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Siting implications of nuclear energy: **a path to net zero**

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Foreword

In the UK, nuclear energy seems to be assuming more importance after decades of comparative, if productive, obscurity.

The legal obligation to achieve net zero by 2050 has been the main motivator, with many acknowledging that reaching such an ambitious target requires at least some degree of new nuclear generation. Alongside this, the sharp rise in energy costs experienced in the past year has reiterated the importance of diversity in energy generation, with over-reliance on imported gas having made British energy users particularly vulnerable to rising prices and volatility.

As such, reinvigoration of British nuclear energy cannot come too soon. At its peak output in 1998, UK nuclear power generated 100 TWh of electricity; last year it was 46 TWh, the lowest since 1982. Indeed, nuclear output will continue to fall throughout this decade as ageing plants retire, with Hinkley Point C (anticipated in 2026) providing only partial compensation.

To complicate matters, simply replacing the lost electricity generating capacity with new plants will not meet the UK's energy challenges. To reach net zero, low-carbon transport and heating technologies are essential, as well as replacing the sizeable contribution of gas to electricity generation. Last summer, The University of Manchester's Dalton Nuclear Institute released *Nuclear Energy for Net Zero: A strategy for action*, which identified the scope for non-electrical outputs from nuclear energy. For an expansion of the necessary scale, the limited number of nominated nuclear sites in the UK is insufficient. Delivering on these ambitions will therefore require new nuclear sites to be identified, and new communities to accept the presence of nuclear facilities.

This is not a trivial task, and common to all discussions about nuclear energy generation is the ever-present question of waste. Now would be a good time to ask ourselves questions concerning future waste policy: What will be the strategy concerning spent fuel? Are the safety standards for licensing (and de-licensing) sites fit-for-purpose? What kind of legacy should we tolerate from our nuclear sector? What input do local communities have in determining the suitability of nuclear sites? Are the historic definitions of low, intermediate and high level waste suitable for our current needs?

Delivery of nuclear energy is a complex process, and we must aim to understand the whole nuclear lifecycle, and the societal context in which it exists, if we are to make the right decisions. This report aims to further discussion on the matter, and provides recommendations on how to deliver a responsible nuclear sector which makes a full contribution to net zero.

Professor Francis Livens
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Executive summary

Recent government publications have envisaged a 'Three Wave' nuclear energy programme in the UK, consisting of GW-sized Light Water Reactors (LWRs), Small Modular Reactors (SMRs; essentially smaller LWRs) and advanced reactors optimised around producing high temperature heat, assumed to be High Temperature Gas-cooled Reactors (HTGRs).

This will involve the extension of the nuclear energy market from the current provision of firm electrical generation to the potentially much larger market of low carbon heat for industry, transport and other applications. This potentially much enlarged market would lead to the prospect of a large number of reactors, with the associated requirement for many new reactor sites.

This paper examines the effects of this Three Wave nuclear energy programme in the UK, with particular attention paid to the need for new reactor sites and to the process of achieving acceptance of the selection these sites. The implications of such an extensive programme are also examined, with particular attention to the procedures for dealing with legacy plants, spent fuel, waste, and the approach to stakeholder acceptance which will be vital to such programmes.

At present, there is little overall vision of how the Three Waves might interact in time and in the energy market. There is a need for a framework which identifies the range of possible programmes and ensures that a 'cradle to grave – and beyond' approach is considered and modelled.

Recommendation one:* *The UK government should develop an integrated framework for delivery of nuclear energy in the UK to ensure the whole lifecycle is understood.

The present role of the Nuclear Decommissioning Authority (NDA) is to deal with the legacy waste from the nuclear sector. It presents a Single-use vision of sites rather than a dynamic system where Site Re-use is part of the overall philosophy.

Recommendation two:* *The UK government should integrate the NDA mission into this framework, supporting waste management and site clearance for reuse.

The current criterion for delicensing a nuclear site relies on a 'no danger' concept which includes doses to the public which are extremely low and, in some cases, not likely to occur in practice. This in no way detracts from the overall logic and robustness of the existing regulatory arrangements, but does reveal where the lack of a well-defined risk-based end point could further a holistic view of a nuclear plant cycle.

Recommendation three:* *The UK's existing regulatory arrangements are robust and any technology deployed in the UK should conform wholly to those requirements. However, interpretation of concepts like 'no danger' should be rational and risk-based, and avoid limits which are disproportionate to any other area of regulation.

Nuclear waste in the UK is dominated by two extreme categories: 95% of waste by volume is Low Level Waste, and is responsible for less than 0.01% of the total radioactivity; at the other extreme, High Level Waste makes up 0.03% of the total waste by volume, yet comprises 76% of the total radioactivity. Between these categories, a broad definition for Intermediate Level Waste exists: 5% of the volume and 24% of the radioactivity. There is a need to examine whether the current system of waste classification, treatment and disposal is optimal, or even fit for purpose. An overall vision of the Three Wave programme could provide much-needed clarity on the treatment of different wastes. It would also provide clearer information to inform opinions near existing and projected new nuclear sites.

***Recommendation four:* The UK government should re-examine the current, very broad definition of Intermediate Level Waste to consider whether more optimal routing of waste streams can be progressed to appropriate end points.**

There is currently no policy for the treatment of spent fuel for the planned Three Waves, and clearly the local, regional and national choices in this area will affect the futures of the new build sites. This could modify the attitudes of any locality to new build.

***Recommendation five:* The UK government should develop an integrated strategy for management of spent fission fuel from a range of operators and technologies.**

Current knowledge of stakeholder views and values on nuclear matters is largely based on knowledge gained by the BNFL National Stakeholder Dialogue which was conducted two decades ago. This should be brought up to date by a similar stakeholder study, drawing on the observations gained by the BEIS Public Dialogue on Advanced Nuclear Technologies [1].

***Recommendation six:* To support a Three Wave nuclear fission programme, a significant study of stakeholder views and values should be undertaken to update the findings of the BNFL National Stakeholder Dialogue and reflected in the BEIS Public Dialogue on Advanced Nuclear Technologies.**

Within a framework for a Three Wave nuclear fission programme, it is essential that the proponents of any particular initiative are appropriate for such a programme. This will involve a defined outline of the entire lifetime of the proposal, and defining a plan for communicating the proposal to stakeholders, including local communities likely to be involved.

***Recommendation seven:* Within this framework, any nuclear development, fission or fusion, needs to define at the start the entire lifecycle of its technology and sites, and communicate this openly and effectively to current and potential future host communities and other stakeholders.**

In particular, stakeholder involvement should recognise the progress currently being made by the GDF volunteer-based process, and the implications of this process to reactor siting.

***Recommendation eight:* Any nuclear development should recognise the progress made using the GDF volunteer-based process, and the expectations for community participation raised by that process, alongside the challenges and timescales which are inevitably associated with open and effective community engagement.**

The government's Three Wave nuclear fission programme should be evolved with the active participation of developers and developers' organisations, which should ensure that all development activities should embody the principles and practices which are developed.

***Recommendation nine:* The developers and operators should be actively involved in the evolution and promulgation of government frameworks and guidance, and all development activities should embody the principles and practices which are developed.**

1 Introduction

For the first time in over half a century, the UK has a coherent policy on nuclear energy which envisages a significant role for this low carbon energy source on the path to achieving net zero carbon emissions by 2050 [2, 3].

This policy envisages 'Three Waves' of nuclear energy [4, Fig. 6]:

1. GWe-scale Gen III+ Light Water Reactors (LWRs; deployable now),
2. Small Modular Reactors (SMRs; deployable in the early 2030s), and
3. Advanced Modular Reactors (AMRs), assumed to be in the form of High Temperature Gas-cooled Reactors (HTGRs; with ambitions for a demonstrator by the early 2030s [5, p. 4])*.

Waves one and two are currently envisaged to be primarily dedicated to the traditional roles for nuclear power (i.e. firm electricity production), while the HTGRs are capable of providing low carbon heat for hydrogen production and industrial applications. This potentially much enlarged market would lead to the prospect of a large number of reactors, with the potential requirement for many new reactor sites. Figure 1 (page 7) summarises the Three Waves, and illustrates the imminent decline of the existing fleet.

This paper examines the effects of this Three Wave nuclear energy programme in the UK, with particular attention to the need for new reactor sites and the process of achieving acceptance for the use of these sites. The implications of such an extensive programme are also examined with particular attention to the procedures for dealing with legacy plants, spent fuel, waste, and the approach to stakeholder acceptance which will be vital to such programmes.

As will be discussed, the advent of a significant programme of building new nuclear energy facilities will involve achieving public acceptance at national, regional and local levels. For much of the past, discussions concerning the societal aspects of nuclear energy have largely involved picking sides and 'throwing rocks' at opponents, often with a marked absence of rational fact-seeking and debate.

Experience with the process of finding a site for a Geological Disposal Facility (GDF) highlights some of the difficulties faced, and possibly a potential solution. An initiative to site a GDF for the disposal of radioactive waste was unsuccessful due to the government refusing permission following opposition from Cumbria County Council, and an associated public inquiry in 1997 [9, Para. 2.1]. Another failed attempt followed in 2013, again due to opposition from Cumbria County Council, this time in spite of approval at the district level by Copeland and Allerdale Councils [10, Para. 6].

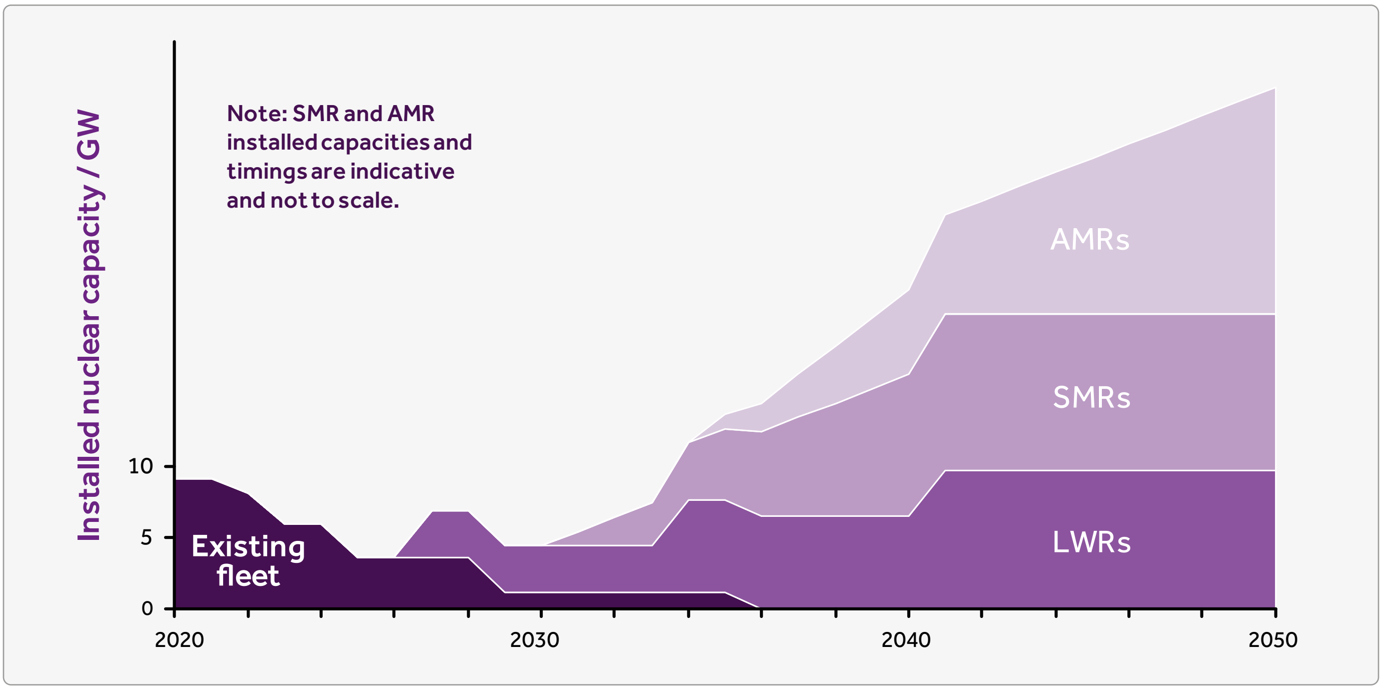
** There are sometimes differences in notation regarding SMRs. Here, we consider SMRs as small, modular LWRs; and AMRs as more exotic (i.e. non-LWR) reactor variants.*

Currently, however, a local-consent-based process seems to be making measured progress on a GDF, with four communities currently involved in local engagement processes. This progress, while modest, may well have convinced all sides that a rational consent-based process of nuclear site selection would be preferable to either 'pitched battles in the courts' or confrontations 'in front of the bulldozers'.

Fortunately, reasoned debate and gathering of stakeholder views concerning nuclear energy has been previously achieved, and was demonstrated extensively during the BNFL National Stakeholder Dialogue [11]. While this is now two decades ago, many of its observations have been recently mirrored by the evidence gained during the BEIS Public Dialogue on Advanced Nuclear Technologies [1].

The remainder of this paper does not attempt to cover the 'how' of a social engagement process to incorporate nuclear energy into net zero ambitions, but does outline what will need to be covered, and identifies some of the key points upon which consensus may depend.

Figure 1. The decline of the UK's existing nuclear reactor fleet and the proposed Three Waves of new nuclear, adapted from [6, Fig. 1]. The LWR plot assumes EPR pairs at Hinkley Point, and two other sites [7, 8]. Only one reactor from the current fleet will remain operational by the end of this decade.



2 Legacy versus progression

At present, there is little overall vision of how the Three Waves might interact in time and in the energy market. There is a need for a framework which identifies the range of possible programmes and ensures that a 'cradle to grave – and beyond' approach is considered and modelled.

Recommendation one: The UK government should develop an integrated framework for delivery of nuclear energy in the UK to ensure the whole lifecycle is understood.

The programmes envisaged will require more sites than are currently identified for nuclear power stations [12, Sec. C], which raises the questions of how new sites will be made available, and on what basis? The vision of a programme rolling out over decades also raises questions on how ongoing nuclear energy activities will be integrated into the overall UK energy and industrial programmes. This paper explores considerations in this area.

The UK's nuclear sector began with dedicated facilities for the weapons programme. This progressed to electricity generation with the Magnox reactors, the earliest of which were dual-purpose power plants which delivered plutonium for use in weapons. All of these sites are now shut down, with current nuclear generation being provided by the fleet of Advanced Gas-cooled Reactors (AGRs; scheduled for retirement themselves before 2030) and one LWR. These Magnox and weapons sites have left us with a legacy, the clean-up of which has been allocated to the Nuclear Decommissioning Authority (NDA), a non-departmental public body. To date it has not, however, been the subject of an overall agreed programme for the decommissioning and removal of facilities. This 'end of life' role for NDA has been recently underlined by BEIS [13]:

> *"The UK government and EDF have agreed improved arrangements to safely and efficiently decommission Britain's 7 AGRs, due to reach the end of their operational lives this decade."*
>
> *"[Under this agreement,] EDF will aim to shorten the time they take to safely remove the fuel from the power stations as they come offline, before working closely with the NDA to transfer ownership of the stations to the NDA, [whose] expertise and the economies of scale of working on [the Magnox stations] and the AGR nuclear reactors combined, will ensure the long-term clean-up of these sites is done more efficiently."*

This arrangement would appear to emphasise nuclear reactor sites as 'Single-use' entities; i.e. with a site designated, reactors built, operated, and shut down, but with no agreed timescale or parameters regarding the decommissioning and removal phases; and certainly no agreed end point which would leave the sites suitable for some nominated future use, or able to be released as 'walk-away safe'. This end-state would be determined by the Nuclear Installations Act requirement that residual activity should represent 'no danger' [14, Sec. 4], which is currently interpreted by the Office of Nuclear Regulation [14, Para. 163] as:

> *"Applying this to licensed nuclear sites, any residual radioactivity above the average natural background, which can be satisfactorily demonstrated to pose a risk of death to the most exposed individual of less than one in a million per year is 'broadly acceptable'."*

Short of a definitive commitment and programme to meet this criterion, the de facto interim end-state of Magnox and AGR stations would probably be defueled reactors and 'cleaned-up' reactor buildings with ducts etc. removed. Such a strategy would leave a typical reactor site with two large concrete buildings housing the pressure vessels and moderator graphite core structures still in place. In effect, the site has ceased to be an electricity generator, but the main buildings are still physically present. While these structures require very little attention/observation, they will still contain enough radioactive contamination and activation to be a considerable source of radioactive waste.

In a hypothetical UK with little need for further nuclear sites, this Single-use strategy may have been tolerable, but the programmes now envisaged will require both the re-use of existing sites, and the selection and development of new ones. There is a wide range of potential site requirements, particularly for the sites which may be needed for HTGRs. Speculation has extended to 'Hydrogen Gigafactories' [15, Sec. 3.2] where potentially 36 reactors, each of 600 MWt are co-sited, with 10 such sites envisaged; but even a less ambitious programme could involve many tens of reactors on several tens of sites. This is crucial, because new sites (i.e. those with no historic nuclear presence) will require the acceptance of new reactor build in areas with surrounding publics with no experience of (or vested interest in) a new local reactor. When considering new sites, it is worth bearing in mind that the last UK nuclear site to be opened was Torness, where work on the site's AGRs started over 40 years ago. Both the UK nuclear industry and the processes involved in permissioning developments have changed very significantly since then.

If the future nuclear programmes that are envisaged are to be achieved, the UK will need to gain access to viable sites, both with and without a history of nuclear activity. This considered, the position begins to look much easier to promote if the strategy of 'build, operate, decommission, add to the legacy' became 'build, operate, decommission, remove, re-use' (summarised in Figure 2, page 10) – where 're-use' could be further nuclear or non-nuclear activity. This would involve the operation of a nuclear power station becoming part of a site lifecycle, not simply a one-off, which would allow, indeed require, greater connection to be made between clean-up and new build. This would, of course, have a considerable effect on NDA's vision and mission, changing 'clean-up of the nuclear legacy' to, for many sites, 'clean-up for Site Re-use'. This would provide NDA with a significant driver to proceed to particular site states and timescales, and create an opportunity for the organisation to modify its vision for the future and take on a role as an important contributor to the UK's overall nuclear ambitions.

***Recommendation two:* The UK government should integrate the NDA mission into this framework, supporting waste management and site clearance for reuse.**

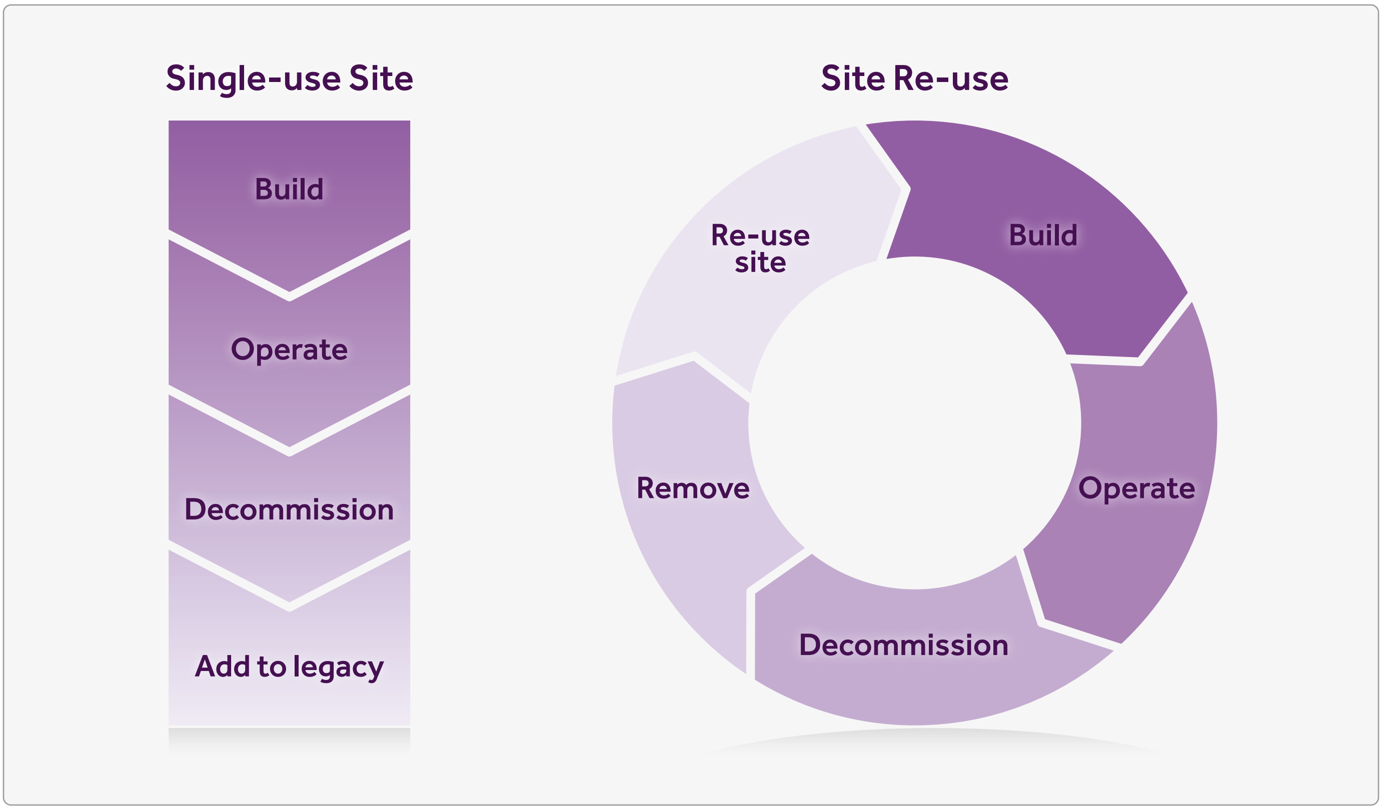
If the examination of future site uses became an integral part of the site evolution, this would favour a more explicit examination of the costs and benefits of Site Re-use. Currently, with NDA/RWM (Radioactive Waste Management, a wholly-owned subsidiary of NDA) merely administering the legacy, it is easy to prioritise extreme emphasis on low doses/high certainty, while remaining divorced from the inevitably escalating costs. In particular, the aforementioned 'no danger' criterion depends on the dose received by the 'most exposed individual', and there are examples where the 'one in a million' individual dose could be demonstrated to have an extremely low chance of actually occurring. At best, this is extremely cautious, but more likely, is demonstrably over-conservative. This in no way detracts from the overall logic and robustness of the existing regulatory arrangements, but does point out where the lack of a well-defined risk-based end point could further a holistic view of a nuclear plant cycle.

***Recommendation three:* The UK's existing regulatory arrangements are robust and any technology deployed in the UK should conform wholly to those requirements. However, interpretation of concepts like 'no danger' should be rational and risk-based, and avoid limits which are disproportionate to any other area of regulation.**

A shift towards a more understandable, pragmatic and practically significant site end point would inevitably bring more clarity to the cost and practical reality of achieving site closure. It would also provide a background where fuel cycle/reactor sites with major contamination such as Sellafield are more objectively compared with 'normal' shut down reactor sites, putting the costs of nuclear site contamination into better perspective.

The move towards a 'site lifecycle' approach should also allow a more balanced view to be sought in a spectrum of concern arising from scientifically calculated risks into national and local public opinion, and this mission should be incorporated into any exercise in finding new nuclear sites.

Figure 2. Diagram summarising the difference between the strategies of Single-use Sites and that of Site Re-use.



3 Fossilised sites

As discussed, the perception is that hosting a first generation nuclear site appears to the public to leave a permanent nuclear legacy, with an added consequence of sizeable concrete structures forever populating the landscape. This is probably a manageable scenario for the current siting policy, which states that [16, p. 33]:

> *"[There are eight sites] that the Government has determined are potentially suitable for the deployment of new nuclear power stations in England and Wales before the end of 2025."*

These sites* are all adjacent to closed down or currently operating reactors. This version of new nuclear siting gives various attributes useful for new build, such as:

- On, or adjacent to, a nuclear licensed site,
- Availability of grid, cooling water and other infrastructure,
- A skilled local workforce, otherwise facing diminishing future opportunities, and
- A local community which is nuclear-familiar and likely to be broadly supportive.

However, taking community support for new build in existing nuclear communities for granted would be complacent – especially where previous plants may have been perceived to have damaged the environment, left other negative impacts behind or indeed, be leaving reductions in employment that are deemed rectifiable only by new nuclear build. To add to this need for caution, the probable requirement for new sites raises a requirement for local acceptance of a sort that has not been sought for around

* *Bradwell, Hartlepool, Heysham, Hinkley Point, Oldbury, Sizewell, Sellafield and Wylfa [16]. Trawsfynydd is not listed, though there are several schemes supported locally that envisage new reactor siting there.*

half a century. This new requirement will also arise in a world in which local acceptance looms considerably larger in the societal process than it did in the past, especially against the background of a lifetime plan which currently appears as a 'build it now – and it's there forever' reactor lifetime. This 'there forever' discussion will need to be examined in comparison to a 'build – operate – decommission – remove' cycle, which would surely be far less alarming. These comparisons will be unavoidably linked to nuclear energy's generation and treatment of radioactive waste. To an extent, the availability of the required new sites is likely to be inextricably affected by radioactive waste policy and its delivery. Certainly, the proposition of a permanent visible legacy resulting from a new nuclear site can at the very least be considered a barrier to the development of new sites, and ultimately could render the delivery of the required sites unachievable.

3.1 **Sterilisation by waste?**

This is a parallel scenario to the 'decommission and remove' debate. The past few years have seen long-delayed progress on the provision of a GDF, based on a local consent process which (as of early 2022) involves four volunteer areas, although this number may increase or decrease as the process advances. Many studies and surveys have accepted that, whatever the future of nuclear energy in the UK, the current situation demands a GDF [17, 18][†]. Progress on a GDF has been subject to several initiatives over decades, all of which have foundered because of political and/or public disagreement.

Progress is now being made utilising a process which relies on the combination of both a suitable geology and a willing community – the latter being judged by a test of public support in the communities concerned. The process currently involves the participation of three areas in West Cumbria and one in Lincolnshire. An overarching feature of the current initiative is that it will proceed at the rate determined by the local representatives – it cannot be dictated to, and it cannot be 'hurried up'. Currently progress is encouraging, but the process must surely have implications for other areas of nuclear operations, with the examination of the role of local permission; it is probably inconceivable that localities will not seek to influence, for example, the siting of a reactor in the same way as 'those in the GDF process are influencing their process'. Certainly, whatever the new build siting process evolves into, it will have to take into account the principles and expectations raised by the GDF arrangements.

[†] *It should be noted that the Scottish Government does not support the policy of geological disposal [30].*

4 Future waste policy

In the UK, radioactive waste is classified into High, Intermediate, and Low Level Waste (HLW, ILW, and LLW respectively) [19, Sec. 3]. HLW is generated from reprocessing spent nuclear fuel. It contains many of the fission products which derive from the fission process within the reactor core. Short-lived fission products are highly radioactive, so this waste category comprises most of the radioactivity in waste inventories (~76%), despite making up only 0.03% of the volume.

LLW in contrast is waste with a radioactive content below 4 GBq/t for alpha activity, or 12 GBq/t of beta/gamma activity. 95% of waste by volume is LLW, and two thirds of this is designated Very Low Level Waste (VLLW), which can be disposed of in landfill or as industrial waste. LLW contributes <0.1% of the total radioactivity of the UK's nuclear waste.

ILW exceeds the radioactive boundaries for LLW, but does not generate significant amounts of heat to warrant special consideration for storage or disposal. This is a broad category, and the largest portion of ILW in the UK is the graphite cores of the reactor fleet.

HLW from a future new build programme should be manageable with the currently proposed GDF; though a study in this area covering the likely HTGR programmes will be needed. This implies that the current GDF programme could at least initially accept the HLW burden of a new build programme – but a large question within the 'decommission and remove' debate is what to do with the large quantities of ILW generated by the dismantling of old reactors. A significant development on this is the current NDA process, which emphasises Near Surface Disposal (NSD). This involves [20, p. 4]:

> *"...assessing the technical, environmental and economic case for purpose-built engineered facilities located either at the surface or up to tens of metres below ground. If NSD is implemented, it would not replace a GDF and would be developed in tandem to provide an earlier and more cost-effective solution for a limited proportion of the less hazardous wastes in the ILW category."*

> *"Such an approach aligns with [NDA's] Radioactive Waste Strategy that recommends risk-informed waste management and flexible decision-making, focused on the most appropriate treatment and disposal routes that take account of the risks posed by the nature of wastes rather than strict classification."*

The outcome of these strategic developments will determine the number and location of the NSD sites proposed by the NDA to service their existing sites. The regulation and safety cases of these NSD sites will affect the extent to which 'decommission and remove' is likely to be achieved. These factors will, in turn, affect the expectations of communities selected for new nuclear sites, with any ongoing restrictions from the disposal of waste factored into the attitudes of the affected communities.

The initial informal NDA reaction when the NSD and GDF were discussed was that the process of choosing and implementing NSD sites would not involve local consent. It is up for debate whether this exclusion of local involvement, as waste categorisation changes from HLW to ILW could be a viable societal approach. There is certainly a need to study the expectations of the varying local stakeholders for new build, NSD and GDF facilities. This is one of the many areas where plans for a more ambitious new build programme might erode the clarity needed to help deliver a successful GDF. This points strongly towards the need for an integrated view on nuclear energy, encompassing both legacy clean-up and potential new build. Such an integrated view will be a vital component of a successful forward programme on both sides. This is emphasised by the fact that the approval of any new build programme depends on whether it has been accepted that the waste produced can be managed. This derives from the Flowers Report which recommended that [21, Para. 338]:

> *"There should be no commitment to a large programme of nuclear fission power until it has been demonstrated beyond reasonable doubt that a method exists to ensure the safe containment of long-lived, highly radioactive waste for the indefinite future."*

This was formalised in the white paper of 2008, which stated that [22, p. 99]:

> *"Our policy is that before development consents for new nuclear power stations are granted, the Government will need to be satisfied that effective arrangements exist or will exist to manage and dispose of the waste they will produce."*

Thus the entire Three Wave programme effectively depends on the continued progress in waste management in general, and on the GDF in particular. This means that clarification of waste routes and end points remains a critical step underpinning the nuclear contribution to net zero by 2050.

4.1 Waste classification and waste policy

The possibility of NSD of some ILW raises the question of whether the current system of waste classification, treatment and disposal is optimal, or even fit for purpose. In particular, the range of wastes falling into the ILW category is very wide, and will at the very least, need to be re-examined in the course of assessing the applicability of NSD. Revisiting waste categorisation with current understanding, and a vision of the Three Wave programme could provide much-needed clarity on the treatment of different wastes. It would also provide clearer information to inform opinions near existing and projected new nuclear sites.

There is thus a need to examine whether the current system of waste classification, treatment and disposal is optimal, or even fit for purpose. An overall vision of the Three Wave programme could provide much-needed clarity on the treatment of different wastes. It would also provide clearer information to inform opinions near existing and projected new nuclear sites.

***Recommendation four:* The UK government should re-examine the current, very broad definition of Intermediate Level Waste to consider whether more optimal routing of waste streams can be progressed to appropriate end points.**

As the Magnox, AGR and HTGR reactor technologies involve considerable quantities of graphite, the treatment and classification of these wastes will be of particular interest.

4.2 Spent fuel and spent fuel storage

One essential element of a successful new build programme will be to make a decision on the how to manage the spent fuel. Current views on the Three Wave programme seem to be firmly committed to the once-through fuel cycle, which involves storage and eventual disposal of the spent fuel. Given the potential to have multiple different operators for fission new build, there is a need to define a UK strategy for spent fuel management. Historically, the fuel from the Magnox reactors was transported to Sellafield for reprocessing. Spent AGR fuel is shipped for storage in the Thermal Oxide Reprocessing Plant (THORP) ponds at Sellafield, but this was essentially a tactical rather than a strategic choice (i.e. the ponds were available) and it was decided that NDA should manage the AGR spent fuel and closed down reactors. The only modern reactor in the UK, Sizewell B, currently stores its spent fuel in purpose-built stores on the reactor site.

For Hinkley Point C [23, Sec. 7]:

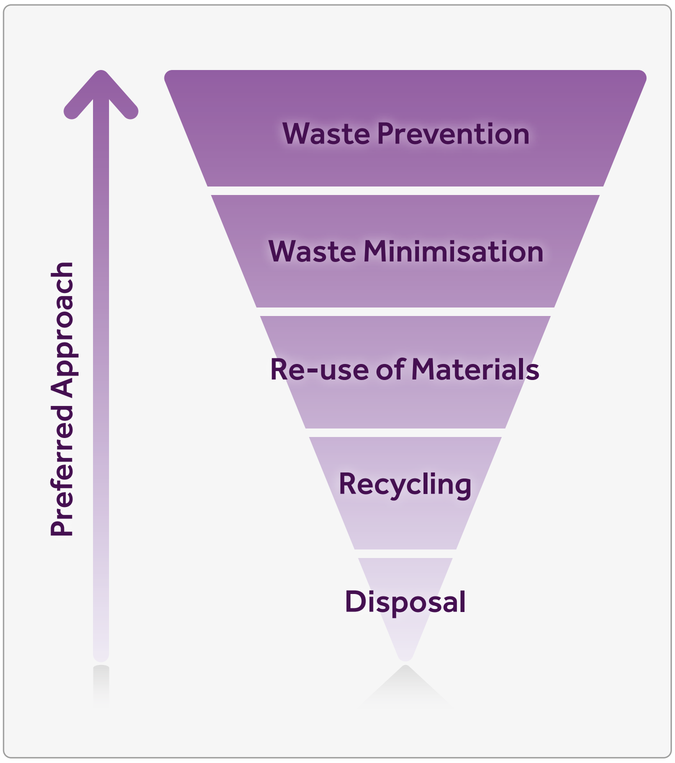
> *"The current strategy...is that the spent fuel will be stored in a purpose built storage facility on site prior to disposal at a geological disposal facility (GDF).*

There is currently no policy for the treatment of spent fuel for the planned Three Waves, and clearly the local, regional and national choices in this area will affect the futures of the new build sites, and could modify the attitudes of any locality to new build.

Recommendation five:* *The UK government should develop an integrated strategy for management of spent fission fuel from a range of operators and technologies.

For wastes other than spent fuel, the Three Waves would certainly be a valid trigger for a re-examination of the waste hierarchy and how the UK is proposing to interpret and conform to this. There are various versions of the waste hierarchy, with a high level of agreement between them; NDA's version, from its Radioactive Waste Strategy [24, p. 9] is shown in Figure 3.

Figure 3. NDA's waste hierarchy, which progresses from minimising the creation of waste, via waste reduction and re-use to disposal as the least preferred outcome [24, p. 9].



A recent review of environmental impacts of closed and open cycles [25] reveals the potential waste volume and activity advantages to be gained by closing the fuel cycle. However, the current overall economic position on fuel recycling is far from promising, and HTGR tristructural isotropic (TRISO) particle fuel [26] is particularly unpromising in this regard. This considered, the treatment of the whole spectrum of waste from spent fuel to Low Level Waste (LLW) could usefully be at least reaffirmed so that the details of any undertaking are made clear for the local stakeholders of any new or modified siting. This is particularly important in respect of a siting strategy which would potentially involve multiple Site Re-use for nuclear use. Communities must not feel that they are being asked to agree to indefinite nuclear activity on their doorsteps without the opportunity to be consulted appropriately as the development and re-purposing of the site proceeds.

4.3 Transport

In many ways transport is the 'yin' to spent fuel's 'yang'; local storage leaves fuel on site, while centralised or regionalised storage involves transport. The decisions on decommissioning, GDF, and NSD will also materially define the 'when', 'what' and 'where to' of the transport of radioactive material. Though transport is a significant public concern, it is an area with a significant body of relatively incontrovertible facts. Many studies have shown that the detriments of radioactive transport are overwhelmingly those of transport more generally, i.e. carbon emissions, road accidents etc. [27] and this would appear to be an area where reasoned debate should be achievable.

4.4 Accidents

The possibility of major accidents, combined with those that have actually occurred, is perhaps the major impediment to overall acceptance of an essential role for nuclear energy in the path to net zero. Though subject to fact manipulation to support conclusions, there is now certainly enough literature to enable the filtering out of both the most catastrophic *and* most complacent ends of the spectrum, and carry out a reasoned debate on likely accident consequences as applied to the UK. One regrettable development is for vendors of advanced systems to proclaim their design as the safest, leading inevitably to anxiety and focus on those older and contemporary systems which, by implication, are viewed as less safe. A more constructive approach would be to start with an appreciation of the safety standards embodied in the UK's nuclear regulatory system, and the firm policy commitment that only systems wholly conforming to these high standards will have the opportunity to be built and operated in the UK.

Any consideration of 'accidents' for nuclear would be incomplete without referring to the risk from malicious acts. A major problem here is, of course, that the counter-measures to prevent such malicious acts must by their very nature be secret. There is, however, enough public domain material (e.g. [28]) to provide reasonable reassurance that this area is treated very seriously, with significant resources effectively deployed.

4.5 **Discharges**

Discharges into the environment offer an analogous situation to accidents. Over half a century of progressive regulation has ensured that the effects of the peak permitted discharges can be demonstrated to involve very low doses, and the actual discharges are predominantly maintained well below the permitted maximum. Almost all industrial and social activities have discharges into, and consequences for, the environment. A cross-comparison of the regulation and performance standards of activities such as sewerage and agriculture could make a good case that discharges from nuclear generation are maintained well below any level of meaningful harm.

4.6 **Fusion**

Fusion energy in the UK has progressed as far as seeking a site for a Spherical Tokamak for Energy Production (STEP) demonstration power generating reactor. An open call to local authorities in England for sites in August 2021 provided many volunteer communities, and 15 sites were long-listed, with five sites subsequently shortlisted in October 2021. Notably, only one of those sites (Moorside, Cumbria), has been involved in the identification of new build fission nuclear sites, so STEP will need to deal with the spectrum of questions that must also be addressed by new fission nuclear build.

The information released as part of the site process (such as [29]) does not elaborate on the fusion fuel cycle, while stating that [29, p. 14]:

> *"We should be clear that STEP is not a fission plant. Our scale of risk is fundamentally different. Our regulatory parameters are currently different."*

In fact, the role of waste in the ongoing functioning of fusion energy is quite significant, and while no fission is involved, the handling and containment of tritium (the main fuel component), and the results from the irradiation of structural materials, is likely to involve volumes of waste at least comparable to fission power, on a 'per MWh' basis.

5 Conclusions

It is clear that there are many aspects to achieving public acceptance of a significant programme of building new nuclear energy facilities at national, regional and local levels. It is also clear that there is a far greater body of demonstrable facts which can be used as a basis for debate.

There will always be values-driven difference in the importance attributed to any particular parameter *x*, but the debate can be very much more meaningful if it can be agreed that the parameter is indeed *x* rather than 100*x* or 0.001*x*. There has been a great deal of experience in balanced stakeholder assessment over the last two decades, and many process lessons have been learnt. Much will now depend on how nuclear's role in the net zero initiative is organised, and the clear definition of the various roles defined over the next years and decades. In particular, the knowledge of stakeholder views and values on nuclear matters is largely based on knowledge gained by the BNFL National Stakeholder Dialogue two decades ago. This should be brought up to date by a similar stakeholder study, drawing on the observations gained by the BEIS Public Dialogue on Advanced Nuclear Technologies.

***Recommendation six:* To support a Three Wave nuclear fission programme, a significant study of stakeholder views and values should be undertaken to update the findings of the BNFL National Stakeholder Dialogue and reflected in the BEIS Public Dialogue on Advanced Nuclear Technologies.**

With a framework for a Three Wave nuclear fission programme, it is essential that the proponents of any particular initiative are appropriate for such a programme. This will involve a defined outline of the entire lifetime of the proposal, and defining a plan for communicating the proposal to stakeholders, including local communities likely to be involved.

***Recommendation seven:* Within this framework, any nuclear development, fission or fusion, needs to define at the start the entire lifecycle of its technology and sites, and communicate this openly and effectively to current and potential future host communities and other stakeholders.**

In particular, stakeholder involvement should recognise the progress currently being made by the GDF volunteer-based process, and the implications of this process to reactor siting.

***Recommendation eight:* Any nuclear development should recognise the progress made using the GDF volunteer-based process, and the expectations for community participation raised by that process, alongside the challenges and timescales which are inevitably associated with open and effective community engagement.**

The government's Three Wave nuclear fission programme should be evolved with the active participation of developers and developers' organisations, which should ensure that all development activities should embody the principles and practices which are developed.

Recommendation nine:* *The developers and operators should be actively involved in the evolution and promulgation of government frameworks and guidance, and all development activities should embody the principles and practices which are developed.

Recommendations

To UK government (and devolved administrations where appropriate):

Recommendation one

The UK government should develop an integrated framework for delivery of nuclear energy in the UK to ensure the whole lifecycle is understood.

Recommendation two

The UK government should integrate the NDA mission into this framework, supporting waste management and site clearance for reuse.

Recommendation three

The UK's existing regulatory arrangements are robust and any technology deployed in the UK should conform wholly to those requirements. However, interpretation of concepts like 'no danger' should be rational and risk-based, and avoid limits which are disproportionate to any other area of regulation.

Recommendation four

The UK government should re-examine the current, very broad definition of Intermediate Level Waste to consider whether more optimal routing of waste streams can be progressed to appropriate end points.

Recommendation five

The UK government should develop an integrated strategy for management of spent fission fuel from a range of operators and technologies.

Recommendation six

To support a Three Wave nuclear fission programme, a significant study of stakeholder views and values should be undertaken to update the findings of the BNFL National Stakeholder Dialogue and reflected in the BEIS Public Dialogue on Advanced Nuclear Technologies.

To developers and operators:

Recommendation seven

Within this framework, any nuclear development, fission or fusion, needs to define at the start the entire lifecycle of its technology and sites, and communicate this openly and effectively to current and potential future host communities and other stakeholders.

Recommendation eight

Any nuclear development should recognise the progress made using the GDF volunteer-based process, and the expectations for community participation raised by that process, alongside the challenges and timescales which are inevitably associated with open and effective community engagement.

Recommendation nine

The developers and operators should be actively involved in the evolution and promulgation of government frameworks and guidance, and all development activities should embody the principles and practices which are developed.

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