. Doses below the lower ERL should not trigger countermeasures, as to do so would cause more damage than benefit; doses above the higher ERL countermeasures should be introduced (unless it would clearly contravene the underlying principles of justification and optimisation to do so); while introduction of countermeasures should be considered, but not necessarily implemented, if doses fell between the two ERLs.[3] However, it can be argued that the implications – in particular concerning the balance between the radiological advantages of evacuation and the social disadvantages (stress, panic, accidents during the physical evacuation) – were not fully understood at the time of Fukushima. In particular, it can be questioned whether it is appropriate to have a single set of values for ERLs when the characteristics of the population in question may vary considerably from plant to plant (or accident scenario to accident scenario – for example, evacuation is clearly a much more difficult measure to take against the background of a devastating tsunami than it would be under more 'normal' conditions.)

Doses to the population might have been significantly higher had it not been for the rather fortuitous seaward prevailing wind, though it remains unlikely that even had the wind been blowing inward doses would have reached levels associated with observable health effects in the short or long term.

These issues were relevant at Chernobyl, but that accident happened in a Communist command society with weak property rights and where much of the land was of relatively low economic value and quite sparsely populated. Fukushima emphasised much more strongly 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.[4] It should be noted however that models had been developed before Fukushima for considering the financial implications of major accidents.[5]

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:

- 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.;

[3] http://www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1317135086215, NRPB (1990), *Documents of the NRPB Vol. 1 No. 4.*
[4] EPSRC UK grant EP/K007580/1 2012-2014.
[5] http://www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1228894737581, Higgins N.A. *et al.* (2008), *COCO-2, a model to assess the economic impact of an accident,* Health Protection Agency.

- technical factors, e.g. the ability of the geology to withstand the very high weight of a nuclear power reactor;
- social factors – levels of local public and political support; availability of skilled workforce; history of positive engagement in the area;
- 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)
- 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 six 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.[6]

The earliest 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 (the locations often being some way away from major roads);
- providing and accommodating a workforce (the motor car being far less ubiquitous than it is today);
- the quality of the local environment (Dungeness in Kent is ta present not regarded as suitable for new build, despite hosting an AGR and a decommissioned Magnox station, because of classification of the local environment as a European Special Area of Conservation);
- in some case, the distance form the centres of power demand, requiring expensive and unsightly grid connections and leading to increased transmission losses.

[6] Haire, T. P. and Usher, E. F. F. W. (1975), 'Nuclear power station siting experience in the United Kingdom', in *Siting of nuclear facilities*, IAEA (Vienna).

The ultimate size of the boilers for the Calder Hall nuclear power station on the Windscale/Sellafield site, which began generating in 1956, was determined not by engineering limits but by the maximum clearance available on the road through the village of Egremont through which the boilers had to be transported en route to the site. [7]

A further illustration of the point involves the UK fast reactor programme which was established at Dounreay on the north coast of Scotland. Although the project was abandoned in the 1990s largely for economic and technical reasons, the low price of electricity in an area of very sparse population had a serious effect on the economics of the 250 MW Prototype Fast Reactor, leading to it closing earlier than it might have done had it been nearer to centres of power demand.[8] Furthermore, its distance from Parliament may have served to put the project out of sight and out of mind for many involved in administration and regulation. Had the project been located at Winfrith, say, such obstacles would have been less pronounced. In the case of the Fast Reactor research programme the ultimate outcome would undoubtedly have been no different. However, it may be the case that where a decision to build a nuclear power plant is a marginal one, say on grounds of cost, the challenges associated with isolated locations may be sufficient to tip the balance against a decision to invest.

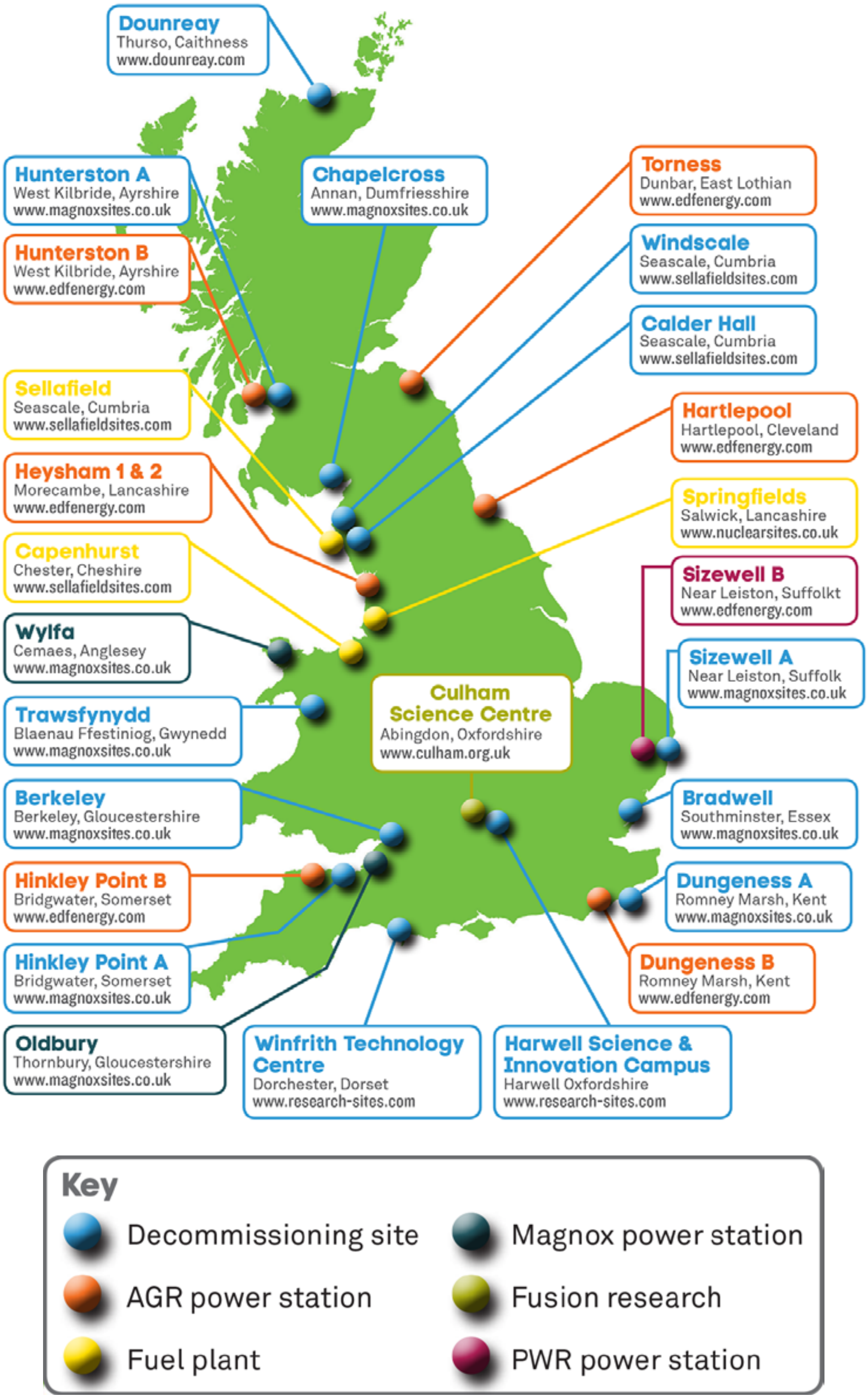
The first reactors of the AGR programme (decisions on construction being taken between 1965 and the late 1970s) were built alongside the existing Magnox stations at Dungeness in Kent, Hinkley Point in Somerset and Hunterston in Strathclyde. However, the later stations included new sites closer to centres 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.

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 on nuclear power[9] 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.

[7] Pocock R. F. (1977), *Nuclear power: its development in the United Kingdom*, Unwin Brothers: London

[8] Milne R. (1992), 'Dounreay closure jeopardises fast breeders', *New Scientist* Vol. 135, Issue 1834.

[9] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/47859/2009-nps-for-nuclear-volumeI.pdf, DECC (2011), *National Policy Statement for nuclear power generation, EN-6.*



UK nuclear sites[10]

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

[10] http://www.niauk.org/locations-in-the-uk, Nuclear Industry Association (2013), *Locations in the UK.*

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. 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".[11] This would imply a relaxation of emergency measures – such proposals have been put forward in the USA[12] – 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. (Routine discharges, being very low, have not generally been regarded as a significant siting issue.)

The potential development of Small Modular Reactors (SMRs), with units which would have lower requirements in terms of land take and access to cooling water, for example, may make some previous or current nuclear sites, such as Trawsfynydd and Dungeness in the UK, more suitable for new build than they would be for a 1000MW+ reactor.

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 (then in Lancashire, subsequently Cheshire), Springfields (Lancashire) and Windscale (Cumbria). Motivations included the desire to create an independent UK nuclear deterrent 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 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 reactors, as follows.

[11] http://www.un.org/ga/search/view_doc.asp?symbol=A/67/46, UNSCEAR (2012), *Report of the United Nations Scientific Committee on the Effects of Atomic Radiation, Fifty-ninth session (21-25 May 2012)*, United Nations.

[12] http://www.nti.org/gsn/article/white-house-advances-controversial-nuclear-incident-response-guide/, Guarino D. P. (2013), 'White House advances controversial nuclear incident response guide', *NTI Global Security Newswire.*

"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. Most of those suggested had very few temporary buildings and offered little advantages over open sites; we were left with a short list of Duxford (near Cambridge), South Cerney (near Cirencester), Benson and Harwell [in Oxfordshire]. Duxford, in spite of the great advantages of proximity to Cambridge, was voted to be too inaccessible to most universities and there was not enough water available. South Cerney was an attractive airfield but somewhat too isolated; so in the end we were given Harwell, and on a windy day of February 1946 ... I was able to look closely at our heritage."[13]

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".[14]

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

[13] Cockcroft J. (1948), "The Genesis of AERE." Reproduced in Sandalls J. (2004), *Thirty Six Years at the Atomic – My Time at AERE Harwell 1958-1994*, Perfect Image Press.
[14] Arnold L. (1992), *Windscale 1957 – anatomy of a nuclear accident*. Macmillan.

energy was a defence industry, hence speed was vitally necessary and great risk of failure had to be accepted”.[15]

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 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, thought it remained known as Sellafield locally. Windscale Pile No. 1 became operational in October 1950 and Windscale Pile No. 2 in June 1951.[16]

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 site was originally chosen following enthusiastic lobbying by the local Conservative MP Sir David Robertson in 1953 (offering a reminder of the importance of political and even personal factors in site selection issues – it seems that there had been little thought of setting up a facility in the Highlands before Robertson’s involvement. Lord Hume, then Scottish Secretary, described the decision over the site as “a striking example of cooperation between the local authority and a potential new industry” [17]). However, when Sir David Eccles MP, Minster of Works, announced the establishment of the site in 1954 he explained that a fast reactor needed a very large site in open country, ideally on the coast, with a source of fresh water and with a modern town within easy reach to provide for the workforce. The airfield at Dounreay “meets all these requirements better than any other site, and it has the further advantage that development there should make a big contribution to the revival of the Highlands”.[18]

The potential dangers of the facility were explicitly accepted by Christopher Hinton when he addressed local residents at Thurso Town Hall in 1955, an approach which did much to allay local suspicions and fears.[19] 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.”[20]

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.

[15] Hall T. (1986), *Nuclear politics: the history of nuclear power in Britain*, Penguin Books.
[16] Bolter H. (1996), *Inside Sellafield*, Quartet Books.
[17] Pocock R. F. (1977), *Nuclear power: its development in the United Kingdom*, Unwin Brothers: London
[18] http://hansard.millbanksystems.com/commons/1954/mar/01/atomic-energy-authority-bill#S5CV0524P0_19540301_HOC_252, *Hansard* (1954), ‘Atomic Energy Authority Bill’, HMSO.
[19] http://www.internet-promotions.co.uk/archives/dounreay/doun3.htm, Cashmore S. (1998), *Highland archives, Dounreay 1954 – the fear and the facts*, UKAEA.
[20] http://www.neimagazine.com/news/newsdounreay-fast-reactor-celebrates-fifty-years, Nuclear Engineering International (2009), ‘Dounreay fast reactor celebrates 50 years’, November 10 2009.

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.[21] Some 70 sites were considered but eventually Winfrith Heath in Dorset was chosen. In contrast to the earlier research establishment, this was in effect 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.[22]

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."[23] These themes will be considered in more detail below.

The first power programme – Magnox

The UK government's 1955 White Paper *A Programme of Nuclear Power*[24] 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 case for nuclear power received a further boost the following year. The Suez Crisis of 1956 can be regarded as one of the first wars for oil. Although oil was a minor fuel for electricity generation in the UK at the time, its use was growing[25]; the unsuccessful military operation in Egypt left the Britain's access to oil from the Persian Gulf appearing very tentative. The Magnox programme was duly expanded[26], and although the programme was subsequently scaled back some 26 Magnox reactors were eventually being built on 11 nuclear sites across the UK, with total capacity 4200 MW. (Two Magnox stations were exported, to Italy and Japan.) The commercial

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[21] http://www.nda.gov.uk/ukinventory/sites/winfrith/, NDA (2010), *Winfrith.*
[22] http://www.dorsetlife.co.uk/2009/11/how-the-mighty-atom-came-to-dorset/, Miller A.J. (2009), 'How the mighty atom came to Dorset', *Dorset Life.*
[23] http://www.hse.gov.uk/landuseplanning/land-use-planning.pdf, HSE (2008), *Land use planning and the siting of nuclear installations in the United Kingdom.*
[24] http://filestore.nationalarchives.gov.uk/pdfs/small/cab-129-73-c-55-31-31.pdf, Ministry of Fuel and Power (1955), *A programme of nuclear power*, Cmnd 9389, HMSO.
[25] https://www.gov.uk/government/statistical-data-sets/historical-electricity-data-1920-to-2011, DECC (2012), *Historical electricity data: 1920-2011.*
[26] Ministry of Fuel and Power (1957), *Capital investment in the coal, gas and electricity industries*, Cmnd 132, HMSO.

stations contained twin Magnox reactors while the military stations at Calder Hall and Chapelcross each had four.

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 some concern about the potential effects of atmospheric atom bomb tests. However, the month after the 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."[27]

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 degree 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 degree limits.[28]

[27] http://hansard.millbanksystems.com/commons/1955/mar/22/nuclear-explosions-genetic-effects, *Hansard* (1955), 'Nuclear explosions (genetic effects)', HMSO.
[28] Marley W. G. and Fry T. M. (1955), 'Radiological hazards from an escape of fission products and the implications in power reactor location', *Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Geneva*, United Nations.

The infamous 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). 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.[29] 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".[30] As a result the fire did not affect siting criteria for the Magnox programme then being planned or under construction.

Initially nuclear reactor sites were subject to the approval of the Reactor Location Committee, which was made up of members from the United Kingdom Atomic Energy Authority and the Central Electricity Generating Board. The Nuclear Installations (Licensing and Insurance) Act of 1959 was largely a response to the Windscale fire and had three aims: to provide for licences for those who wanted to operate nuclear installations; to impose on licensees absolute liability, or at any rate a wide measure of liability, for damage to third parties; to ensure that licensees should have adequate funds at their disposal to meet what could well be extremely heavy claims.[31] Under the Act responsibility for the licensing of nuclear installations passed to the Minister of Power (subsequently Secretary of State for Energy; for Trade and Industry; and for Energy and Climate Change). Pursuant to the implementation of the Act the government created the INI and the Nuclear Safety Advisory Committee (NuSAC), comprised of 'independent experts', to give advice on matters of nuclear safety.[32] The 1965 revision of the Act states, "… no person shall use any site for the purpose of installing or operating any nuclear reactor (other than such a reactor comprised in a means of transport, whether by land, water or air), or any other installation designed or adapted for the production or use of atomic energy or the carrying out of any process which is preparatory or ancillary to the production or use of atomic energy, or the storage processing or disposal of nuclear fuel, unless a licence to do so has been granted in respect of that site by the Minister." Contravention of the Act could carry a fine of up to £500 and/or five years in prison.[33] The INI was renamed the Nuclear Installations Inspectorate, NII.

One issue which exercised planners at the time was the possibility of rapid population growth near to existing Magnox power stations undermining the calculations on which the siting decision had originally been based – indeed, in isolated sites some development would be inevitable to provide accommodation for the workforce and support services. In June 1961 a letter by the then Minister of Housing and Local Government, Henry Brooke, identified three safeguarding zones (inner, middle and outer) around each site. Local councils were asked to consult the Minister on certain

[29] http://www.independent.co.uk/news/obituaries/thomas-tuohy-windscale-manager-who-doused-the-flames-of-the-1957-fire-800546.html, Fishlock D. (2008), "Thomas Tuohy: Windscale manager who doused the flames of the 1957 fire" *Independent* March 26 2008.
[30] Ministry of Fuel and Power (1957), *Accident at Windscale No. 1 Pile on 10 October 1957*, Cmnd 302.
[31] http://hansard.millbanksystems.com/lords/1965/mar/04/nuclear-installations-amendment-bill#S5LV0263P0_19650304_HOL_68, *Hansard*, 4 March 1965.
[32] Haire, T. P. and Usher, E. F. F. W. (1975), 'Nuclear power station siting experience in the United Kingdom', in *Siting of nuclear facilities*, IAEA (Vienna).
[33] http://www.legislation.gov.uk/ukpga/1965/57, Nuclear Installations Act 1965.

proposed developments within each of the three zones. The inner and middle zones were based on 1 and 2 mile radii, with the contours adjusted to avoid cutting through centres of population and to follow natural boundaries. The boundary of the outer zone was set at 5 miles from the station. It was considered at the time that the control given by the above safeguarding zones would be sufficient to ensure that population growth around the sites would not take place without the knowledge of the regulators.[34] This measure remains in place: in 2009 the NII objected to a proposed housing development some 500 metres from the Aldermaston atomic weapons establishment perimeter fence in Berkshire, stating that the population levels near the site were already at a maximum safety level. After a Public Inquiry planning permission was granted.[35] This is not just an issue for nuclear sites, concerns being raised for example about the safety implications of the proposed Thames Gateway development with regard to the Shell Haven refinery.[36]

A contemporary report on the establishment of the Sizewell A Magnox station[37] listed a number of reasons for the choice of the site, including its suitable geology, ability to take the weight of the station (around 65,000 tonnes), proximity to the sea as a source of cooling water for the turbines, its position near to a source of high electricity demand (the south east of England) 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 and Leiston (a mile and a half inland) a small town with few more than 4,000 inhabitants.

Similarly, Hunterston was chosen as the site for Scotland's first commercial (Magnox) nuclear power station because it could offer a large area of level ground, a firm foundation of rock to carry the great weight of the reactor buildings, proximity to a plentiful supply of cooling water virtually on a level with the site to minimise the need for the pumping and reasonably near the load centre. The main issue at the Public Inquiry seems to have been the threat to the great beauty of the site, on a promontory of the Ayrshire coast near West Kilbride sheltered on the landward side by Goldenberry Hill and facing out across the Firth of Clyde to the islands of Cumbrae and the peaks of Arran, rather than fears for local people in the case of an accident.[38]

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.[39] A growing sentiment was that, "As we move into an era of increasing demand for nuclear power, it is clear

[34] http://www.hse.gov.uk/aboutus/meetings/iacs/nusac/030708/p12-sittingpaper.pdf, Highton J. and Senior D. (2008), *The siting of nuclear installations in the UK*, HSE.
[35] http://www.thisishampshire.net/news/9106411.115_home_scheme_gets_the_thumbs_up_despite_concern/, Morton H. (2011), 'Home scheme gets the thumbs up despite concern', *This is Hampshire*, June 25 2011.
[36] http://www.hse.gov.uk/consult/condocs/cd212response.pdf, HSE (2007), *Proposals for revised policies to address societal risk around onshore non-nuclear major hazard installations.*
[37] *Electrical Times*, October 2 1960.
[38] http://www.hunterston.eu/hunterstona/index.htm, Virtual Hunterston (2013), *The Hunterston A story – choice of site.*
[39] Gronow W. S. (1969), 'Application of safety and siting policy to nuclear plants in the United Kingdom', in *Environmental contamination by radioactivity*, IAEA, Vienna.

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."[40] 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.[41]

Marley and Fry's initial approach to acceptable population levels near nuclear facilities was modified by degrees to permit a more flexible assessment of population distribution. The final development of the criteria was reported in 1963.[42] 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 degree 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*[43], 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 5,000-8,000 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 (or at least the criteria by which these particular sites had been selected). 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.*[44] 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.

A changing international debate

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[40] Charlesworth F.R. and Gronow W.S. (1967), 'A summary of experience in the practical application of siting policy in the United Kingdom', *Proceedings of a symposium on the containment and siting of NPPs*, IAEA, April 3-7 1967.
[41] Haire, T. P. and Usher, E. F. F. W. (1975), 'Nuclear power station siting experience in the United Kingdom', in *Siting of nuclear facilities*, IAEA (Vienna).
[42] Bell G. D. and Charlesworth F. R. (1963), 'The evacuation of power reactor sites', *Siting of reactors and nuclear research centres*, IAEA, Vienna.
[43] Department of State and Official Bodies and Ministry of Power (1964), *The Second Nuclear Power Programme.*
[44] http://www.iaea.org/Publications/Magazines/Bulletin/Bull093/09302102930.pdf, IAEA (1967), *Where should nuclear power stations be built?*

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.[45]

A similar sentiment was expressed by Davis and Robb[46] with regard to the USA. In their opinion, the principal factors affecting siting included supplies of cooling water, land costs and availability, transportation of heavy components, links with transmission systems, population distribution, taxes and labour, together with physical considerations such as meteorology, geology, high winds and the possibility of earthquakes. They considered that safety had been so well defined that plants could be located anywhere except in major metropolitan areas. Indeed, the population within a 5 miles radius of 32 projected nuclear sites in the USA (total of 43 reactors) – not all of which were subsequently built – ranged from 0 (at Turkey Point FL) to 119,370 (at Burlington NJ). The 'average' was 16,000 but this was effectively meaningless, as very few of the sites had a population density close to that figure. Five sites (Burlington NJ, Indian Point NY, Oyster Creek NJ, Millstone CT and Humboldt Bay CA) could be classified as 'high' population density, the rest as 'low'.

Hake[47] and Boyd[48] discussed plans to build the Pickering plant in Canada some 35 km from central Toronto, 7 km from the city's outskirts and with a sizeable urban development at the northern exclusion boundary 1 km from the site centre. This was far closer to a large centre of population than any other plant of comparable size which had so far been agreed to elsewhere and

[45] Farmer F. R (1967), 'Siting criteria: a new approach', *Proceedings of a symposium on the containment and siting of NPPs*, IAEA, April 3-7 1967.
[46] Davis W. K. and Robb J. E. (1967), 'Nuclear plant siting in the United States of America', *Proceedings of a symposium on the containment and siting of NPPs*, IAEA, April 3-7 1967.
[47] Hake G. (1967), 'The relation of reactor design to siting and containment in Canada', *Proceedings of a symposium on the containment and siting of NPPs*, IAEA, April 3-7 1967.
[48] Boyd F. C. (1967), 'Containment and siting requirements in Canada', *Proceedings of a symposium on the containment and siting of NPPs*, IAEA, April 3-7 1967.

in an area which had one of the fastest population growth rates in North America. Hake noted that, in contrast with other countries, the regulator (the Atomic Energy Control Board) was a relatively small body, heavily dependent on the competence and assurances of the applicant. He characterised the views of the AECB that as time progressed, operating experience would give assurance of the low probability of equipment failure, so allowing the requirements for containment and siting to be relaxed. A threefold approach – that 'dangerous' faults should not occur more than once every three years; that protective measures to limit the effects of such a fault should be available 99.7% of the time; and that containment should prevent any radioactivity that escapes these protective measures from reaching the environment 99.7% of the time – would provide those assurances.

The symposium chairman, M. Osredkar of Yugoslavia, considered that the symposium had shown that "important advances had been made in understanding technical views and in dispelling fear of nuclear power." 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.)

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. It is highly radiotoxic, 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 1,000,000 people lying at 20-30 miles, with subgroups of 10,000 to 50,000 people in the range 5 to 20 miles and background population of 300 people per square;

- (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 ½-10 miles, typical of wide suburban areas around large cities in the UK.[49]

In densely populated countries such as the UK, the difference between the three curves is taken to represent the maximum safety advantage that can be obtained from remote site selection.

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 to 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 that "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."[50]

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.[51] 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 that "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",[52] 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."[53] (Concerns about the dangers of an accident in a reactor providing propulsion for large shipping when the vessel was in harbours close to centres of densely populated towns had been one factor in the abandonment of research into maritime propulsion in the early 1960s.[54]) 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

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[49] Beattie J. R. (1975), 'Rationale of reactor site selection for public safety', *Nuclear Technology* Vol. 27 No. 2.

[50] Dunster H. J. and Clarke R. H. (1980), 'Remote siting brings small benefits', *Nuclear Engineering International* Vol. 25.

[51] 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.

[52] http://hansard.millbanksystems.com/commons/1968/feb/06/nuclear-power-stations-siting-1, *Hansard*, 6 February 1968.

[53] http://hansard.millbanksystems.com/written_answers/1968/mar/12/nuclear-power-stations-siting#S5CV0760P0_19680312_CWA_22, *Hansard*, 12 March 1968.

[54] Pocock R. F. (1977), *Nuclear power – its development in the United Kingdom*, Unwin Brothers: Woking.

was in the heartland of the Durham coalmining industry, an issue which caused considerable opposition from the National Coal Board at the time)[55]. 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".[56]

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.[57]

The Royal Commission on Environmental Pollution (RCEP) examined siting policy for reactors in its Sixth Report, chaired by Brian (later Lord) Flowers[58]. 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. (The reactors at Obninsk, USSR, and subsequently at Cernavoda in Romania have supplied district heating[59] while Calder Hall was used to provide process steam for the Sellafield site and reactors in countries such as Germany, Switzerland and Canada have generated steam for other industries.[60]) 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).[61]

The Prototype Fast Reactor (PFR)

Notwithstanding the above discussion, siting of nuclear plants remained influenced by political factors as well as technical ones. This is illustrated by the decision to construct the 250 MW

[55] Tromans S. and Fitzgerald J. (1997), *The law of nuclear installations and radioactive substances*, Sweet & Maxwell.
[56] Durham County Council Planning Committee Minutes, April 17 1968.
[57] http://www.admlc.org.uk/documents/r91.pdf, Clarke R. H. (1979), *A model for short and medium range dispersion of radionuclides released to the atmosphere*, NRPB: Chilton, Oxon.
[58] Flowers B. et al. (1976), *Sixth Report, Nuclear Power and the Environment*, Cm 6618, RCEP.
[59] http://www.candu.org/cernavoda.html, CANDU Owners Group (2013), *Cernavoda nuclear power plant.*
[60] http://www-pub.iaea.org/MTCD/Meetings/PDFplus/2007/cn152/cn152p/Verfondern%202007%20IAEA%20CN%20152%2059%20Potential%20Presentation2.pdf, Verfondern K. (2007), *Potential for nuclear process heat application*, IAEA.
[61] http://www.jstor.org/stable/20001626, Openshaw S. (1980), 'A geographical appraisal of nuclear reactor sites', *Area* Volume 12 No. 4.

Prototype Fast Reactor, needed to supplement the information gathered from the operation of the 15 MW DFR which had started up in 1959 at Dounreay. As noted earlier, political lobbying had been a major factor in the choice of the Caithness site in 1954. When it came to the much larger PFR, the UKAEA strongly preferred Winfrith, both because of its much closer location to London and to demonstrate confidence that large plants could be built close to towns like Weymouth and Swanage.[62] However, in February 1966 Minister of Technology Frank Cousins MP announced that the station would be built at Dounreay, stating that: "The Highland and Islands Development Board presented one of the best cases I have heard for this kind of approach to the question of the North of Scotland". This decision was popular with the local population, and indeed the Labour Party gained the Caithness and Sutherland parliamentary seat the following month (by 64 votes) for the first time since the constituency was formed in 1918.[63]

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. (There was at the time a vigorous debate about the future of nuclear power technology in the UK, with the AGR, the Steam Generating Heavy Water Reactor (SGHWR, another unique UK design with some similarities to the Canadian CANDU), the Fast Reactor and the PWR all having passionate advocates and opponents.) 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. I am assured that the technique of welding is now so advanced that these vessels can be considered as absolutely safe. But it is not so many years since a conventional boiler drum in the UK broke in half at the circumferential weld while it was being lifted into position and 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."[64]

A similar view was expressed by Sir Alan Cottrell, Chief Scientific Adviser to the Cabinet, who concluded:

- rapid fracture, from large cracks or defects in thick sections, was in principle possible in steel pressure vessels under operational conditions;
- in light water reactor (LWR) vessels the estimated critical crack size for unstable growth is smaller than the wall thickness, so that the 'leak-before-break' safety feature is unavailable;
- in these circumstances, the security of an LWR vessel against fracture depends on the maintenance of rigorous manufacturing and quality control standards and on thorough,

[62] Wilson H. (1971), *The Labour Government 1964-1970*, Weidenfeld.
[63] Pocock R. F. (1977), *Nuclear power – its development in the United Kingdom*, Unwin Brothers: Woking.
[64] http://www.waltpatterson.org/goingcritical.pdf, Patterson W. (1985), *Going critical, an unofficial history of British nuclear power*, Paladin.

effective and regularly repeated examination of the vessel by the ultrasonic crack-detection technique;

- the possible gradual growth of small cracks in highly stressed regions, by ageing and corrosion effects during service, needs further scientific investigation, as does also the effect of thermal shock from emergency cooling water in a loss-of-coolant incident.[65]

(Embrittlement of the welds in the steel pressure vessel under prolonged irradiation ultimately led to the closure of the Trawsfynydd Magnox station in 1993.)

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.[66] 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.

The guidelines included numerical values which were "generally consistent with past NRC practice and reflected consideration of severe accidents as well as the demographic and geographic conditions of the United States." Preferably a reactor should be located so that, at the time of initial site approval and for about 5 years afterwards, the population density, including weighted transient population, averaged over any radial distance out to 20 miles (cumulative population at a distance divided by the circular area at that distance), would not exceed 500 persons per square mile (a total of about 630,000 for an inland site). A reactor should not be located at a site where the population density was well in excess of this value. If the population density of the proposed site modestly exceeded the preferred value, the analysis of alternatives should pay particular attention to sites having lower population density.

There was some flexibility – indeed, the very establishment of the site would be expected to have a notable effect on local demography and population density, especially in more isolated areas. Consideration could be given to other factors such as safety, environmental or economic considerations, which may result in the site with the higher population density being found acceptable. Examples of such factors might include the higher population density site being more seismically stable, having better rail or highway access, shorter transmission line requirements or a less significant environmental impact upon undeveloped areas, wetlands or endangered species. Projected changes in population within about 5 years after initial site approval should be evaluated for the proposed site and for any alternative sites considered. Population growth in the site vicinity after initial site approval was recognised as normal and expected and would be periodically factored into the emergency plan for the site but population increase after initial site approval

[65] In 2012 Belgium temporarily shut down its Doel-3 PWR plant after the country's regulator discovered 'several anomalies', including possible cracks, in the reactor pressure vessel. http://www.nucnet.org/all-the-news/2012/08/10/doel-3-shut-down-after-discovery-of-possible-cracks, *NucNet* (2012), 'Doel-3 shut down after discovery of possible cracks', August 10 2012.

[66] http://www.nrc.gov/reading-rm/doc-collections/reg-guides/environmental-siting/rg/04-007/#_1_6, NRC (1975), *Regulatory Guide 4.7, general site suitability criteria for nuclear power stations.*

would not be a factor in licence renewal or, by itself, used to impose other licence conditions or restrictions on an operating plant.[67] These new guidelines represented a noticeable tightening of the siting criteria in comparison with those which had been applied in practice in the mid-1960s and described by Davis and Robb at the IAEA conference less than a decade previously.[68]

Growing unease

In the event it would be nearly another decade before the UK was to order its first (and so far only) civil PWR power reactor. However, concern was also growing over safety standards at the UK's largest nuclear site, at Windscale in Cumbria. A *Daily Mirror* headline in October 1975 had dubbed the site 'the world's nuclear dustbin' and a Nuclear Installations Inspectorate report of 1981[69] stated: "A few incidents, including the two major leakages of radioactivity into the ground, have been a cause for concern to us because of the implications of multiple failures of safety precautions. There is evidence of a failure to learn from previous events which should have been recognized as indications that these incidents might occur ... It was clear to us that insufficient attention has been given to extending plant operating instructions to deal with reasonably foreseeable abnormal plant operating conditions." A significant contamination accident in 1983, which became known as the Sellafield Beach Incident and which led to local residents being recommended to avoid the beaches in the area for several months, further heightened public concerns, as did the discovery of the first radioactive 'beach particle' at Dounreay in 1984 – over 200 had been identified by 2013. In 1983 a television programme called *Windscale – the nuclear laundry* identified an excess of childhood leukaemia cases near the plant especially in the 'company town' of Seascale and led to the creation of the Committee on Medical Aspects of Radiation in the Environment (COMARE).[70]

In its Fourth Report[71], COMARE stated: "On current knowledge, environmental radiation exposure from authorised or unplanned releases could not account for the excess. Much work has been done to reduce the uncertainties in the previous assessment although some uncertainties do still remain. On current knowledge occupational exposure to radiation is very unlikely to account for the excess. Although there are uncertainties regarding internal radiation exposures it is not clear how these could affect the population of Seascale and not the other residents of small towns and villages nearby where workers from the Sellafield site also live." Similarly, in 1993 the High Court in London found that on the balance of probabilities it was 'decisively' unlikely that paternal exposure to radiation could account for the excess of leukaemia cases in the area.[72] Nonetheless,

[67] In the UK a single licence is granted for the lifetime of a nuclear site, subject to validation through Periodic Safety Reviews which consider issues such as applications for plant extension. See http://www.hse.gov.uk/nuclear/periodic-safety-review/index.htm, ONR (2013), 'Periodic Safety Reviews (PSR)'.

[68] Davis W. K. and Robb J. E. (1967), 'Nuclear plant siting in the United States of America', *Proceedings of a symposium on the containment and siting of NPPs*. SM-89/34, IAEA, April 3-7 1967.

[69] NII (1981), *The management of safety at Windscale.*

[70] http://www.comare.org.uk/documents/COMARE1-6reports.pdf, COMARE (1986), *First Report: the implications of the new data on the releases from Sellafield in the 1950s for the conclusions of the Report on the Investigation of the Possible Increased Incidence of Cancer in West Cumbria,* Department of Health, London.

[71] http://www.comare.org.uk/documents/COMARE1-6reports.pdf, COMARE (1996), *Fourth Report: the incidence of cancer and leukaemia in young people in the vicinity of the Sellafield site, West Cumbria – further studies and an update of the situation since the publication of the report of the Black Advisory Group in 1984,* Department of Health, London.

[72] http://iopscience.iop.org/0952-4746/14/4/001, Wakeford R. and Tawn E.J. (1994), 'Childhood leukaemia and Sellafield: the legal cases', *Journal of Radiological Protection* Vol. 14 No. 4.

public fears continued in the absence of a widely accepted alternative explanation. Returning the name of the complex to 'Sellafield' did little to allay concerns or build public trust.

The UK did have some experience of the PWR concept following the 1958 US-UK Mutual Defence Agreement. HMS Dreadnought, the UK's first nuclear-powered submarine (commissioned by the Royal Navy in 1963), was powered by a Westinghouse S5W reactor, with subsequent submarines being propelled by a British-developed variants, the PWR1 (superseded by the PWR2 in the late 1980s).[73] However, it has been reported that the PWR1 had a thermal output of about 70 MW, around one fiftieth that of a 1GW(e)+ power reactor such as Sizewell B.[74] It was becoming clear, then, that for the beginnings of a PWR power reactor programme (or one based on SGHWR, also a design new to the UK and indeed anywhere in the world, though with some similarities to the Canadian CANDU and Soviet RBMK reactors), a return to the conservative siting criteria which had been applied to the Magnox programme would be appropriate 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."[75] 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."[76]

Anthony also made clear that the constraints on population growth near nuclear sites, first set out in 1961, were still in force. These required that general site demographic characteristics, as they existed at the time of licensing, should be maintained throughout the entire life cycle of the plant, with an allowance for future developments to account for natural growth whilst restricting inward migration. A site would only be acceptable if the surrounding population together with any likely future development would remain consistent with the siting policy. "The distribution of population around a site is an important factor in the assessment. Others are the location of schools and hospitals, local communications, population mobility and any other special features which might affect emergency countermeasures which might be necessary should an accident occur. Once a site has been accepted for a nuclear station, arrangements are made to ensure that residential and industrial developments are so controlled that the general site characteristics of the site are preserved, and local authorities consult the Inspectorate with regard to any proposed new development falling outside guidelines which have been laid down."

The population constraints concerning the first UK PWRs would be as strict as those which had been applied to the Magnox programme, but 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 900-1,800 persons per

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[73] Ed. Chumbley S. (1996), *Conway's All The World's Fighting Ships 1947-1995*, US Naval Institute Press, Annapolis.

[74] http://www.bellona.org/reports/The_Russian_Northern_Fleet_report_chapters/1151421090.79/htmlreport_view, Bellona (1996), *The Russian Northern Fleet – report*.

[75] Anthony R. D. (1983), *Sizewell B Public Inquiry*, daily transcripts days 56-60

[76] Ryder E. A. (1989), *Hinkley Point C Public Inquiry*, transcripts February 2 1989.

square kilometre in the most populated 30 degree 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, did nothing to foster comfort over 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. The most dramatic example of the effects of the TMI accident on siting policy – albeit a retrospective one – was at the Shoreham plant on Long Island, New York State.[77, 78]

The project had already been delayed by several years by the time of the accident, and in June 1979 15,000 protesters met at Shoreham for the largest demonstration in Long Island history. Furthermore, Three Mile Island led to federal regulators declaring that operators of nuclear plants would have to work out evacuation plans in cooperation with state and local governments. In February 1983 the Suffolk County Legislature declared (in a 15-1 vote) that the county could not be safely evacuated. Despite this setback the Long Island Light Company (LILCO) pressed ahead and completed Shoreham in 1984, winning federal permission for low power tests the following year. But by the late 1980s the failure to agree evacuation plans was still delaying an operating licence for the plant. The Chernobyl accident in 1986 made commissioning even less attractive. The New York legislature created the Long Island Power Authority (LIPA) as a vehicle to close Shoreham and take over LILCO and in February 1989, after more than two years of negotiations and abortive deals, New York Mayor Mario Cuomo and the chairman of LILCO signed an agreement that prevented the plant ever operating but made electricity consumers responsible for most of Shoreham's costs.

Shoreham demonstrates clearly the dangers that face investors in nuclear energy. As a source of electricity which is heavily capital-intensive, the economics of nuclear energy are particularly sensitive to changes in political stances or regulation which will have significant effects on the duration and costs of the construction phase or which may delay (or even prevent) opening of the plant once it is completed. In effect, the siting criteria for Shoreham changed fatally between the time it received its construction licence and the time when it was ready to operate.

The Chernobyl nuclear accident in Ukraine in April 1986 had a profound effect on the nuclear power industry globally. Italy closed its three operating nuclear stations (which included one of the two Magnox plants which had been exported from the UK in the 1950s); countries such as Sweden and Germany took a decision to phase out their existing plants before the end of their technical or economic lifetimes; many countries put in place legal or policy obstacles to developing nuclear power.

Chernobyl also brought into sharper focus the potential implications of nuclear plant location for neighbouring countries. Belarus and areas of Russia were heavily contaminated by fallout from the accident and indeed the detection of radioactive caesium in the UK and the subsequent banning of

[77] http://www.newsday.com/community/guide/lihistory/ny-history-hs9shore,0,563942.story?coll=ny-lihistory-navigation, Fagin D. (1995), *Lights out at Shoreham – anti-nuclear activism spurs the closing of a new $6 billion plant*, newsday.com.
[78] Nuttall W.J. (2005), *Nuclear renaissance – technologies and policies for the future of nuclear power*, Taylor and Francis, IOP.

eating sheep from a number of highland areas (restrictions only finally lifted in 2012[79]) further damaged public confidence in nuclear power. Cross-border tensions over nuclear power developed over such plants as Chooz (situated in France on a 'panhandle' protrusion into Belgium) and Temelin in the Czech Republic, 100 km from the Austrian border.[80] The UK's island status had reduced the influence of such considerations on plant location, although the Irish government had raised concerns over operations especially at Sellafield, but also at Wylfa and Hinkley Point, on many occasions.[81]

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. They were revised again in 1992 in line with the Tolerability of Risk concept (see below) and expressed in a form that could be applied more generally to all nuclear installations, not just nuclear power reactors, by combining them with the separate set of SAPs which had been developed for nuclear chemical plants and published in 1983.[82] (As discussed later, a further revision of the SAPs was published in 2006.) The 1992 SAPs were of central importance to the siting of new nuclear power stations because they specified a number of key siting principles (P56 - P60) including:

- if a company wishes to build a plant, it has to satisfy the NII that the site conforms with the government's siting policy;
- 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.

To underpin this revision, in 1988 the HSE had published a rationale of its approach to regulation for public consultation with regard to perceptions of risk from nuclear installations, the final version being published in 1992.[83] Subsequently the HSE published its broad approach to risk management at nuclear installations, expanding this thinking in 2001 to apply more generally to all risk management activities regulated by HSE.[84]

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. The UK had significant reserves of natural gas and a large number of efficient new CCGT

[79] http://www.telegraph.co.uk/news/uknews/9156393/Chernobyl-sheep-movement-restrictions-finally-lifted.html, Hall J. (2012), 'Chernobyl sheep restrictions finally lifted', *Daily Telegraph*, March 20 2012.
[80] http://www.bbc.co.uk/news/world-europe-16359991, Bell B. (2012), 'Austria and Czech Republic divided over nuclear power', *BBC website.*
[81] For example, see http://www.environ.ie/en/PublicationsDocuments/FileDownLoad,31607,en.pdf, Government of Eire (2012), *Risks to Ireland from incidents at the Sellafield site,* Department of the Environment.
[82] http://www.hse.gov.uk/nuclear/saps/saps1992.pdf, HSE (1979 rev. 1992), *Safety Assessment Principles for nuclear plants*, HMSO.
[83] http://www.hse.gov.uk/nuclear/tolerability.pdf, HSE (1992), *The tolerability of risk from nuclear power stations*, HMSO.
[84] http://www.hse.gov.uk/risk/theory/r2p2.pdf, HSE (2001), *Reducing risks, protecting people – HSE's decision-making process*, HMSO.

(Combined Cycle Gas Turbine) power stations, while the 'dash for gas' (away from coal) was delivering a reduction in carbon dioxide emissions. Although this was not the primary motivation for the dash for gas it nonetheless allowed the UK to meet its international environmental commitments under the Rio and Kyoto Protocols by some margin.

International and trans-national perspectives

The IAEA places responsibility for siting and associated safety issues firmly with the national authorities in question, though with reference to cross-border issues. In its publication on safety standards it notes: "Regulating safety is a national responsibility. However, radiation risks may transcend national borders, and international cooperation serves to promote and enhance safety globally by exchanging experience and by improving capabilities to control hazards, to prevent accidents, to respond to emergencies and to mitigate any harmful consequences. International cooperation is facilitated by international safety related conventions, codes of conduct and safety standards."[85] With regard to compensation in the event of an accident, it notes: "It is recognised that the consequences of an accident occurring at a nuclear installation or during the transport of nuclear substances would not stop at political or geographical borders, that victims should be compensated equitably and that such compensation could only be assured through the establishment of an international nuclear liability regime." There is also reference to public perceptions of nuclear in neighbouring countries where relevant. However, the IAEA's fundamental stance is that: "A nuclear power plant project is a national undertaking and hence its introduction and implementation within the country is a matter to be handled primarily by national (and regional) governmental organisations and authorities."[86]

A further development in nuclear safety in the wake of the accidents at Three Mile Island and Chernobyl were the formation of associations of operating companies – the Institute of Nuclear Power Operators (INPO), established in the USA in 1979[87] and the World Association of Nuclear Operators (WANO), based in London with regional centres in Moscow, Atlanta, Tokyo and Paris and formally established in 1989. Both organisations promote a programme of peer reviews, 'twinning' arrangements, databases of incidents at nuclear power stations, awards for good practice and other ways of sharing experience which have been highly effective in improving safety standards. All nuclear power plants in the world, plus a number of other organisations for example in nuclear safety regulation and decommissioning, are now members of on or both of these bodies.

(In 1999 the Western European Nuclear Regulators Association, WENRA, was created, with membership including all European Union countries with nuclear power plants plus Switzerland. Subsequently membership was extended to include the accession states of central and eastern Europe, and regulators in other countries such as the Russian Federation, Ukraine and Armenia were granted 'observer' status. WENRA's initial twin objectives were to develop a common approach to nuclear safety and to provide an independent capability to examine nuclear safety in countries which were applying to join the EU, many of which were host to ageing Soviet-built reactors. Through the late 1990s and early 2000s pressure was brought to bear on countries such as Bulgaria, Lithuania and Slovakia to develop plans to shut down older Soviet-era nuclear plants as a

[85] http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1273_web.pdf, IAEA (2006), *Fundamental safety principles.*
[86] http://www-pub.iaea.org/MTCD/Publications/PDF/te_1555_web.pdf, IAEA (2007), *Managing the first nuclear power plant project.*
[87] http://www.inpo.info/,

condition of joining the EU – the five reactors at Greifswald in the former East Germany had already been closed on German reunification in 1989.[88])

Irrespective of any such developments, in truth the forthcoming deregulation of the electricity supply industry, coupled with the opportunities represented by the discovery of North Sea gas, was already starting to undermine the case for any nuclear new build after Sizewell B. In 1979 the then Energy Secretary, David Howells, had said: “the electricity supply industry has advised that even on cautious assumptions it would need to order at least one new nuclear power station a year in the decade from 1982, or a programme of the order of 15,000 MW over 10 years. The precise level of future ordering will depend upon the development of electricity demand and the performance of the industry but we consider this is a reasonable prospect against which the nuclear and power plant industries can plan.”[89] By the mid-1980s this had been scaled back to a proposed four. The nuclear stations were subsequently pulled from the privatisation of the UK electricity supply industry in 1989, initially facing a five-year moratorium on new build. In effect this became indefinite after the government nuclear review launched in 1994 concluded: “There is at present no evidence to support the view that new nuclear build is needed in the near future on emission abatement grounds… nor is there any case for the intervention in the market in support of additional nuclear capacity on diversity grounds”.[90] However, the 1994 Review did pave the way for the privatisation of the AGRs and Sizewell B as British Energy in 1996 (the Magnox plants remaining in government ownership).[91]

The search for a waste repository

In the UK, then, the issue of siting shifted to the search for a suitable location for a disposal site for radioactive waste. The 1955 White Paper which launched the UK nuclear programme said: “The disposal of radioactive waste products should not present a major difficulty. The problem is primarily one for the chemical processing plants, which will be few in number, and not for the power stations. The volume of waste will be small and great efforts are being made to determine the most economical methods of storing or disposing of it. There are many valuable uses for it which may be able to absorb a great part of the output. Any material that is discharged will be tested to ensure that it is of extremely low radioactivity, so that it will be harmless and comparable in effect to the natural background radioactivity which is always present.”[92]

In the event, this sanguine view of the ease of identifying a site for waste disposal and implementing its use has not proved accurate. The search for a site for disposing of the UK’s more highly radioactive wastes has been a long and so far fruitless one.

The UK’s Low Level Waste (LLW) Repository has operated near Drigg in Cumbria since 1959. Waste was originally disposed by tipping into trenches that have been subsequently been capped off. Following a major upgrade of disposal operations in 1995, the waste is now placed in engineered concrete vaults. Suitable LLW is compacted and placed in containers before being

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[88] http://www.wenra.org/about-us/, WENRA (2003), ‘The mission of WENRA’.
[89] http://hansard.millbanksystems.com/commons/1979/dec/18/nuclear-power, *Hansard*, December 18 1979.
[90] DTI/Scottish Office (1995), *The prospects for nuclear power in the UK: conclusions of the government’s nuclear review*, Cm2860, HMSO.
[91] http://hansard.millbanksystems.com/commons/1995/dec/06/nuclear-privatisation, ‘Nuclear privatisation’, *Hansard*, December 6, 1995.
[92] http://filestore.nationalarchives.gov.uk/pdfs/small/cab-129-73-c-55-31-31.pdf, Ministry of Fuel and Power (1955), *A programme of nuclear power*, Cmnd 9389, HMSO.

transferred to Drigg, where the final waste packages are placed in the vaults.[93] There was a smaller low level waste disposal facility at Dounreay, only receiving waste from the other facilities at that site.[94] Construction on a new waste store at Dounreay began in 2011, as the Scottish Executive/Government confirmed that it no longer wished to use the Drigg repository for low levels waste produced in Scottish reactors.[95]

In the mid to late 1970s the UK Atomic Energy Authority applied for planning permission to carry out test drilling to investigate the geological suitability of three sites for disposal of high level waste (HLW), which consists largely of the fission products of nuclear reactions (separated from spent fuel during reprocessing). The first application, at Mullwharchar Hill near Loch Doon on the border of the regions of Strathclyde and Dumfries & Galloway in southwest Scotland, was rejected by the local council in 1978. The subsequent Public Inquiry was met with vigorous opposition both locally and elsewhere in Scotland. The second application, for test drilling at Altnabreac in northeast Scotland (about 15 miles from Dounreay), was submitted to Caithness District Council in 1978. Planning permission was granted and 27 boreholes were drilled between November 1978 and May 1979. Planning applications were also made to Alnwick and Berwick District Councils in the summer of 1978 for test drilling in two granite areas in the Northumbria National Park and these went to Public Inquiry in 1980. Subsequent applications for drilling in Somerset, Leicestershire and Nottinghamshire in England, and Gwynedd and Powys in Wales, were also rejected. In the face of growing public opposition at all sites the government abandoned the programme of test drilling in December 1981, stating that vitrified HLW should be stored for at least 50 years until the rate of heat generation had substantially reduced.

Focus then turned to finding a site for Intermediate Level Waste (ILW) and longer-lived LLW, made more urgent by the banning of sea dumping of radioactive waste in 1983. In 1983 Nirex, the agency created to find a site for disposing of ILW and LLW, announced that a deep anhydrite mine at ICI's Billingham site in Cleveland was proposed as a site for ILW, and Elstow in Bedfordshire was proposed as a site for the shallow burial of LLW. Once again opposition was followed by abandonment of this policy as ICI withdrew its permission for investigation.

In 1986 Nirex announced it was to investigate four sites – Elstow in Bedfordshire, Bradwell in Essex, Fulbeck in Lincolnshire and South Killingholme in Humberside – to see if they were suitable for the construction of a facility for the disposal by shallow burial of 'short-lived' ILW and LLW. When test drilling was due to start in August/September 1986, physical obstruction by members of the public kept contractors from the sites for some three weeks. In May 1987 the government abandoned these four sites and decided to pursue a deep geological disposal option for ILW and to include disposal of longer-lived LLW in the same facility.[96]

Over the following decade further sites were identified and eliminated, with Dounreay and Sellafield being announced for detailed investigation in 1989 and Dounreay abandoned in 1991. In 1997, however, Nirex was refused permission to construct a deep-level laboratory to examine the Sellafield geology in more detail. In effect the process went back to the starting point, with the

[93] http://www.nda.gov.uk/ukinventory/sites/llw_repository_near_drigg/, NDA (2013), *Low Level Waste Repository near Drigg.*
[94] http://www.oecd-nea.org/rwm/reports/1999/low-level-waste-repository-costs.pdf, NEA (1999), *Low Level Radioactive Waste repositories – an analysis of costs,* OECD.
[95] http://www.sepa.org.uk/radioactive_substances/decommissioning/dounreay/proposed_llw_facilities.aspx, SEPA (2012), 'Proposed low level waste facilities'.
[96] Bolter H. (1996), *Inside Sellafield*, Quartet Books.

creation by the Department for the Environment, Food and Rural Affairs (Defra) of a new Committee on Radioactive Waste Management (CoRWM).

In the late 1980s and early 1990s proposals were made to develop dry stores for spent nuclear fuel from AGR reactors, in order to give the operating companies an alternative to sending such waste to Sellafield for reprocessing, a course which those companies increasingly regarded as poor value for money. Heysham in Lancashire was proposed by the CEGB in the 1980s and Torness by Scottish Nuclear Ltd in the 1990s. In due course however both schemes were abandoned.

In July 2006 CoRWM recommended a policy of deep geological disposal for the management of Britain's more active radioactive wastes, thereby confirming what had been official policy for two decades. However, recognising that previous attempts to find a site for such a repository had proved politically undeliverable, CoRWM proposed an approach which would proceed stepwise over several years, based on the philosophy of voluntarism which was being successfully applied in Sweden and Finland. Local communities would be allowed to volunteer to host a site by making an 'Expression of Interest' but would have rights to withdraw from the site selection process at a number of agreed stages in the process. For example site selection might involve both an open siting process potentially available for any local community to volunteer and a focussed siting process looking at sites where nuclear facilities already exist.

A White Paper of 2008 set out the framework for delivering a deep repository within the voluntarist framework.[97] It states that: "An Expression of Interest will enable without commitment discussion between local communities and Government to begin. The scope of initial discussions will be for mutual agreement between the local community/ies and government. It could include discussion of what support might be available to assist continuing community engagement up until the next stage and of the point at which the Nuclear Decommissioning Authority (NDA) (and others) might become involved in discussions. At the same time the British Geological Survey (BGS) will be asked to apply sub-surface screening criteria in order to eliminate from the process any area that is obviously geologically unsuitable." Various comments are made about the need for evidence that there is local support at each stage, based on good local consultation and communication.

However, the White Paper is somewhat vague about what is meant by the 'local community' – indeed it makes a virtue of "not wishing to be over-prescriptive about the way that the voluntarism and partnership arrangements should work at the outset as individual local circumstances differ and, to a degree, a tailored approach to any discussions will need to be taken." The White Paper identifies three types of community.

- Host Community – the community in which any facility will be built. This will be a small geographically defined area and include the population of that area and the owners of the land. For example, it could be a town or village.
- Decision Making Body – the Local Government decision-making authority for the host community.
- Wider Local Interests – other communities that have an interest in whether or not a facility should be built in the Host Community. Such as the next village, a neighbouring district or a community on the local transport routes to the Host Community.

[97] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/68927/7386.pdf, Defra/BERR/Devolved Administrations of Scotland And Wales (2008), *Managing radioactive waste safely – a framework for implementing geological disposal*

All three levels of community will need to liaise closely with one another as the process is taken forward. Both Government and the NDA will engage with all three 'communities'.

Unfortunately, the White Paper did not state what the procedure should be where there was two-tier local government, with both the County and the Borough(s) involved having a say on the planning of major projects. In the absence of clarity over this issue, in 2011 Cumbria County Council and the Borough Councils of Copeland and Allerdale agreed a Memorandum of Understanding, which in effect stipulated that there would have to be agreement at both County and Borough level (i.e. the County Council and at least one of the two affected Borough Councils). The government endorsed this approach in letters from the then Energy Minister Charles Hendry to the three Council Leaders in November 2011.[98] The letters say unequivocally: "The government accepts that if either a Borough Council (in respect of its area), or the County Council in a Cabinet decision, or the government, after considering the issues, continues to have genuine concerns and no longer wishes to participate, then the principles of partnership to which we have all been committed cannot be met. Accordingly, we would not proceed with the Managing Radioactive Waste Safely process in west Cumbria."

In the event, in 2013 the Cabinets of the two Borough Councils of Copeland and Allerdale voted in favour of moving to Stage 4 of the process but the Cumbria County Council Cabinet did not.[99] Local MP Jamie Reed, an advocate of the area remaining in the process, expressed his intention to try to persuade the government to allow Copeland to go ahead with its own preliminary surveys of the area's geology and to introduce a Private Members' Bill aimed at getting Parliament's backing to recognise Copeland's wishes for desktop studies without any commitment to eventually hosting an underground repository, though the firm nature of Hendry's undertaking was a clear obstacle to any change in government's stance on the matter. Energy Minister Baroness Verma gave an assurance that the right of withdrawal from the process right up to the start of repository construction would be made legally binding – a lack of clarity over this issue had been cited by the County Council as the main reason for it withdrawing from the process.[100] However, alongside the withdrawal from the volunteering process of Shepway District Council representing a site near Dungeness in Kent in 2012, the Cumbria decision left the process with no active expressions of interest.

As with nuclear power new build, then, the siting criteria were not tested with regard to the potential location of a radioactive waste repository. It can, however, be asked whether voluntarism might be a concept relevant to the siting of new nuclear power stations as well.

In practice there are essentially four main differences between the siting of a nuclear power station and the siting of a radioactive waste facility: the differing lifecycles of the plants; the risks they present; the complexity of the licensing processes; and the differing degree of dependence on local geology.

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[98] http://www.westcumbriamrws.org.uk/documents/240-letter_from_DECC_regarding_DtP_and_RoW_7_Nov_2011.pdf, Hendry C. (2011), Letter, Managing Radioactive Waste Safely (MRWS) decision making process.

[99] http://www.cumbria.gov.uk/news/2013/January/30_01_2013-150007.asp, Cumbria County Council (2013), *Cumbria says 'no' to underground radioactive waste repository*.

[100] http://www.whitehavennews.co.uk/news/copeland-may-go-it-alone-in-n-waste-search-1.1031536?referrerPath=home, Irving A. (2013), "Copeland 'may go it alone' in n-search", *Whitehaven News*, January 31 2013.

- A new nuclear power station has a limited lifecycle of around 100 years (10 years for reactor licensing and construction, 60 years for operation and perhaps 30 years for decommissioning – longer for existing gas-cooled reactors) whereas a waste repository is effectively permanent, since the repository would probably need to remain essentially intact for up to 10,000 years (or maybe even longer).
- A repository would not present any danger of a sudden major release of radioactive material in an emergency situation.
- Reactor licensing now benefits from a single stage combined planning permission and nuclear safety licence that can be delivered relatively quickly within around two to five years. Indeed, it can be argued that this is essential if investors are to have the confidence to commit the funds necessary for new build, and creating such regulatory stability has been a major goal of government policy in recent years. A waste facility, by contrast, would probably need a series of licensing decision points linked to multi-staged planning consents, perhaps over a 10 to 20 year timeframe, especially in the context of a voluntarist approach involving local communities.
- From a technical perspective, one of the main differences between the siting of a nuclear reactor and the siting of a waste repository is the importance of local geology. Nuclear reactor siting is relatively independent of geology as long as the ground rock is strong enough to take the weight of the reactor and other facilities,[101] whereas the siting of a repository would strongly depend on finding a site with suitable hydrogeology. The problem is somewhat different to the siting of standardised nuclear power station designs because the design of a repository would be much more closely connected with the nature of the site. Many aspects of the design of the repository are likely to be site specific and some iteration will probably be necessary between site characteristics, safety case assessment, repository design and facility construction. Moreover there is an established consenting process for the granting of planning permission for nuclear power stations (although it has changed significantly over the decades since permission for the first nuclear power stations was granted), the most recent example being Hinkley Point C, for which permission was given in March 2013. The planning process includes full and detailed public consultation and is designed to enable stakeholders to voice their opinions. In principle the planning process for nuclear power station siting is no different to that followed for conventional power stations.

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.[102] 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 petered out, as coal reasserted itself as a fuel for electricity.[103] Nuclear power began to look much more attractive to many commentators.

[101] The main geological requirement for nuclear power station siting is to find a location that is not vulnerable to earthquakes and where the ground is stable enough to support the weight of the power station over the 100 year lifecycle of the reactor.
[102] http://www.bp.com/sectionbodycopy.do?categoryId=7500&contentId=7068481, BP (2012), *BP statistical review of world energy*.
[103] http://data.gov.uk/dataset/uk_greenhouse_gas_emissions, DECC (2013), *UK greenhouse gas emissions.*

The Energy White Paper, published in 2007,[104] noted that since the nuclear option had (just about) been 'left open' in the 2003 Energy White Paper, a number of things had changed, viz.:

- increasing evidence of climate change and wider international recognition of the need for global action;
- significant progress in tackling the legacy waste issue;
- significant changes in the economics of nuclear power relative to other electricity generation technologies, driven by two main factors (greater than expected increases in fossil fuel prices and the introduction of a market price for carbon which requires investors to take account of the cost of carbon emissions in their investment decisions[105]), both of which factors had increased the relative costs of fossil fuel electricity generation;
- some energy companies expressing a strong interest in investing in new nuclear power stations.

In 2001 the HSE had published the Radiation (Emergency Preparedness and Public Information) Requirements (REPPIR).[106] 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[107] 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. Concerns about nuclear liabilities also led for example to the creation of the Nuclear Decommissioning Authority (NDA) under the Energy Act 2004. The NDA brought together the formerly separate decommissioning activities managed by UKAEA, British Nuclear Fuels (BNFL) and Magnox Electric (the company formed to manage the Magnox stations which remained in state hands when British Energy was privatised in 1996), becoming responsible for 20 sites.

The Nuclear White Paper of 2008[108] 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."

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[104] http://www.berr.gov.uk/files/file39387.pdf, DTI (2007), *Meeting the energy challenge, a White Paper on energy*, TSO.

[105] In the event, the carbon price through the European Union Trading Scheme (ETS) collapsed as the recession delivered sufficient carbon emission reductions from 'business as usual'. In the summer of 2008 the price peaked at €32 per tonne of carbon emitted but had fallen to below €3 per tonne of carbon emitted in early 2013. See http://www.guardian.co.uk/environment/2013/jan/24/eu-carbon-price-crash-record-low, Carrington D. (2013), "EU carbon price crashes to a new low", *Guardian* January 24 2013. In its Electricity Market Reforms published in 2012 the government proposed introducing a carbon floor price - see http://services.parliament.uk/bills/2012-13/energy.html, Parliament UK (2013), *Energy Bill 2012-13*, TSO.

[106] http://www.legislation.gov.uk/uksi/2001/2975/pdfs/uksi_20012975_en.pdf HM Government (2001), *The Radiation (Emergency Preparedness and Public Information) Regulations 2001*, The Stationery Office.

[107] http://www.hse.gov.uk/nuclear/saps/saps2006.pdf, HSE (2008), *Safety Assessment Principles for Nuclear Facilities 2006 Edition, Revision 1*, HSE, Bootle, Merseyside, UK.

[108] http://webarchive.nationalarchives.gov.uk/+/http:/www.berr.gov.uk/files/file43006.pdf, BERR (2008), *Meeting the energy challenge: a White Paper on nuclear power.*

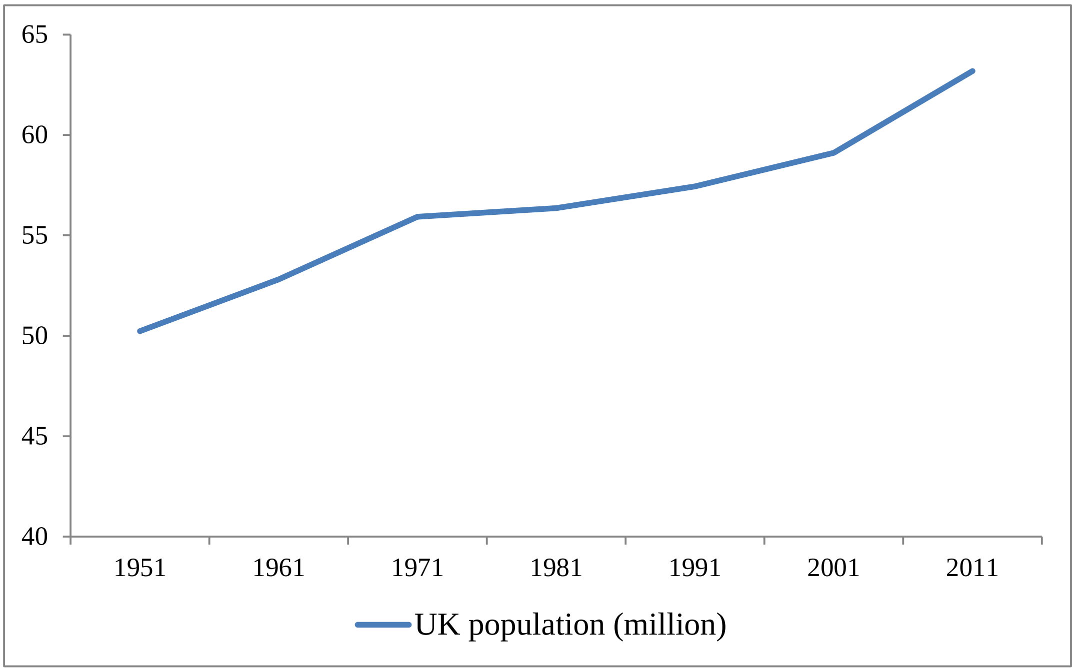
The Prime Minister's statement also said that the electricity industry should be "allowed to build and operate new nuclear power stations, subject to meeting the normal planning and regulatory requirements." Although there was (and is) a lack of clarity about the extent to which government would intervene in the market for electricity to incentivise nuclear new build, it was clear that the government expected any future nuclear power plant to be built and run by the private sector, a stance which did not change with the election of a new Conservative/Liberal Democrat coalition government in 2010.

In the following period the main model which emerged for funding nuclear new build concerned the creation of three consortia involving reactor vendors, utility companies and investors – NNB Generation Company, led by EDF with Centrica; Horizon Energy, originally owned by RWE and E.On; and NuGen, initially owned by GDF Suez, Iberdrola and SSE. Over time SSE and Centrica pulled out, while, after the German reaction to the Fukushima accident in 2011, RWE and E.On sold Horizon to Hitachi-GE.

As noted earlier, 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.[109] Although these factors are also relevant when such decisions are taken by state-owned bodies, it is likely that the commercial considerations will be proportionally more important (and social considerations less so) to commercial entities than to effectively social ones. 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.[110]

These considerations should also be viewed against the background of a UK population which had grown by some 25% between 1951 and 2011[111]. Although the degree of urbanisation increased marginally over this period (from 78.4% in 1960 to 79.6% in 2011)[112], the national population growth inevitably led to an expansion in the population density of some rural areas.

[109] Gerrard M. (1994), *Whose backyard, whose risk? Fear and fairness in toxic and nuclear waste,* MIT Press.
[110] http://news.bbc.co.uk/1/hi/scotland/4175624.stm, 'Planning protest goes to landmark', *BBC website*, August 23 2005: http://www.bbc.co.uk/news/uk-wales-mid-wales-13040549, 'Powys electricity substation: National grid protest', *BBC website*, April 11 2011: http://www.stopwestpinchbeckwindfarm.org.uk/2012/06/dont-forget-the-pylons/, 'Don't forget the pylons', *Stop West Pinchback Windfarm website*, June 24 2012
[111] http://www.visionofbritain.org.uk/maps/, *Census reports*, A Vision of Britain through Time (2013).
[112] http://www.indexmundi.com/facts/united-kingdom/urban-population, Index Mundi (2013), *United Kingdom – urban population.*



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 preexistence 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:[113]

1. existing nuclear power sites (14);
2. other existing nuclear power sites (5);
3. conventional power sites (about 80);
4. greenfield sites.

In a 2008 paper for the Nuclear Safety Advisory Committee[114], 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."

Following consultation, the government's policy on siting of new nuclear power stations was set out in its National Policy Statement (NPS) on nuclear power.[115] One major motivation behind the NPS process was to reduce the regulatory burden and risk on potential nuclear plant investors – the Sizewell B Public Inquiry took evidence for two years, from 1983 to 1985. (By contrast, the

[113] Jackson I. and Jackson S. (2006), *Siting new nuclear power stations: availability and options for government*, DTI.

[114] http://www.hse.gov.uk/aboutus/meetings/iacs/nusac/030708/p12-sittingpaper.pdf, Highton J. and Senior D. (2008), *The siting of nuclear installations in the United Kingdom*, HSE Nuclear Installations Inspectorate.

[115] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/47859/2009-nps-for-nuclear-volumeI.pdf, DECC (2011), *National Policy Statement for nuclear power generation, EN-6 – Part 1.*

Public Inquiry into establishing the Winfrith site, which eventually hosted nine reactors, opened on January 8 1957; construction at the site began that September.[116])

In 2006 the HSE and the Environment Agency (EA) began work on a Generic Design Assessment process (GDA)[117], whereby new nuclear reactor designs were assessed in advance of any site-specific proposals to build a nuclear power station. The process offered a number of claimed advantages.

- It allowed regulators to get involved with designers at the earliest stage, where they could have the most influence.
- It was a step-wise process, with assessments getting increasingly detailed, allowing regulators to identify issues early in the process and so reduce the financial and regulatory risks for potential operators.
- It separated design issues from specific site related issues, improving the overall efficiency of the regulatory process (i.e. obviating the need to argue the safety of an approved design each time an application is made, as was the case in the Sizewell B and Hinkley Point C Public Inquiries in the 1980s).
- It was open and transparent, allowing the public to view detailed design information on the web and comment on it, with regulators giving regular feedback on how assessments are progressing and publishing reports at the end of key stages.

Potential investors were to be free to choose what in their view would be the most economic type of nuclear power plant, provided that the design had achieved a positive GDA.

Initially four designs were submitted to the NII for possible consideration – Areva's EPR (a 1600 MW PWR); Toshiba-Westinghouse's AP1000 (1100 MW PWR); GE-Hitachi's ESBWR (1600 MW BWR) and AECL's Advanced CANDU, ACR (1200 MW). Subsequently AECL pulled out and GE-Hitachi 'suspended' its interest. Decisions on the Areva and Westinghouse designs were expected in June 2011 but were delayed by the ONR's request for specific information on possible modifications to the designs following the Fukushima accident in March 2011. In December 2011 the ONR and the EA issued interim approvals but several outstanding issues requiring resolution were identified. Westinghouse 'suspended' its involvement as there was no licensee expressing interest in constructing the AP1000 at that point. Areva continued to work on resolving the outstanding issues and in December 2012 full approval was granted to the EPR. In early 2013 an application was entered for Hitachi-GE's ABWR (a 1500 MW Boiling Water Reactor which had been built in Japan), to be operated by Horizon Energy.

Under the 2004 Justification of Practices Involving Ionising Radiation Regulations[118] 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 (and also the AP1000) design.[119]

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[116] http://www.dorsetlife.co.uk/2009/11/how-the-mighty-atom-came-to-dorset/, Miller A.J. (2009), 'How the mighty atom came to Dorset', *Dorset Life*.

[117] http://www.hse.gov.uk/newreactors/background.htm, *Background - The Generic Design Assessment process*, ONR/HSE (2013).

[118] http://www.opsi.gov.uk/si/si2004/20041769.htm, Defra (2004), *Justification of practices involving ionising radiation regulations*.

[119] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/47936/666-decision-EPR-nuclear-reactor.pdf, DECC (2010), *The Justification of practices involving ionising radiation*

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.[120] 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.[121]

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.[122] 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

regulations 2004 the reasons for the Secretary of State's decision as Justifying Authority on the regulatory justification of the class or type of practice being: 'The generation of electricity from nuclear energy using oxide fuel of low enrichment in fissile content in a light water cooled, light water moderated thermal reactor currently known as the EPR designed by AREVA NP.'

[120] http://www.hse.gov.uk/nuclear/licensing-nuclear-installations.pdf, ONR (2012), *Licensing nuclear installations.*

[121] http://www.hse.gov.uk/nuclear/hinkley-point-c/assessment-reports.htm, ONR (2012), *Hinkley Point C assessment reports.*

[122] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/47860/1943-nps-nuclear-power-annex-volII.pdf, DECC (2011), *National Policy Statement for nuclear power generation, EN-6 – Part 2*

(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.

The SSA process also took into account regulations introduced in England and Wales in 2004 implementing the EC Strategic Environmental Assessment (SEA) Directive which was adopted in June 2001.[123] The SEA Directive was designed to ensure that the environmental consequences of certain plans and programmes, including new nuclear power stations, would be identified and assessed during their preparation and before their adoption and implementation. SEA required all reasonable alternative options to be assessed before a decision was made. The intention was that public and environmental authorities could submit their opinion in the planning process and that all results would be taken into account during the course of the planning procedure to select and implement the preferred option. As well as the 11 sites under consideration in the SSA consultation process, then, the government commissioned an alternative sites study[124]. Three sites without nuclear experience – Druridge Bay in Northumberland (which had been considered for a nuclear plant in the 1980s), Kingsnorth in Kent (alongside a coal-fired plant, subsequently closed) and Owston Ferry in North Lincolnshire – were said to be worthy of further investigation for potential use after 2025. However, in 2011 the government announced that, having considered all of the sites nominated and those identified in the alternative sites study, only eight sites were potentially suitable for the deployment of new nuclear power stations in England and Wales by the end of 2025, viz.:

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

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

[123] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2001:197:0030:0037:EN:PDF, EC (2001), *Directive on the Assessment of the Effects of Certain Plans and Programmes on the Environment,* Council Directive 2001/42/EC, 5th June 2001.

[124] http://webarchive.nationalarchives.gov.uk/20110302182042/data.energynpsconsultation.decc.gov.uk/documents/atkins.pdf , Atkins (2009), *A consideration of alternative sites to those nominated as part of the government's Strategic Siting Assessment process for new nuclear power stations,* DECC.

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. Similarly, applications for non-SSA sites would not be ruled out entirely, though the decision would ultimately be taken by the Secretary of State for Energy and Climate Change rather than the Infrastructure Planning Unit, though based on IPU advice. (Kent County Council and Shepway District Council launched a vigorous campaign to have Dungeness included on the SSA approved list.)

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.[125] 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.[126]

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 in Japan. 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.[127]

Similarly Weightman did not rule out the development of sites with multiple reactors (an important factor at Fukushima). The report did recommend that the UK nuclear industry should ensure that safety cases for new sites for multiple reactors adequately demonstrate that multiple serious concurrent events induced by extreme off-site hazards can be handled. (The issue had been considered by the NII before Fukushima, for example in the 2006 update of the SAPs.[128])

However, the Japanese tsunami did bring back into focus a debate which had been discussed for some time. As noted earlier, most UK nuclear power station sites, including those on the SSA

[125] http://infrastructure.planningportal.gov.uk/projects/South%20West/Hinkley-Point-C-New-Nuclear-Power-Station/, National Infrastructure Planning (2013), *Hinkley Point C new nuclear power station.*

[126] http://a0768b4a8a31e106d8b0-50dc802554eb38a24458b98ff72d550b.r19.cf3.rackcdn.com/LIT_7929_d2fe43.pdf, Environment Agency (2013), *Applications by NNB Generation Company Limited for environmental permits for a proposed new nuclear power station at Hinkley Point, Somerset: our decisions.*

[127] http://www.hse.gov.uk/nuclear/fukushima/final-report.pdf, Weightman M. (2011), *Japanese earthquake and tsunami: implications for the UK nuclear industry – final report,* Office for Nuclear Regulation.

[128] http://www.hse.gov.uk/nuclear/saps/saps2006v1.pdf, HSE (2006), *Safety Assessment Principles for nuclear facilities, 2006 edition.*

approved list, are in low lying coastal locations. In 2005 Nirex published a research report suggesting that many coastal nuclear sites were vulnerable to the effects of sea level rise from climate change, particularly storm surges which could cause severe but temporary coastal flooding and accelerated coastal erosion.[129] The sites that Nirex highlighted as at greatest risk were generally located in low lying areas of the south of England where electricity demand from new nuclear capacity was forecast to be greatest. Greenpeace published a review focusing on four such sites (Dungeness, Bradwell, Sizewell and Hinkley Point), arguing that, with expected sea level rises and increases in storm surge over the following 200 years as predicted under a high-emission scenario, Dungeness was highly threatened, Bradwell under significant threat and Hinkley Point also vulnerable, with the situation at Sizewell less clear. None of the sites were to be regarded as completely threat-free as a location for a new nuclear power plant. Even the lowest estimates of sea level rise could significantly increase long-term dependence on engineered defence at the stations and increase the rate of loss in the physical stability of the environments in which the stations were situated.[130]

However, risks from extreme weather conditions and flooding had been taken into account within licensing requirements for nuclear plants since the 1970s, with obligations that nuclear plants be protected from extreme weather events that could occur once in every 10,000 years.[131] The Weightman report said: “Flooding risks are unlikely to prevent construction of new nuclear power stations at potential development sites in the UK over the next few years. For sites with a flooding risk, detailed consideration may require changes to plant layout and the provision of particular protection against flooding.”

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 radiation-related health damage as a result of that accident (it will clearly take some time to determine whether there is any statistically significant increase in such health effects over the next decades) but there is clearly observed psychological illness, over and above the trauma caused by the earthquake and tsunami.[132] Psychological effects also dominated the health consequences of Three Mile Island[133] and, arguably, Chernobyl.[134] New York psychiatrist Evelyn Bromet reported that 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. 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

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[129] http://www.nda.gov.uk/documents/upload/Summary-note-for-CoRWM-on-impact-of-rising-sea-levels-on-coastal-sites-with-radioactive-waste-stores-A-Technical-Note-2005.pdf, Nirex (2005), *Summary note for CoRWM on the impact of rising sea levels on coastal sites with radioactive waste stores*, Technical note no. 484385.

[130] http://www.greenpeace.org.uk/files/pdfs/nuclear/8179.pdf, Greenpeace UK (2007), *The impacts of climate change on nuclear power stations sites.*

[131] http://www.hse.gov.uk/nuclear/saps/saps1992.pdf, HSE (1979 rev. 1992), *Safety Assessment Principles for nuclear plants*, HMSO.

[132] http://www.nippon.com/en/features/c00705/, Nippon.com (2011), *Effects of the Fukushima Dai-ichi nuclear disaster.*

[133] http://www.pddoc.com/tmi2/kemeny/index.htm, Kemeny J. et al. (1979), *Report of The President’s Commission on the Accident at Three Mile Island.*

[134] http://www.ncbi.nlm.nih.gov/pubmed/18049228, Bromet E. J. and Havenaar J. M. (2007), ‘Psychological and perceived health effects of the Chernobyl disaster: a 20-year review’, *Health Physics* Vol. 93.

presumably this will be more so when the zone itself is delimited. 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. One resident, whose family left their home 18 miles to the north of the plant, said, "If it really is safe, I want them to come back. But it's hard to know. Different people say different things, and that adds to my stress. I don't know whom to trust."[135] 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.[136] In 2013 the White House Management and Budget Office completed a review of the Environmental Protection Agency's protective action guidance for radiological incidents, recommending that cleanups after nuclear plant accidents or 'dirty bombs' would not have to comply with a single set of public health guidelines irrespective of the features of the incident in question, established during the 1980s by the EPA Superfund programme. Instead, a principle of 'optimisation' would be adopted which would allow for unique remediation standards for a given incident. The report argued that the Fukushima accident demonstrated that abandoning normal EPA standards would be beneficial in some cases, noting that contamination was detectable over an area the size of Connecticut. To remediate such an area to EPA Superfund criteria would be prohibitively expensive for very modest health benefit.[137] 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."[138] (As noted earlier, the UK approach has been based on 30 degree sectors rather than circles.) Commentators like Paul Dorfman have argued for much more vigorous international involvement, including international reviews of security and safety, binding international standards on safety and security and international cooperation to

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[135] http://www.intelihealth.com/IH/ihtIH/E/333/8014/1481430.html, 'Stress emerges as major health issue at Fukushima', Associated Press, March 8 2013.

[136] http://www.ncrponline.org/Docs_in_Review/NCRPM1302.pdf, National Council on Radiation Protection and Measurements (2013), *Decision making for late-phase recovery from nuclear or radiological incidents.*

[137] http://www.nti.org/gsn/article/white-house-advances-controversial-nuclear-incident-response-guide/, Guarino D. P. (2013), 'White House advances controversial nuclear incident response guide', *NTI Global Security Newswire.*

[138] http://www.greenpeace.org/international/Global/international/publications/nuclear/2012/Fukushima/Lessons-from-Fukushima.pdf, Greenpeace International (2012), *Lessons from Fukushima*.

ensure regulatory effectiveness.[139] Others 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.[140] There may also be more calls for giving countries more powers over siting decisions involving nuclear plants in neighbouring countries near their own borders.

There has been a recent revival in interest in smaller and simpler nuclear generating units, generally referred to as 'Small Modular Reactors' (SMRs). The International Atomic Energy Agency (IAEA) defines 'small' as under 300 MWe while units in the range 300 – 700 MW are described as 'medium'.[141] The motivation for developing such reactors includes the high capital cost of large power reactors and the need to serve small electricity grids under below about 4 GW. SMRs may be built independently or as modules in a larger complex. It is argued, for example, that passive or inherent safety measures can play a larger role in smaller reactors, thereby partially obviating the need for expensive engineered safety systems. Similarly the economies of scale enjoyed by large units may at least to an extent be offset by series economies coming from building larger numbers of identical smaller units.[142]

In March 2012 the US Department of Energy signed agreements with three companies interested in constructing demonstration SMRs at Savannah River site in South Carolina, the designs in question ranging from 25 MW to 140 MW.[143] The most advanced modular project is in China, where Chinergy is constructing a 210 MW High Temperature Gas Reactor (HTR), consisting of two 105 MW units.[144] In 2013 Toshiba-Westinghouse and China's State Nuclear Power Technology Company (SNPTC) signed a memorandum of understanding to work together developing a PWR-type SMR based on Westinghouse's 225 MW design.[145] Rosatom has been progressing plans to build a 70 MW floating nuclear power plant.[146] There is also interest in very small fast reactors of output below 50 MWe. Among small reactors operating globally are the four units of the Bilibino cogeneration plant in Siberia, each unit providing 62 MWt for district heating and electricity production (11 MWe per unit); the Indian 220 MWe pressurised heavy water reactors (PHWRs); and the Chinese 300-325 MWe PWR such as those built at Qinshan Phase I (China) and Chashma (Pakistan).

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[139] Dorfman P. Fucic A. and Thomas S. (2013), 'Late lessons from Chernobyl, early warnings from Fukushima', in http://www.eea.europa.eu/publications/late-lessons-2/#, *Late lessons from early warnings: science, precaution, innovation*, European Environment Agency.

[140] http://www.huffingtonpost.com/2013/04/10/shadow-nuclear-evacuation-study-zone-congress_n_3051750.html?view=print&comm_ref=false, Donn J. (2013), 'Nuclear evacuation study shows that communities outside 10-mile zone may bog down system', *Huffington Post.*

[141] http://www.iaea.org/NuclearPower/SMR/index.html, IAEA (2013), *Small and medium sized reactors: development, assessment and deployment.*

[142] http://www2.ans.org/pi/smr/ans-smr-report.pdf, American Nuclear Society (2010), *Interim report of the American Nuclear Society President's Special Committee on small and medium sized reactors: general licensing issues.*

[143] http://energy.gov/articles/energy-department-announces-small-modular-reactor-technology-partnerships-savannah-river, USDOE (2012), 'Energy Department announces small modular reactor technology partnerships at Savannah River site', *energy.gov* website.

[144] http://www.iaea.org/NuclearPower/Downloads/Technology/meetings/2011-March-TWG-GCR/Day1/HTR-PM-Status-SYL-20110328.pdf, Sun Y. (2011), *HTR-PM project status and test programme*, IAEA.

[145] http://www.powerengineeringint.com/articles/2013/05/westinghouse-and-chinas-snptc-sign-smr-nuclear-pact.html, Ross K. (2013), 'Westinghouse and China's SNPTC sign SMR nuclear pact', *Power Engineering International.*

[146] http://csis.org/blog/russias-floating-nuclear-reactors, Friedman J. (2011), 'Russia's floating nuclear stations', *Centre for Strategic and International Studies.*

The siting requirements for a small reactor, in terms of land occupied and water required for example, are likely to be considerably more modest than those for a 1000 MW+. Existing nuclear sites such as Trawsfynydd and Dungeness, ruled out in the Strategic Site Assessment process, may be much more attractive if a smaller project is feasible. Although SMRs remain some way away from commercial availability – for example none has been submitted for GDA in the UK – they may become an option after 2025.

Conclusions

Several factors are relevant to decisions over siting of nuclear facilities. In its guidance for countries considering constructing their first nuclear reactor, the IAEA lists the following factors as relevant when making decision on site selection:[147]

- ease of integration into the electricity system;
- geology and tectonics;
- seismology;
- heat removal capability;
- hydrology;
- demography;
- meteorology;
- nuclear safety and radiation protection aspects;
- environmental effects;
- risks from man-made events;
- availability of local infrastructure;
- ease of access;
- legal aspects;
- public acceptance (including in neighbouring countries if the site is close to a border).

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[148]. "The purpose of site evaluation is to demonstrate that the preferred sites are acceptable from all aspects and in particular from the safety point of view."

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. They included sites using highly radioactive materials and hosting reactors – the research establishments at Harwell (Oxon.) and Winfrith (Dorset), the production facility at Windscale in the northwest of England, the fact reactor research establishment at Dounreay and the atomic weapons research establishment at Aldermaston in Berkshire. 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

[147] http://www-pub.iaea.org/MTCD/Publications/PDF/te_1555_web.pdf, IAEA (2007), *Managing the first nuclear power plant project.*
[148] http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1177_web.pdf , IAEA (2003), *Site evaluation for nuclear installations, safety requirements*, IAEA Safety Standards Series No. NS-R-3.

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. (Other early facilities did not involve use of reactors or large quantities of highly active materials and so did not have the same need for isolated sites. These included the fuel fabrication facility at Springfields near Preston, the enrichment plant at Capenhurst in Cheshire established in 1949, and the production division headquarters at Risley in Lancashire which did not deal with active materials, although a 300 kW(th) research reactor for university use operated there from 1962 to 1991. The Radiochemical Laboratory at Amersham, Buckinghamshire, which was to become part of the UK Atomic Energy Authority in 1954 and privatised in 1983, had been established in 1940 to manufacture luminous paint containing radium.[149])

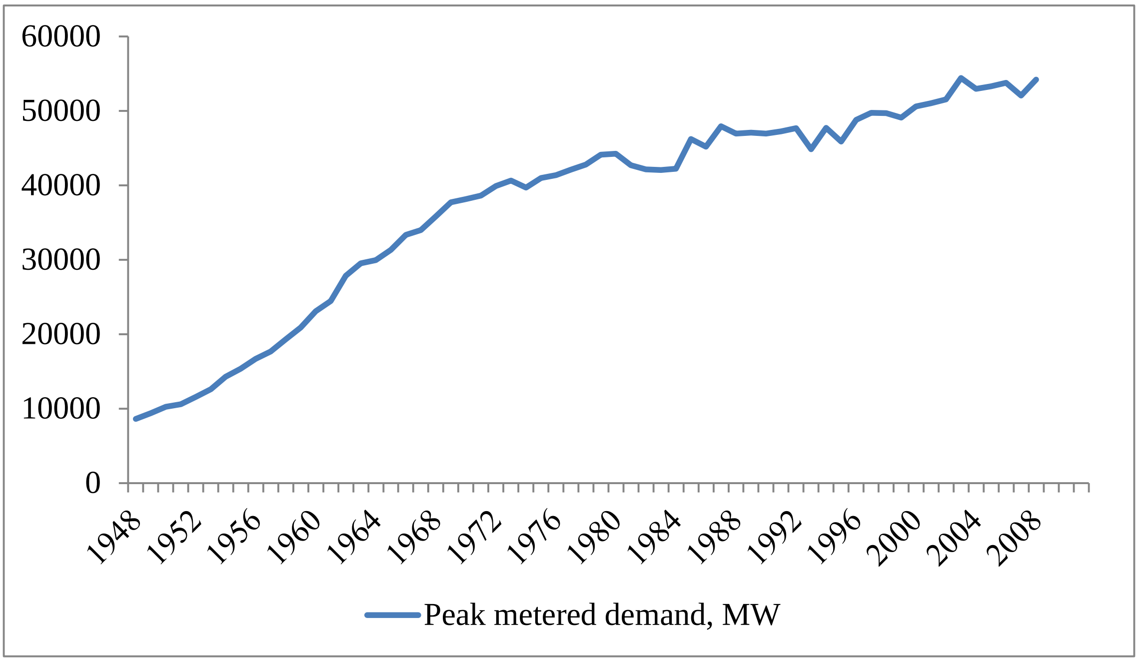
Parallels can be drawn with the development of heavy fossil fuel-fired generating plant in the UK. Desires to locate facilities close to centres of demand led to power stations such as Battersea (coal) and Bankside (oil) being built in central London in the inter-War and immediately post-War period. 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 4,000 people, disrupted travel for several days and led to the Clean Air Act of 1956.[150] 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. This in turn created the international problem of acid rain and led to the European Union Large Plant Directive, which mandates early closure of much coal-fired capacity in the mid-2010s. (A further factor was the increasing size of generating units. The more than thirty power stations in London operating in the early 1960s had outputs in the range of 11 MW to 105 MW. The 2,000 MW units now being proposed would burn something like 20,000 tonnes of coal per day, or 6 million tonnes per year. Previously it had been cheaper to take coal to the stations, but with such large units, coupled with much improved efficiency in the national grid, it became more economic to site the power stations near to the coalfields, or oil importation terminals such as Fawley near Southampton, and transport the electricity to the end user: 'coal by wire'.)[151]

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.[152]

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

[149] Pocock R. F. (1977), *Nuclear power – its development in the United Kingdom*, Unwin Brothers: Woking.
[150] http://www.metoffice.gov.uk/education/teens/case-studies/great-smog, Met Office Education (2013), *The great smog of 1952*.
[151] See http://www.aboutblyth.co.uk/html/cegbstory.html, Cochrane R. and Schaefer M. (1990), *The CEGB story*.
[152] http://hansard.millbanksystems.com/commons/1974/may/02/nuclear-reactors, Hansard (1974), debate on nuclear reactors, May 2 1974.

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.



Peak metered demand, England and Wales (MW) – total gross system demand is typically some 10-15% higher[153]

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,

[153] http://www.nationalgrid.com/uk/Electricity/Data/Demand+Data/, National Grid (2013), *Metered half-hourly electricity demands.*

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 run out of steam by the mid to late 1980s, for reasons not directly connected with siting problems (although the growing antinuclear feeling in the country, notably after the accidents at Three Mile Island in 1979 and Chernobyl in 1986, was contributing to increasing costs in the siting process, notably through the very long Public Inquiry into Sizewell B).

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 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 proposals for eight new plants to replace AGR capacity 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 ever embark on a programme of anything like Hawkins proportions, new sites might ultimately 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, the fifth phase is a distant one and other 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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