Nuclear Decommissioning Authority

Site Restoration

Magnox Reactor Dismantling Timing and Sequencing Strategy (Gate 0)

December 2014

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Executive Summary

A Gate 0 Strategy Management System (SMS) paper has been prepared on the pace and priority for Magnox reactor dismantling, to support a strategic review to determine whether to remain with the current strategy, or to change to an alternative strategy.

This work will inform the development of an updated position on strategy development for Magnox reactor dismantling timing for the next NDA Strategy publication.

The current strategy is to defer reactor dismantling for around 85 years following reactor shutdown. This results in a period of fleet wide quiescence for over 30 years when all the Magnox sites are in the Care & Maintenance (C&M) phase at the same time.

Historic drivers for deferral include achieving the benefits from radioactive decay, avoiding the need for interim storage of reactor dismantling waste pending availability of a disposal route, and the reduction with increasing deferral time of Magnox lifecycle costs on a discounted or net present value basis.

There are risks associated with long deferral periods that may be exacerbated by an extended period of fleet wide quiescence. These include the threat of loss of corporate memory, skills, knowledge and organisational capability, and that estimated costs during the C&M phase escalate as a consequence of plant deterioration, or equipment obsolescence.

A phased programme of reactor dismantling, commencing prior to the end of the Magnox C&M Preparations (C&M Preps) phase, and continuing until Magnox reactor dismantling is complete, would avoid a period of fleet wide quiescence, and could offer new prospects.

The Magnox organisation, comprising a skilled workforce with increasing decommissioning experience, could be deployed to manage such a programme, whilst continuing to support sites in C&M. Such a strategy would demonstrate visible progress towards clearing the Magnox sites, contributing to the socio-economic wellbeing of communities by retaining skilled employment for longer, and enabling land to be released earlier for re-use.

It is appropriate to undertake a strategic review at this time to reflect the changing strategic context and circumstances. Advances in reactor dismantling and international experience demonstrate that nuclear power reactors can be dismantled promptly. Supporting work shows that the benefits of radioactive decay over the deferral period may not be as significant as previously considered. In addition, there are new waste options which could be applied to the long term management of reactor dismantling wastes.

There is a limited window of time prior to the end of the Magnox C&M Preps phase in which commencing a reactor dismantling programme at one or more sites would

enable funding to be spent on decommissioning rather than asset management, avoiding nugatory spend associated with preparations for quiescence at such sites, and making best use of the workforce and available infrastructure. Realisable benefits will erode over time as the Magnox sites progress toward the C&M phase and the workforce is reduced.

The following recommendations are made:

(1) The NDA should take into account the strategic context, the drivers for change and the strategic options identified in this paper for the development of an updated strategy position for the timing of Magnox reactor dismantling;

(2) Strategy development work should be carried out to identify preferred options, and to develop a business case to enable a decision to remain with the current deferred reactor dismantling strategy, or to change to an alternative strategy; and

(3) A structured programme of public and stakeholder engagement should be designed, to support the next stages of strategy development.

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	Name	Signature	Date
AUTHOR:	Adam Meehan, Energy*Solutions* (EU) Ltd.		
VERIFIED:	May Yeung, Energy*Solutions* (EU) Ltd.		
ENDORSED:	Benjamin Bridgewater, Magnox Ltd.		
STRATEGIC AUTHORITY:	Anna Clark, Head of Decommissioning and Site Restoration, NDA		
APPROVED:	Adrian Simper, Strategy and Technology Director, NDA		

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1 Purpose and scope

The purpose of this strategy development is to identify the optimal timing and sequencing for Magnox reactor dismantling, taking into account the NDA's decommissioning objective to deliver site end states as soon as reasonably practicable with a progressive reduction of risk and hazard. The Energy Act 2004 requires the NDA to review and publish its Strategy at least every five years. This work will inform the development of an updated position on strategy development for Magnox reactor dismantling.

The strategy development is being undertaken in accordance with the NDA's Strategy Management System (SMS), which is a 4 stage process: Stage 0 – research and development (R&D); Stage A – identify credible options; Stage B – identify preferred options; and Stage C – develop implementation plans and actions. The NDA's developing framework and processes for prioritisation is being applied to this strategy development to ensure a consistent approach with other Site License Company (SLC) programmes and to support improved transparency for prioritisation and business justification decisions across the estate.

This paper sets out the following:

- The basis for the current strategy, and the reasons for undertaking a strategic review of reactor dismantling timing strategy at this time;
- A description of the strategic context, the risks associated with the current strategy and the drivers for change;
- A summary of trends and experience in reactor dismantling in other countries, illustrating a range of relevant factors and constraints;
- Key interfaces and dependencies, for example with the development of Higher Activity Waste (HAW) Strategy, and for the disposal of reactor wastes;
- Options for the timing of reactor dismantling, along with options for programme sequencing, to cover a range of potential strategies, and to enable testing of strategic tolerances;
- A range of factors that could be used to discriminate between the strategic options, mapped to the NDA's Value Framework [i] and consistent with those for use with the NDA's prioritisation process [ii];
- Relevant site-specific information for the Magnox sites to help with future assessment of pace and priority for reactor dismantling;
- Constraints on reactor dismantling timing and sequencing, and opportunities that could contribute to programme optimisation; and
- A plan of future scope that could be undertaken to help to fill identified data and information gaps and to reduce strategic uncertainties.

The scope and boundaries of the current work are summarised in Table 1.

This paper provides the basis for an assessment of the pace and priority of reactor dismantling during 2015/16, leading to preparation of a Gate A/ B paper identifying credible and preferred options for reactor dismantling timing and sequencing.

The overall objective for this strategy development is preparation of a Gate C paper setting out the business case to either remain with the current Magnox strategy or for a change of strategy, for planned submission to the NDA in September 2016.

Table 1 Scope and Boundaries for this Strategy Development

Title	**Magnox Reactor Dismantling Timing and Sequencing Strategy**
SMS stage	Stage 0 - strategic context, drivers for change, strategic options, discriminating factors, constraints and opportunities.
Target level of strategy	Gate 0 - research and development on strategic options and relevant factors to support future stages of the SMS process
Lifecycle phases	This strategy development has potential implications for: • Care & Maintenance Preparations (C&M Preps); • Care & Maintenance (C&M); • Final Site Clearance (FSC); and • A long term storage phase for Magnox sites in Scotland, pending availability of a disposal route.
Sites	10 Magnox Ltd. sites and the Calder Hall Magnox site Consideration of strategic options for reactor dismantling timing and sequencing potentially on a site and fleet wide basis
Inventory	The inventory of activated radioactive materials within the reactors up to and including the biological shield (commonly known as the bioshield), including radioactive components stored in reactor voids. This inventory has historically been that which has been considered to influence reactor dismantling timing strategy. The inventory comprises the following materials: • Core graphite and reflector graphite; • Mild steel, stainless steel and other metals, either as structural materials or reactor components; and • Structural concrete associated with the bioshield. Other radioactive materials, present in periphery reactor building rooms, or as contaminated land or drains, and operational waste in interim storage, are not considered to have a material influence on timing and are considered only in so far that such waste will require future management to enable site end states to be achieved.

2 Topic background and context

The current strategy is to defer reactor dismantling for around 85 years following reactor shutdown, with the reactor dismantling programme scheduled in a phased manner across the Magnox sites to benefit from learning from experience.

However, this strategy of deferral results in a period of fleet wide quiescence for over 30 years when all the Magnox sites are in the C&M phase at the same time. The length of time and geographical extent of quiescence across the sites influences the level of restoration that must take place during C&M Preps to ensure passively safe sites for the C&M phase, and the management arrangements during C&M[1] for example for site security, monitoring, maintenance and records management.

The industry has for many years assessed the benefits and detriments of undertaking Magnox reactor dismantling sooner. The conclusions are kept under review.

Drivers for the current deferred reactor dismantling strategy include:

- The benefits from radioactive decay (dose rate reductions that would enable dismantling to be undertaken with significant worker access; changes in the categorisation of radioactive wastes, for example reductions in the volume of ILW; and reductions in dose rates and shielding requirements for such waste);
- Avoiding the need for interim storage of reactor waste pending consignment to the Geological Disposal Facility (GDF) which was not assumed to become available for Magnox wastes until around 2060; and
- The substantial reduction with increasing deferral time of Magnox lifecycle costs on a discounted or Net Present Value (NPV) basis.

There are risks associated with long deferral periods that may be exacerbated by an extended period of fleet wide quiescence. These include the threat of loss of corporate memory, the threat of loss of skills, knowledge and organisational capability, and the threat that estimated costs during the C&M phase escalate as a consequence of plant deterioration, or equipment obsolescence.

That said, there may be value in continuing with the current strategy, or considering longer deferral times, for example to benefit from in-situ decay of the reactor inventory within the Safestore buildings, which could minimise or avoid the need for interim storage facilities for reactor wastes pending the availability of a HAW route[2].

There are also merits in considering alternative timing strategies. For example, a phased programme of reactor dismantling, commencing prior to the end of the

[1] The current vision is for a small Tier 1 C&M Hub organisation which is competent to hold the necessary site licences and permissions and which relies upon Tier 2 and 3 contract organisations to deliver the work necessary to remain compliant.

[2] For example, the GDF for Magnox sites in England and Wales, or a near surface disposal facility or facilities for sites in Scotland.

Magnox C&M Preps phase (currently 2028), and continuing until Magnox reactor dismantling is complete, would avoid a period of fleet wide quiescence. The Magnox organisation, which comprises a skilled workforce with increasing experience in decommissioning, could be deployed to manage the reactor dismantling programme, whilst continuing to support sites in the C&M phase, thus modifying the C&M management arrangements. Such a continuous decommissioning strategy would deliver wider benefits by demonstrating progress in reactor decommissioning, contributing to the socio-economic wellbeing of communities by retaining skilled employment for longer, and enabling land to be released earlier for re-use.

A recent study [iii] demonstrated that the undiscounted decommissioning cost estimate for an early reactor dismantling project commencing 30 - 40 years after reactor shutdown is not substantially different to that for a deferred project commencing 85 years after reactor shutdown. This is partially a consequence of advances in remote handling technology which enable immediate decommissioning of nuclear power reactors without the need for prolonged worker access. This study highlighted that the increased base decommissioning cost for an early reactor dismantling project will be significantly less than costs relating to unique preparations for quiescence, and associated with security, maintenance and monitoring during the C&M phase. Appendix A includes a summary of the findings.

A preliminary high level cost model to support this strategy review has been produced by the NDA. Results appear to be similar to those presented in Ref. [iii]. The reduction in base decommissioning costs, including costs for waste management, is largely offset by the increase in C&M Preps and C&M phase costs, as the deferral time increases. The variance in costs across the sites is relatively small. Results of this and future cost modelling will be incorporated at future stages of the strategy development process.

There are few differences in the scope that would be required during the C&M Preps phase to enable a continuous decommissioning strategy. Nugatory spend could be avoided at some sites, for example associated with Safestore development, building recladding and asset management. At some sites there may also be opportunities to defer the decommissioning of waste plants and infrastructure, to make beneficial use of these assets for reactor dismantling. Magnox arrangements include mechanisms to remove scope uniquely associated with preparations for planned long periods of quiescence should alternative strategies mature for insertion into Magnox plans[3].

[3] In this context it should be noted that whilst accelerating C&M Preps scope is generally considered to be beneficial, it could reduce realisable benefits for alternative reactor dismantling strategies at some sites e.g. by forcing Safestore development and entry into C&M. This should be borne in mind when considering opportunities to accelerate scope.

3 Why review the strategy now?

It is appropriate to review the strategy at this time to provide an updated position for the next NDA Strategy publication, recognising the changing strategic context and circumstances within the UK.

The following suggest that such a review is timely:

- Advances in reactor dismantling techniques and international experience demonstrate that nuclear power reactors can be dismantled promptly using remote techniques without the need for significant worker access;
- There is an improved understanding of the implications of radioactive decay, particularly in relation to waste routes for HAW, that show that the benefits of radioactive decay may not be as significant as previously considered;
- New waste routes have become available for the management of Out of Scope waste, for the disposal of Lower Activity LLW (LA-LLW) to permitted landfill, for the recycling of metals, and for the interim storage of HAW;
- Some stakeholders consider that one or more Magnox reactor sites should be cleared to demonstrate that the work can be done in a safe, environmentally sound and cost effective manner, improving the underpinning for waste management and decommissioning[4]; and
- International bodies such as the International Atomic Energy Agency (IAEA) and the Nuclear Energy Agency (NEA) hold the view that reactor dismantling should be carried out as soon as possible, and have questioned the high weighting given to cost calculations on a discounted cost basis.

There is a limited window of time prior to the end of the Magnox C&M Preps phase in which commencing a reactor dismantling programme at one or more sites would contribute to the realisation of wider benefits by enabling funding to be spent on decommissioning rather than asset management, making best use of the workforce, organisational capability and infrastructure, and simplifying the C&M management arrangements. The magnitude of these realisable benefits will erode over time as the Magnox sites progress toward the C&M phase and the workforce is reduced.

4 Project Inventory

The study inventory is made up of activated radioactive materials within the reactors up to and including the reactor bioshield, including any radioactive components stored in reactor voids. This inventory has historically been that which has been considered to influence reactor dismantling timing strategy.

[4] This is of possible relevance to the interest rate for funding new nuclear plants, for which estimated lifecycle costs which include those for waste management and decommissioning are taken into account.

The inventory comprises the following materials:

- Core graphite and reflector graphite;
- Mild steel, stainless steel and other metals, either as structural materials or reactor components; and
- Structural concrete associated with the bioshield.

Other radioactive materials, in periphery reactor building rooms, or as contaminated land or drains, is not considered to have a material influence on reactor dismantling timing, although could influence the strategy for achievement of site end states. In a similar manner, operational waste stored in interim ILW Stores is considered only in so far that it will require future management to enable site end states to be achieved. These wastes are not subject to any detailed consideration in this study.

The management of hazardous (e.g. asbestos), non-hazardous and inert wastes stemming from reactor dismantling are considered, for example in terms of the future availability of waste management and disposal routes.

Waste is classed for strategic planning purposes according to its suitability for consignment to available waste routes:

- Lower activity waste (LAW) is radioactive waste categorised as Low Level Waste (LLW)[5] for which waste routes are currently available; and
- Higher activity waste (HAW) comprises High Level Waste (HLW)[6] and Intermediate Level Waste (ILW), and any LLW unsuitable for consignment to the LLWR.

The activated reactor materials can be broadly classed as follows:

- Higher activity waste (HAW) - mainly core graphite, stainless steel and other metals, a proportion of the mild steel at all sites, and a proportion of the concrete at short decay times at some sites;
- Lower activity waste (LAW) - mainly concrete, a proportion of the mild steel, small volumes of stainless steel and other metals, and a small volume of the graphite located at the extremity of the cores at some sites; and
- Out of Scope waste - mainly concrete, and limited volumes of other materials particularly at long decay times.

A detailed reactor inventory data set was produced to support the project, at a range of defined timescales t = 20, 30, 40, 50, 60, 70, 80, 90 and 100 years after reactor

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[5] Comprises of sub-categories Lower Activity LLW (LA-LLW) and Higher Activity LLW (HA-LLW) as defined in Table 2.

[6] HLW is a by-product of the reprocessing of spent nuclear fuel which is consigned to the Sellafield site during de-fueling. There is no HLW at Magnox reactor sites.

shutdown, for 10 Magnox reactor sites. The reactor activation model[7] was used to produce the data set. The model represents reactor components at a level of spatial resolution to enable the reporting of more specific results than is afforded through use of the derived UK Radioactive Waste Inventory (UKRWI) data set.

Each reactor component in the inventory data set was assigned a classification as Out of Scope, LA-LLW, HA-LLW or ILW, according to their specific activity (SA) in comparison with the criteria set out in Table 2.

Table 2: Waste Categorisation Criteria

Waste Category	Criteria
Out of Scope	Consistent with radionuclide specific activity levels specified in the Environmental Permitting Regulations (EPR)
LA-LLW	Out of Scope < SA < 200 Bq/g [8]
HA-LLW	200 Bq/g < SA < 12,000 Bq/g beta-gamma, 4,000 Bq/g alpha
ILW	SA > 12,000 Bq/g beta-gamma or 4,000 Bq/g alpha

The baseline conditioning and packaging strategy for reactor waste is to grout the waste in a 4 m box with appropriate shielding (up to an assumed maximum 300 mm shielding) such that it is suitable for transport to the GDF. For this study, it is assumed that any wastes requiring a shielding thickness greater than 300 mm would be packaged in a 3 m^3 box. The waste packaging and shielding options that have been considered are set out in Table 3.

Table 3: Waste Packaging Options Considered for Reactor Dismantling Wastes

Waste Packaging Option
4 m box, no shielding
4 m box, 100 mm shielding
4 m box, 200 mm shielding
4 m box, 300 mm shielding
3 m^3 box

[7] The flux exposed to each component is calculated using MCBEND, an industry benchmarked code that has been validated for reactor modelling against flux measurements. The MCBEND flux calculations are considered to be fit for the purpose for evaluating the activation inventories of the reactor wastes.

[8] Waste < 200 Bq/g is generally considered to be suitable for disposal to permitted landfills for LA-LLW, although acceptance would depend on adherence to radionuclide specific Waste Acceptance Criteria (WAC) for specific sites, and could potentially be > 200 Bq/g.

Geological disposal is considered from a technical perspective to be suitable for any HAW arising from reactor dismantling. Reactor components have also been assessed for suitability to consign to the alternative waste routes set out in Table 4.

Table 4: Waste Routes Assessed for the Alternative Management of HAW

Waste Route
Metal melting and recycling route for metals based on compatibility with current European and US facility Waste Acceptance Criteria (WAC)
Disposal to a facility at the surface, where common modes of human intrusion must be assumed e.g. the Low Level Waste Repository (LLWR), or a new facility
Disposal to a new near surface facility at >5 m depth, a depth that is generally considered to mitigate against common modes of human intrusion

Results of the analyses have been reported for the evolution with time of the categorisation of the reactor waste [iv], packaging options for off-site transport and the number of packages needed [v], and the feasibility for consignment to alternative waste management and disposal routes [vi].

The conclusions of the waste data analyses undertaken are provided in the following appendices:

- Appendix B – packaging options;
- Appendix C – waste categorisation;
- Appendix D – feasibility for metals recycling; and
- Appendix E – feasibility to apply alternative disposal options to the waste.

5 Current situation and underpinning

The current strategy is based on a systematic and progressive reduction of hazard which takes advantage where possible of the process of radioactive decay.

The current decommissioning strategy comprises three main phases:

1. ***The C&M Preps phase*.** The most significant hazards are removed or reduced such that they pose no significant threat and render the site passively safe. Activities include ponds draining and decontamination or stabilisation; reactor de-planting and asbestos removal; ILW Store build; fuel element debris processing; LLW and non-radioactive waste management; turbine hall demolition; Safestore development; conventional plant demolition; ILW processing; ILW interim storage; and contaminated land management.
2. ***The C&M phase*.** The site is maintained in a quiescent state of passive safety for a prolonged period of time. Activities include Safestore re-cladding; plant maintenance, monitoring and records keeping; and at sites in England and Wales, ILW consignment and ILW Store demolition.

3. ***The FSC phase*****.** The reactor Safestore buildings and any ancillary buildings are dismantled over a period of about 10 years, commencing about 85 years after reactor shutdown, with wastes consigned to available routes. Activities include the build of reactor dismantling facilities; reactor building demolition; ILW processing and consignment; LLW and non-radiological waste management; contaminated land management; and at sites in Scotland ILW Store build for the HAW arising from FSC and long term HAW storage preparations.

In terms of a HAW disposal route current Magnox plans assume:

- ILW in interim storage at each site in England and Wales will be retrieved and disposed of to the GDF during C&M to a phased schedule some time after its planned availability from around 2040. ILW arising during FSC at sites in England and Wales would be disposed of promptly to the GDF; and
- ILW arising at Magnox sites in Scotland will be managed in accordance with Scotland's higher activity waste policy [vii]. A fully policy compliant baseline will be inserted into Magnox plans and involves storage of HAW at each site for up to 300 years, followed by consignment of any remaining HAW to a near surface, near site disposal facility or facilities to be sited in accordance with the implementation strategy for Scotland's HAW policy [9].

Work on developing Magnox decommissioning strategy started in the 1970s and has been progressively refined to take account of changing circumstances and experience [viii]. Whilst early work demonstrated that reactor dismantling could be completed within about 20 years of reactor shutdown [ix], the conclusions of which were supported by subsequent studies, benefits in deferring reactor dismantling were identified and have remained an integral part of the strategy. The justification for the deferral of reactor dismantling for 85 years was set out in the Magnox Quinquennial Review (QQR) submission to the Healthy and Safety Executive (HSE) in 2000 [x], with further information contained in Ref. [viii], and has changed little since then. The reasons underpinning the 85 year deferral period can be summarised as follows.

The benefits from radioactive decay over the deferral period:

- Dose rates from the reactor structures reduce such that sustained worker access can be achieved following a deferral period of 70 - 90 years, with further reductions occurring up to about 130 years;
- The mass of radioactive waste in the ILW category reduces (by decay to LLW) by about a half following a deferral period of about 50 years, and to less than a third of the mass after 100 years deferral;

[9] This baseline change for the Magnox sites in Scotland would not affect the C&M Preps phase or the reactor dismantling activities which would continue to current timescales, and represents a conservative programme solution in terms of HAW storage against which strategic opportunities that could result in improvements can be assessed.

- Dose rates and shielding requirements for ILW reduce, simplifying waste handling and packaging, and minimising the number of packages needed. This is most marked up to about 30 years after shutdown, although reasonably significant shielding would still be required for deferral periods up to about 70 years after shutdown.

The availability of disposal routes for radioactive waste:

- It was assumed that the GDF might not become available for the emplacement of Magnox wastes until about 2060, some 70 years after the shutdown of Berkeley. It was noted that ideally wastes should not be generated until a disposal route is available, to avoid the need for interim stores for the ILW and to avoid multiple handling of the waste;
- It was acknowledged that capacity at the LLWR was limited and would be prioritised for operational wastes with restrictions for decommissioning wastes and that this should be taken into account in strategy timing decisions.

The effects of discounting which reduce NPV costs for long deferral periods:

- It was calculated that Magnox provisions at the time, which included a financial risk margin to cover uncertainties, when invested at an assumed real rate of return of 2.5% per year, would be sufficient to fully fund reactor dismantling 85 years after shutdown[10].

Taking into account the above, it was stated in Ref. [viii] that the robust, high integrity nature of reactor plant and structures would mean that achieving a passively safe state would be relatively straightforward, that estimated costs associated with security, maintenance and monitoring during the C&M period would be low compared with the savings in NPV terms of deferring reactor dismantling for a significant period, and that the benefits from radioactive decay would be readily achievable.

It was noted that whilst there was no single deferral timing that stood out as best extremes of the range extended from about 30 - 130 years and that in taking a balanced view an appropriate range was about 70 - 100 years. A deferral period of 85 years was chosen on the basis of a specific timing for financial provisioning noting that a decision on strategy timing could not at the time be made with any certainty.

An important area of uncertainty was highlighted which relates to how circumstances may change over time, for example regulatory standards, disposal route availability, technology developments, the rate of return on investments, public and stakeholder views, and societal or institutional developments. Changes since the strategy was last subject to major review are explored in the following sections.

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[10] At a 2.5% discount rate, deferral over a 50 year period reduces costs in NPV terms by about 70%, and deferral over 100 years reduces NPV costs by over 90%.

6 International context and experience

A summary of trends and experience in the development and selection of reactor decommissioning strategies in other countries is provided below, along with lessons learned in implementation, to illustrate the wide range of factors and constraints that could be relevant to this strategy development:

- There is an emerging trend towards immediate reactor dismantling in some countries, supported by the IAEA (see later), which appears to be driven mostly by country, site or plant specific circumstances and policies;
- Whilst the situation is evolving, with plans, supporting infrastructure and funding being established in some countries, there is not a clear pattern, with many projects still being deferred for a number of decades[11];
- Certain non-technical factors have gained in prominence, such as public and stakeholder views, the principles of sustainability, and minimising burdens on future generations, and socio-political and -economic considerations, particularly for local communities at the sites of nuclear power plants;
- The release of land and or facilities for alternative use is a driver for early reactor dismantling in some countries e.g. to support the development of the next generation of nuclear power plants;
- Prioritisation of expenditure on the management of higher hazard nuclear facilities has in some cases resulted in reactor dismantling being deferred, particularly in countries with larger nuclear legacy clean-up programmes;
- Development of industrial capacity in the decommissioning and waste management field including to compete for such work in other countries has proven to be a driver for some countries with developed nuclear programmes;
- Advances in remote handling technology, and decommissioning experience within Tier 1 organisations and the supply chain, have been enablers for immediate dismantling of a number of light water reactors[12];
- Disposal facilities for low and intermediate level waste (L&ILW), safely operated for a number of decades in some countries, have been applied to the disposal of reactor decommissioning wastes;
- By contrast facilities for the disposal of certain long lived wastes, such as core graphite, are only at present available in the US, although plans are being developed in France and Japan, which played a part in national strategy changes to early reactor dismantling in these countries;

[11] In May 2014 there were 149 nuclear reactors being decommissioned. Of these, 18 were fully dismantled, three old reactors remain entombed, 50 reactors were in various phases of dismantling, 57 are in a state of safe enclosure, and strategies are under discussion for 22 shutdown reactors. Almost 50% of projects are in a safe enclosure state, noting this does not include reactors currently being dismantled that were previously in safe enclosure for periods.

[12] Light water reactors typically have higher dose rates from their structures than the Magnox reactors, preventing their manual dismantling for more than 100 years.

- The interim storage of decommissioning waste was not previously considered a viable alternative to disposal. The situation is now different, in that several countries lacking a disposal facility for certain wastes have resorted to, or are planning, interim storage of such wastes in suitable facilities; and
- A new trend has emerged over the last few years, sometimes called continuous decommissioning, where the programme is constrained subject to the available funding, and which could offer new prospects.

In their General Safety Requirements for the Decommissioning of Nuclear Facilities [xi], the IAEA state that the licensee should select a strategy that will form the basis for the planning for decommissioning, consistent with the national policy on the management of radioactive waste. Whilst the IAEA indicate that the preferred decommissioning strategy is immediate dismantling, they recognise there may be situations in which this is not a practicable strategy when all relevant factors are considered. The selection of a decommissioning strategy should be justified by the licensee, demonstrating that, for the strategy selected, the facility will be maintained in a safe configuration at all times and will reach the specified decommissioning end state, and that no undue burdens will be imposed on future generations.

There are concerns over cost estimation, the future availability of funding, and investment performance, which have increased in significance since the 2008 financial crisis. Uncertainties for decommissioning and waste management cost estimates are exacerbated over long time periods, for example in relation to labour and material costs, and resulting from possible future changes in standards. The risk of loss of funds, and uncertainties associated with the real rate of return on investments, both increase significantly with time. Experience from the last 100 years across Europe illustrates that funds and investments have in many case been significantly affected. Threats range from events such as wars, financial crises, and pandemics, to more common events such as economic downturns. The IAEA and the NEA have expressed a preference for immediate dismantling if funding can be made available [xii], to minimise such financial risks.

These international bodies have also articulated a view that it is not good practice to use discounting, or NPV calculations, as a predominant justification for selecting a decommissioning strategy, particularly when such estimates involve deferral periods of tens of years or more. A balanced approach to an NPV calculation requires that benefits delivered later are discounted in the same manner as costs i.e. an early benefit is more significant than a later benefit. This has generally not been done as benefits tend to be non-financial in nature and it is difficult to assign monetary values to them. Likewise, the greater benefits of earlier reductions in liabilities, compared with later reductions in liabilities, have not in the past been taken into account in a direct, quantifiable manner when NPV calculations have been undertaken.

Decommissioning strategies vary from country to country and even within a country. Despite the trend toward immediate dismantling, and international support for this approach, the percentage of immediate reactor dismantling projects has only moderately increased in recent years compared with deferred projects[13].

A supporting review [xiii] provides an in-depth assessment of trends and experience, and discusses the difficulties associated with combining and weighing up relevant factors. Regardless of the large number and types of factors affecting strategy selection, the review concludes that it appears that most decisions are based on very few predominant factors, typically focusing on funding or availability of waste management and disposal routes. Examples from various countries are given of the basis for selection of, and changes to, the timing of reactor dismantling, and lessons from implementation. Appendix F provides a summary of the findings along with information on trends and experience in the management of reactor wastes.

Care should be taken when considering experience from other countries, recognising country-, site- and plant specific circumstances, which may well differ from those in the UK, and in particular taking into account:

- The policies of the UK, Scottish and Welsh Governments, including for new nuclear build, decommissioning, waste management and disposal;
- The scale of the UK clean-up programme, with competing claims on funding and resource, for example for the management of higher hazard facilities; and
- The design and structural and radiological condition of the Magnox reactors, specifically the presence of large volumes of graphite and steels that contain a significant inventory of the long lived radionuclides C-14 and Cl-36.

7 Driver for change

There is a range of drivers for change. Many of these are not of a quantitative nature or amenable to simple assessment and will require subjective consideration.

7.1 NDA strategy drivers

The NDA's core objective is to ensure that civil public sector nuclear legacy sites are decommissioned safely, securely, cost effectively and in ways that protect the environment. Site restoration is the NDA's driving strategic theme and all other strategies support or enable its delivery.

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[13] In the US, where policy does not in principle force the selection of one strategy over another, the number of reactor units subject to safe enclosure (10) is not much less than the number either subject to immediate dismantling or that have already been dismantled (19). Two reactors shutdown recently (Kewaunee and Crystal River 3) will be subject to safe enclosure, whereas as of a recent announcement Units 2 and 3 at San Onofre in California are planned to be dismantled promptly over a 20 year period.

7.1.1 Increased expenditure on site restoration, focusing on optimisation

It is a clear objective of the NDA to increase the proportion of expenditure on site restoration. Early planning for site restoration focused on site by site solutions supported by generic waste and material management approaches. More sophisticated and diverse approaches will be needed to improve delivery and secure best value, enabling stakeholders and local communities to reap benefits in the medium term, such as visible and tangible progress on site restoration, reduced risk profiles and the release of land for other uses.

7.1.2 Making best use of skills, experience and knowledge

The NDA plans to make better use of the wide range of human resources and physical assets across its estate. People with appropriate skills and capabilities are essential to the successful delivery of its mission; it aims to ensure that there is a skilled workforce available at all times within the NDA, the SLCs and the supply chain to support site restoration. The NDA will encourage innovation and, where appropriate, resources such as equipment, skills and experience will be shared between sites to improve estate wide site restoration.

7.1.3 Supporting the economic development of communities

A key part of the NDA's Strategy is to support the economic development of communities affected by its activities, focusing on employment, education and skills, economic and social infrastructure and diversification. The NDA will continue to work closely with Government and in partnership with stakeholders to maintain their confidence, inform policy development and support the maintenance of nuclear industry infrastructure, such as developing skills and ensuring sufficient R&D is undertaken to underpin decommissioning and waste management plans. The NDA will continue to support the sustainable economic development of communities affected by its activities.

7.1.4 Site restoration objectives and prioritisation

The NDA's end goal is to restore its sites to the point where they are released for other uses. In order to prioritise delivery the NDA's site restoration strategy focuses on reducing risks to people and the environment while restoring each site as soon as reasonably practicable to a condition suitable for its next planned use. Due to the unique and varied nature of the NDA's estate, restoration is considered on a case-specific basis. A range of relevant factors is taken into account including the need to reflect Government policy and secure value for money. The NDA applies a prioritisation process to expenditure across its estate, and these priorities drive the allocation of resources. Appendix G provides further information on the NDA's developing prioritisation process which is being applied to this strategy development.

7.1.5 Decommissioning strategy

The objective of the NDA's Decommissioning Strategy is to deliver site end states as soon as reasonably practicable with a progressive reduction of risk and hazard. Case-specific decisions will be made on when and how this is achieved. Decisions will take account of lifecycle risk to people and the environment, and other relevant factors to determine whether continuous or deferred decommissioning[14] is the most appropriate option. Where risk is the dominant relevant factor the NDA's priority is to continuously decommission until the risk is at least tolerable. Both options have been shown to offer long term environmental benefits with continuous decommissioning potentially providing the greatest benefit. The NDA will manage the condition of its plants and facilities to ensure that currently tolerable risks do not increase to become intolerable and that all risks are kept as low as reasonably practicable (ALARP).

Beyond the options for deferred or continuous decommissioning there are two strategic sub-options for managing the products of decommissioning: leaving parts of a facility in place and regarding them as having been disposed of (in-situ disposal) or removing them for disposal elsewhere (ex-situ disposal). The NDA's approach is influenced strongly by the waste hierarchy and the materials and wastes arising from decommissioning will be managed in accordance with the NDA's Integrated Waste Management Strategy. Conversely, the timing and method of decommissioning will influence waste management requirements such as waste processing, interim storage, waste treatment routes and the need for storage and disposal facilities. These strategies are highly interdependent. Planned decommissioning strategies are embedded in lifetime plans, for example deferred decommissioning of the Magnox reactors. The NDA will continue to review such plans to ensure they remain aligned with NDA strategy, deliver value for money and do not compromise the ability of future generations to meet their needs, or other liability holders to deliver their plans.

7.2 Policy framework and related drivers

There are a range of policy related drivers for change:

7.2.1 Decommissioning policy

In September 2004 UK Government and the Devolved Administrations published their policy on the decommissioning of the UK's nuclear facilities [xiv]. This states the objective of decommissioning is to progressively remove the hazard the facility poses, giving due regard to security, the safety of workers and the public, and protecting the environment, while in the longer term reducing the number of sites and acreage of land under regulatory control. Decommissioned sites may represent a valuable resource. The future use of a site could be a significant factor in determining decommissioning activities.

Decommissioning activities should be carried out as soon as reasonably practicable, taking into account all relevant factors. Appendix H sets out the factors included in the policy. These factors should be applied to ensure programmes are optimised and

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[14] *Continuous decommissioning* – commences at the end of operations and continues until final demolition of the plant/ facility/ installation; d*eferred decommissioning* – comprises one or more periods when the plant/ facility/ installation is purposely kept in a state of C&M as part of the programme for achieving the site end state.

to establish the earliest practicable timetable for decommissioning. The relevant factors and their respective importance can only be determined on a case-by-case basis. Decommissioning may involve two or more stages spanning a number of decades. It may be more appropriate to delay particular activities to benefit from developing technologies, from the development of best practice, or to take advantage of radioactive decay. Strategies should harness the benefits of radioactive decay while the problems to which it may give rise should be avoided. Careful consideration should be given to delaying decommissioning activities to allow radioactive decay to occur. This should maximise the amount of materials suitable for re-use or recycling, as opposed to being managed as LLW. Strategies should minimise the volume of radioactive waste created, particularly the volume of ILW. Where possible, wastes should not be created until appropriate waste routes are or will shortly be available.

Operators should maintain the knowledge base, records and skills necessary for decommissioning and waste management. This should include the retention, recruitment and training of staff and the preservation of records to fully underpin decommissioning. Action to acquire new skills or develop existing ones should be carried out as necessary. Operators may also wish to bring forward operations in order to utilise existing skills or knowledge. To enable operators to augment their skills, best practice should be developed and spread to ensure that decommissioning is carried out effectively. The NDA has an objective of championing best practice, and it is important that operators identify, implement and share best practice.

The Government's intention is to ensure that sufficient funds are available to enable the NDA to drive forward decommissioning of its sites in the most effective way. Current and future arrangements may be further influenced by European legislation or by international agreements. Strategies should be reviewed when changes in circumstances, including relevant Government policies, make this necessary.

7.2.2 Managing Radioactive Waste Safely (MRWS)

In 2006 the Committee on Radioactive Waste Management (CoRWM) recommended geological disposal as the best long term management option for the UK's HAW, supported by safe and secure waste storage and a programme of underpinning R&D. A subsequent white paper in 2008 [xv] recognised the need to take account of developments in storage and disposal, as well as possible new technologies, including application of the waste hierarchy, which could reduce the amount of waste requiring geological disposal. Following the 2013 vote in which Cumbria County Council decided not to proceed further with the GDF site selection process, DECC carried out a consultation setting out proposed changes to the site selection process, and a white paper has been published on a renewed process for siting a GDF [xvi].

7.2.3 CoRWM Recommendation 8

CoRWM made a specific recommendation that in determining what reactor decommissioning wastes should be consigned for geological disposal, due regard should be paid to considering other available and publicly acceptable management options, including those that may arise from the low level waste review [xvii]. Feedback from public and stakeholder engagement suggested that there was support for local solutions for reactor decommissioning waste in order to avoid the transportation of these large volumes of waste. Government (for England, Wales, Scotland and Northern Ireland) accepted this recommendation and stated that a review should be undertaken of whether a safety case could be made for the near surface disposal of reactor decommissioning wastes including consideration of on- or near site options in order to minimise transport [xviii].

7.2.4 Scotland's higher activity waste policy

In 2011 the Scottish Government published a statement of Scotland's HAW policy [vii]. The aim of the policy is to ensure that all activities for the long term management of the waste are carried out in a way that protects the health and interests of people and the integrity of the environment now and in the future. This needs to be considered at the time long term management decisions are made and when treatment or storage or disposal of the waste is undertaken; such decisions will need to take into account the risk of foreclosing options and future impacts. The policy states that the long term management of HAW arising in Scotland should be in near surface facilities. Facilities should be located as near to the site where the waste is produced as possible. Developers will need to demonstrate how the facilities will be monitored and how waste packages, or waste, could be retrieved.

The policy is not prescriptive, recognising it applies to waste which may not be produced for decades and for which long term management options may not be feasible at present, or have yet to be developed. Because there remain uncertainties as to how to deal with much of the waste, the policy at the present time is that long term storage is still the primary long term management option. However, recognising that there have been technological developments which enable treatment of some radioactive waste (potentially including treatment at waste facilities outside of Scotland, in the UK or elsewhere), primarily to reduce volumes, the policy enables such options to be considered. Similarly, there are examples in other countries of near surface disposal facilities for radioactive waste that is similar to some of the HAW in Scotland. The policy is consistent with such approaches.

7.2.5 The Welsh Government's higher activity waste consultation

The Welsh Government has recently issued a consultation document on their review of Welsh Government policy on the management and disposal of higher activity waste [xix]. Current Welsh Government policy is neither to support no to oppose the UK Government policy of geological disposal of HAW, nor does the Welsh Government support any other disposal option for HAW. Although the Welsh Government has devolved responsibility for policy relating to the disposal of radioactive waste in Wales this does not mean that waste arising from activities in Wales needs to be disposed of in Wales, even if the Welsh Government does, following consideration of the outcome of this consultation, decide to adopt a policy for the disposal of HAW. Waste arising from activities in Wales forms part of the overall HAW inventory. While it has taken no final decisions the Welsh Government has decided that it should review its current policy with a preferred option of adopting a policy for the disposal of HAW. The Welsh Government has considered different options for the long term future management and disposal of HAW, including those referred to in the responses to a recent call for evidence. While the Welsh Government has made no final decisions about which option it should choose, it consulting on a preferred option for HAW of adopting geological disposal. This consultation paper seeks views about that preferred option and about viable alternative disposal options for HAW.

7.2.6 EU Directive on the management of spent fuel and radioactive waste

In 2011 the European Union (EU) adopted a Directive [xx] establishing a framework for the responsible and safe management of spent fuel and radioactive waste[15]. The Directive states that there should be an ethical obligation to avoid any undue burden on future generations in respect of spent fuel and radioactive waste management, including waste from the decommissioning of nuclear facilities. Member States are obliged to establish and implement national programmes[16] for the management of spent fuel and radioactive waste, and to submit to the EC a first implementation report by August 2015 and every 3 years thereafter on progress and inventory.

7.3 Changes since the last major strategy review

There have been a number of material changes since Magnox reactor dismantling strategy was last reviewed which are set out and discussed below.

7.3.1 Advances in reactor dismantling techniques and experience

In recent decades, cost effective remote dismantling and waste handling techniques have been developed, and are now successfully applied on a routine basis to decommissioning projects in many countries. For example, light water reactors with radiation dose rates much higher than those from Magnox reactors have been subject to immediate dismantling. In practice, these techniques would in any case now be applied to Magnox reactor dismantling as a matter of best practice and to help to minimise conventional safety risks and doses to workers. The benefits of reduced radiation dose rates from the reactor structures with increasing deferral time can no longer be considered to be a discriminating factor for timing considerations.

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[15] The Directive clarifies that storage of radioactive waste, including long term storage, is an interim solution, but not an alternative to disposal. It recognises that the typical disposal concept for LLW and ILW is near surface disposal, whereas deep geological disposal represents the safest and most sustainable option as the end-point of the management of high level waste and spent fuel considered as waste. It also acknowledges that some Member States consider that the sharing of facilities for spent fuel and radioactive waste management, including disposal facilities, is a potentially beneficial, safe and cost-effective option when based on an agreement between the Member States concerned.

[16] These must include milestones and timeframes for waste management and disposal, descriptions of concepts or plans and technical solutions, and underpinning R&D activities, an assessment of costs and details of financing schemes. Member states must ensure that necessary information on the management of radioactive waste is made available and that the public is given the opportunity to participate effectively in the decision-making process in accordance with national legislation and international obligations.

7.3.2 Advances in the management of higher activity wastes

There is now an improved understanding that the core graphite and a proportion of the metallic wastes would still need to be managed as HAW, despite radioactive decay from ILW to LLW, due to the high inventories of the long lived radionuclides C-14 and Cl-36. A supporting study [vi] demonstrates that waste management and disposal options for reactor HAW do not change significantly with decay time and that the volume of such waste potentially suitable for alternative management as a result of radioactive decay is relatively small. These findings are discussed in Appendices D and E.

Nevertheless, there is a range of waste management and disposal options that can be applied to the wastes from reactor dismantling supporting application of the waste management hierarchy and to minimise the number of packages needed.

Metals, such as heat exchangers from Magnox reactors, and to a lesser extent, some reactor components and parts of reactor pressure vessels from light water reactors, have been subject to metal melting, enabling beneficial re-use of the recovered metal[17]. Alternative package designs with improved packing factors could be considered. Waste packages could be filled such that limits for off-site transport would be met at some future time after a period of radioactive decay during interim storage[18]. Waste minimisation techniques, such as sorting and segregation, and cutting, compaction and possibly shredding, could be applied to certain wastes as pre-processing steps.

The lack of a disposal route for HAW was a driver for deferring Magnox reactor dismantling until a suitable disposal route is available, avoiding the need for interim storage and multiple handling of the waste packages. There is now considerable experience in handling, packaging and storage of high dose rate wastes, with remote handling techniques applied to retrieval, conditioning, packaging, on-site transfer and interim storage of operational waste at Magnox sites. The use of such techniques also minimises risks associated with multiple waste handling.

As an alternative to interim storage, many countries practise near surface disposal of reactor wastes, at national, regional or on-site facilities, and some are planning new disposal facilities, or extensions to existing facilities, for decommissioning wastes. There is also growing interest and experience in waste management and disposal options for core graphite and other long lived wastes.

In summary, the significance of a number of factors associated with the management of HAW from reactor dismantling is somewhat diminished since the last strategic

[17] Processing capacity and the availability of a market for the product would need to be confirmed, as activity levels are at the upper end of material considered suitable for melting.

[18] The cost estimates for the options assessment supporting the QQR submission, in calculating the number of waste packages needed for various scenarios, assumed prompt off-site transport of the waste at the time of arising, and hence the number of packages estimated for an immediate reactor dismantling strategy was relatively large.

review and are no longer considered to be constraints. The option of interim storage of reactor waste pending availability of a disposal route is a viable enabling strategy and should be investigated further[19]. There are also opportunities to develop alternative waste management and disposal routes, potentially as enablers, or as demonstration projects, to support a reactor dismantling project or a continuous decommissioning programme, that may warrant further consideration.

7.3.3 Advances in the management of lower activity wastes

New, lower cost waste routes for the management of LAW have become available in recent years, such as the disposal of LA-LLW to permitted landfills, and the recycling of metals. In addition, the Environmental Permitting Regulations (EPR) introduced a modern, risk-informed system to define out of scope waste not subject to the controls of radioactive waste permitting on the basis of a series of radionuclide specific limits which is used to remove waste from the LAW classification.

The use of these new waste routes is likely to result in significant volumes of LAW from reactor dismantling being diverted to lower cost routes than was previously assumed, of particular significance to the large volume of lightly contaminated concrete from bioshield dismantling, and resulting in disposal costs for some wastes an order of magnitude or more lower on a unit volume basis. This will contribute to reserving capacity at the LLWR, and will reduce the waste management costs associated with LAW from reactor dismantling[20].

Whilst there are benefits associated with the radioactive decay of certain LLW to lower categories with increasing decay time, this at most relates to generally no more than about 10% by volume of the reactor inventory. Furthermore, much of the benefit of radioactive decay is achieved in the first 20 years or so after reactor shutdown. These findings are discussed in Appendices C, D and E. When considered in conjunction with the availability of new, lower cost waste routes that are suitable for the management of much of the LAW, this suggests that the decay of LLW to lower categories is unlikely to be a discriminating factor for timing considerations, although this should be tested by further examination of site-specific data.

8 Aspirational outcome

The Strategic Objective for this work is:

[19] The capital cost of a shielded ILW Store for reactor wastes is expected to be relatively small, perhaps up to a few tens £Millions based on the forecast volumes of waste, compared with current estimates for the total cost of the reactor dismantling phase which ranges from about £800 - 1200 M depending on the specific site based on LTP 2013 costs.

[20] The cost assessment supporting the QQR submission included an allowance for the on-site storage of LLW from an immediate reactor dismantling project, on the basis that the use of the LLWR might be prioritised for operational LLW, and hence not be available for a time.

> **To optimise the timing and sequencing of the Magnox reactor dismantling programme, to support delivery of a safe, secure, sustainable and cost effective programme which protects the environment, taking into account the NDA's objective to deliver site end states as soon as reasonably practicable with a progressive reduction of risk and hazard.**

The aspirational outcome for this work is:

> To produce a robust business case to support an optimised Magnox reactor dismantling programme. The purpose is to underpin and inform a decision to either remain with the current baseline or to change to a different strategy.

9 Boundaries and interfaces with other strategic work

Strategy for the timing of Magnox reactor dismantling has a range of interfaces with NDA topic strategies and strategic work areas. There are interfaces with:

9.1 Site restoration

- *Decommissioning Strategy* – there is an interface with decommissioning timing work being conducted across the NDA estate. For example, in parallel with this work, the strategy for "broad front" decommissioning at Sellafield is being reviewed. Common factors and assessment methodology will be used to enable comparisons across SLC decommissioning programmes;
- *Land Quality Strategy* – if an early reactor dismantling strategy were to be implemented the strategy for land management at some sites would likely need to be changed e.g. from a strategy focused on achieving passively safe states, to one focused on more prompt remediation to achieve site end states;
- *Site End States* – the impact of the presence of additional storage facilities for a period of time, or for some opportunities disposal facilities for HAW at or adjacent to sites, would need to be considered. There could be implications for de-licensing, de-designation and the divestment of land, and the timing of such activities. Liability management arrangements would also require consideration i.e. the Paris/ Brussels nuclear liability regime.

9.2 Integrated waste management

- *Higher Activity Waste* – reactor dismantling will generate large volumes of HAW. Capacity might be sought earlier than anticipated for the melting and recycling of metals, if this opportunity proves to be viable. There could be merit in better underpinning management options for graphite wastes [xxi]. If the development of relatively large ILW Stores for reactor wastes is to be avoided a disposal route for HAW will be needed. Changes to timing could have implications for the HAW emplacement schedule and rate of consignments to the GDF. There are interfaces with RWM's upstream optioneering portfolio relating to risk based disposal safety cases and decay storage [xxii], and the GDF shallow vault concept for short-lived ILW [xxiii];

- *Lower Activity Waste* – there are interfaces with LAW Strategy as waste routes will be needed for large quantities of LAW e.g. permitted landfill, metals recycling and LLWR. Implications for the volumetric and radiological capacity of these routes would need to be considered. There are opportunities for re-classification of certain LLW/ ILW boundary wastes. It may also be possible to make greater use of some LAW routes (e.g. LLWR), for example subject to safety case work to support changes to facility waste acceptance criteria;
- *Non-radioactive and Hazardous Wastes* – large volumes of inert, non-hazardous and to a lesser extent hazardous wastes will be produced during reactor dismantling. As landfill routes for such wastes are becoming increasingly restricted, early reactor dismantling would help to mitigate such risks.

9.3 Business optimisation

- *Land and Property Management/ Revenue Optimisation* – changes to the timing of reactor dismantling could have an impact on the options available for the divestment of land. For example early reactor dismantling could at some sites make land available to support nuclear new build activities e.g. at Hinkley Point, Wylfa, Oldbury and possibly Sizewell. Revenue from land sales could be used to support the NDA's decommissioning programme.

9.4 Critical enablers

A change to the timing of reactor dismantling would interface with a wide range of the critical enablers defined in NDA Strategy:

- *Research & Development* – there could be implications for the timing of activities for technology adaptation and tooling development for dismantling, and for the management and disposal of certain radioactive wastes;
- *People (incorporating Skills and Capability)* – capacity planning would be required to ensure sufficient Suitably Qualified and Experienced Persons (SQEP) and capability in organisations across the NDA, Magnox and the regulators to support programme implementation;
- *Asset Management* – changes to the length of the current Magnox quiescent period would have significant implications for asset management strategy and would require careful evaluation of the implications;
- *Contracting and Incentivisation* – contracting/ incentivisation models and arrangements could be very different for an early reactor dismantling programme, in comparison with a deferred programme;
- *Competition* – an early reactor dismantling project or programme would be a substantial package of work that would be attractive to Tier 1 and could be competed to secure world class experience to deliver it;
- *Supply Chain Development* – there are implications for capacity planning to ensure an adequate supply chain to support programme delivery, taking into account competing demands from elsewhere e.g. Sellafield. Sufficient resources would also be required e.g. steels for waste containers;

- *Information and Knowledge Management* – requirements for information and knowledge management for the Magnox sites depend critically on the length of time before reactor dismantling and site clearance;
- *Socio-economics* – reactor dismantling would be a large project employing significant numbers of people for prolonged periods of time (approximately 10 years per site). Early reactor dismantling work would have a significant beneficial impact upon the socio-economics of the surrounding areas[21];
- *Public and Stakeholder Engagement and Communications* – given the potential implications for local communities, structured engagement on an extended basis is likely to be necessary to support a change of strategy;
- *Transport and Logistics* – infrastructure, routes and logistics could be required earlier than anticipated e.g. approved containers, such as the Shielded Waste Transport Container (SWTC). Permissions for the transport of radioactive wastes might be needed to an earlier schedule;
- *Funding* – this is a key critical enabler for an early reactor dismantling timing strategy. The estimated cost of reactor dismantling is around £800 - £1200 M depending on site, over a circa 10 year period [xxiv]. The funding profile across the NDA estate would need to be considered, to assess affordability;
- *International Relations* – advantage should be taken of experience from other countries in reactor dismantling strategy and implementation, and waste management and disposal, particularly where the NDA has established links.

9.5 Magnox work programmes

- *C&M Preps programme* – a change to an early reactor dismantling strategy could have an impact on the planned work at some sites as some activities required to deliver the C&M entry state may no longer be necessary e.g. recladding of buildings, asset management activities. At some sites there may be opportunities to make use, perhaps with modification, of waste processing plants and storage facilities e.g. the Solid ILW Encapsulation (SILWE) plant and ILW Store for operational waste at Hunterston A;
- *C&M management arrangements* – a change to an early reactor dismantling timing strategy for one or more of the Magnox sites would impact upon the planned C&M management arrangements, as a larger than envisaged Tier 1 organisation would be available to support sites in C&M.

[21] This may be particularly significant for those sites which are located in the NDA's defined priority areas, namely Wylfa and Trawsfynydd in Wales (Anglesey and Gwynedd) and Chapelcross in Scotland (the Gretna-Lockerbie-Annan corridor in Dumfries and Galloway). In addition, the priorities set out in the Magnox socio-economic development plan should be considered [xxiv]. This prioritised support to those sites considered to be most impacted by the MODP. Bradwell, Trawsfynyyd and Dungeness A were identified as high priority sites, Chapelcross, Wylfa and Hunterston A as mid-priority and the other sites as low priority.

10 Constraints and dependencies

Strategy for the timing and sequencing of reactor dismantling is subject to a range of constraints and dependencies. These are set out in Tables 5 and 6.

Table 5 Constraints on the Timing and Sequencing of Reactor Dismantling

Constraint	Notes
Committed works for quiescence associated with Magnox C&M Preps phase plans	Opportunities to avoid nugatory spend are constrained by the schedule of activities at some sites. Examples include the planned height reduction at Trawsfynydd, the ongoing Safestore re-cladding project at Bradwell and the lowering of the height of the Berkeley reactor buildings to pile cap level already completed. Hard site-specific constraints resulting from committed works, which limit benefits realisation.
Government appraisal and assessment methodology for NPV calculations [xxv]	A constraint on cost estimation and financial assessment approach which favours long deferral periods. See also the discussion in Section 6 on the application of discounting. Unclear if a hard or soft constraint, clarification from Treasury could be sought.
Tier 1 and supply chain skills set and capacity for reactor dismantling	There is a limited pool of skilled resource with competing demands. A soft constrain, can be addressed through capacity building and incentivisation.
Mobilisation and planning for reactor dismantling	There is a constraint on the time required for planning and mobilisation for a reactor dismantling project. Hard constraint, a number of years would be required.
Site-specific design features of the Magnox reactors e.g. Hunterston A pile cap design	Specific dismantling techniques and handling approaches may be necessary in some cases. A soft site-specific constraint, surmountable through reactor dismantling project design.
Site-specific contamination and radiological conditions e.g. Chapelcross reactor building contamination	Specific dismantling techniques and handling approaches may be necessary in some cases. A soft site-specific constraint, surmountable through reactor dismantling project design.
Affordability and spend profile	An immediate or early reactor dismantling project or programme would result in a significant change to the current spend profile, with a requirement for cash flows to be brought forward.

Funding is not listed as a constraint, as whilst available funding is a limitation it should not at this stage be considered to constrain consideration of options. Affordability is usually considered at a later stage in the SMS process.

Table 6 Dependencies with the Timing and Sequencing of Reactor Dismantling

Dependency	Notes
Magnox site management arrangements	Bringing forward the timing of reactor dismantling would require changes to Magnox management arrangements e.g. a modified Tier 1 organisation to manage reactor dismantling, and sites in quiescence.
Calder Hall and Chapelcross interactions and dependencies with the Sellafield site	Interdependencies with the Sellafield site will require careful evaluation, including the impact of Sellafield plans on these reactor dismantling projects.
Availability of land for reactor dismantling e.g. laydown areas, contractor compounds, etc.	This is more challenging at some sites than others although is considered in all cases to be surmountable through reactor dismantling project design.
Higher Activity Waste Strategy	A HAW disposal route will be needed. Reactor dismantling timing will influence whether interim storage of reactor waste, or the development of a near surface disposal facility, would be necessary to support an early reactor dismantling project.
Lower Activity Waste Strategy	There is a dependency on the availability and capacity of waste routes e.g. permitted landfill for LA-LLW, metals recycling facilities and the LLWR.
De-licensing, de-designation and divestment of land	Changes to the timing of reactor dismantling could impact on site clearance strategies and result in a dependency for the timing and amount of land that can be released from legal controls for divestment.
Site end states	Changes to the timing of reactor dismantling could impact upon site clearance strategies and result in a dependency for the timing of achievement and possibly the definition of site end states.

11 Key assumptions

Key assumptions relating to reactor dismantling timing are described in Table 7.

Table 7 Assumptions for the Timing and Sequencing of Reactor Dismantling

Assumption	Notes
Government policy, standards, legislative, planning and regulatory requirements do not change	Generic policy and regulatory framework assumption. Changes can be expected over the timescales this strategy applies.
Current technologies and approaches for reactor dismantling are assumed	Progressive improvements in technology and approaches are likely, particularly in relation to remotely operated technologies.
Dismantling of reactors primarily using remotely operated machines and handling techniques	Planning assumption. Sustained worker access is no longer assumed.
Funding will be available to support reactor dismantling implementation	Funding assumption.
Government guidance on the value of the discount rate for use in NPV calculations does not change [xxvi]	Changes are possible over the timescales the strategy applies and could have implications for reactor dismantling timing.
Labour and material costs escalate in line with national expectations without any excessive trends	Planning assumption. Changes are possible over the timescales this strategy applies.
Some waste package remediation is necessary whenever an ILW Store is emptied	Consistent with assumption in current plans that a proportion of packages require remediation upon retrieval from ILW Stores.
The GDF will become available for the consignment of higher hazard wastes from around 2040	Planning assumption. Programme delays are possible.
Consignments to the GDF will be to the current planned schedule for Magnox sites	Changes to the schedule of consignments are possible. There may be an opportunity to consign 4 m boxes early, as there are few competing consigners for this specific GDF route.
Detailed planning for the facility or facilities for disposal of HAW from Hunterston A and Chapelcross is not envisaged to commence until these sites have entered C&M.	Planning assumption. Scottish Government's Implementation Strategy for its HAW policy will clarify help to clarify the approach and timescales.

12 Risks, issues and concerns

12.1 Risks associated with this strategy review

There are a number of risks associated with this strategy review:

- There is a risk that stakeholder and local community expectations could be raised at a time when funding is limited;
- There is a risk of destabilising the current work programme for the delivery of Magnox sites into a quiescent C&M state; and
- There is a risk that options for alternative reactor dismantling timing strategies will be foreclosed, or that realisable benefits will be eroded, as the sites progress toward C&M entry.

There are also risks associated with the current strategy, particularly as a consequence of the long quiescent period, and with alternative reactor dismantling timing options. Identified risks are set out in Appendix I.

12.1 Broader issues and concerns

A range of broader issues and concerns have been identified:

- The probability of many risks occurring is related to 'time at risk'. Some stakeholders have a preference for early solutions to mitigate against such threats and achieve earlier hazard reduction and environmental benefits;
- There are concerns over the public acceptability of delaying reactor dismantling - some stakeholders consider that the Magnox sites should be cleared to demonstrate that the work can be done safely and cost effectively;
- A number of communities have expressed support for early reactor dismantling on the basis that this would delay the significant socio-economic impacts associated with a site entering the C&M phase;
- Concerns have been raised about whether deferring reactor dismantling is consistent with the principle of inter-generational equity, given that the burden of clearing the sites will be passed to future generations;
- Some stakeholders are of the view that options for re-use of the sites may become more limited with the passing of time (e.g. for new nuclear build);
- Considerations surrounding cost uncertainties and funding perhaps warrant greater emphasis than has been placed on them in the past. There may have been undue emphasis given in the past to the results of NPV calculations; and

- Societal, socio-economic and -political changes can result in unforeseen risks. Such risks can pose threats to the continuity of organisations, the availability of funding and safety [22].

13 Strategic options

A number of strategic options for the timing of Magnox reactor dismantling, along with approaches to programme sequencing, have been identified to cover a broad range of potential strategies, and to enable testing of strategic tolerances[23].

Options can be considered on a site or fleet wide basis, and strategies constructed based on different options for specific sites, or groups of sites.

13.1 Strategic options for a specific site

The following strategic options cover different timing strategies, ranging from commencement during C&M Preps, to a start date following an extended period of quiescence of over 100 years to obtain the maximum benefit from radioactive decay.

Consistent endpoint assumptions for the disposal of HAW to a disposal route have been made to ensure strategic options are comparable.

The identified strategic options are:

1. ***Immediate dismantling.*** Reactor dismantling commences as soon as practicable, prior to entry of a site into its C&M phase. Interim storage of the waste is assumed, pending the availability of a HAW disposal route.
2. ***Early dismantling.*** Reactor dismantling commences during a site's C&M phase, prior to the availability of a HAW disposal route. Interim storage of the waste is assumed, pending the availability of a HAW disposal route.
3. ***Deferred dismantling until disposal route available.*** Reactor dismantling is deferred pending the availability of a HAW disposal route. Prompt consignment of the waste to a HAW disposal route is assumed.

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[22] Nirex published a report on societal stability and implications for radioactive waste management over long timescales [xxvii]. This describes a range of threats to organisational longevity, the survival of information, the availability of resources and skills, and funding, that could impact the safe storage of radioactive waste. These range from catastrophic events such as wars, financial crises, and pandemics, to more common events such as economic downturns, and events that could lead to the loss of records, such as flooding and fire, and the obsolescence over time of data storage media. A relevant modern example is the collapse of the Soviet Union which resulted in a loss of control of some radioactive waste.

[23] It should be noted that the possibility of entombment and reactor mounding options has not been ruled out. The IAEA no longer consider these to be viable options apart from in exceptional circumstances. Regulators have also raised concerns about such approaches and the likelihood of being able to make an acceptable environmental safety case for disposal e.g. in relation to reactor mounding. Whilst such options could potentially be considered in extreme situations, further assessment is not planned as part of this strategy development.

4. ***Deferred dismantling for 85 years (current strategy).*** Reactor dismantling is deferred for 85 years following reactor shutdown. Prompt consignment of the waste to a HAW disposal route is assumed.
5. ***Late dismantling at 130 years.*** Reactor dismantling is deferred for 130 years following reactor shutdown. Prompt consignment of the waste to a HAW disposal route is assumed.

The main strategic tolerances are considered to relate to:

- Potential benefits that are realisable if reactor dismantling is commenced during a site's C&M Preps phase;
- Whether or not reactor waste can be contact handled, and hence the need for a remotely operated shielded transfer route;
- The availability of a HAW disposal route, and hence whether or not interim storage of the waste is necessary; and
- The capacity to accommodate waste in an existing interim store for operational waste, in order to minimise or possibly avoid the cost of a new interim store or stores for reactor wastes[24].

On a strategic basis, option 1 (immediate dismantling) might be assumed to commence around 2020, option 2 (early dismantling) around 2030, option 3 (deferred dismantling upon disposal route availability) around 2040, option 4 (current strategy) 2070, and option 5 (late dismantling) around 2120. The above timing assumptions are approximate and generally to within say +/- 5 years, noting that the earliest date for commencement of a reactor dismantling project is probably around 2020, and would depend on Magnox programme dependencies and site-specific factors.

It is assumed reactor dismantling would be completed over about a 10 year period.

Interim storage of reactor waste within an on-site facility is assumed for some options, either within an existing store for operational waste if capacity permits, or within a new purpose built store for the waste.

In terms of a HAW disposal route, it is assumed that:

- The GDF will become operational around 2040;
- The GDF will become available from around 2060 to accept Magnox operational waste packaged in 3 m^3 boxes;
- The GDF may possibly be available for reactor dismantling waste packaged in 3 m^3 boxes from around 2070;

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[24] Two new interim stores may be needed, to accommodate high dose rate waste packaged in 3 m^3 boxes and lower dose rate waste packaged in larger 4 m boxes.

- The GDF may be available sooner for reactor dismantling waste packaged in 4 m boxes from perhaps as early as 2040, as there are few competing consigners for this specific waste route to the GDF; and
- It is assumed that a near surface disposal facility or facilities could conceivably become available for waste from Magnox sites in Scotland from about 2040 [25].

The proposed strategic options and timing assumptions will ensure that the range of strategic tolerances can be explored on a consistent basis.

13.2 Programme sequencing approaches for the fleet

There is a range of possible approaches to programme sequencing, based on a variety of drivers and site-specific factors. Possible means to prioritise reactor dismantling are described. For example, priority could be given to:

- Sites furthest from the commencement of C&M Preps, to minimise avoidable costs associated with potential nugatory work e.g. Wylfa and Oldbury
- Sites where reactor dismantling would yield the greatest socio-economic benefits e.g. Chapelcross, Trawsfynydd and Wylfa;
- Sites where new nuclear build is planned or possible, to enable divestment/ re-use of the land e.g. Hinkley Point, Wylfa, Oldbury, and potentially Sizewell;
- Sites where the land has the most perceived value for re-use supporting decommissioning e.g. Calder Hall, to support Sellafield decommissioning;
- A single site from England, Wales and Scotland to support a regional development agenda, with later sites benefiting from the learning in subsequent phases of the programme;
- Sites for which the period since reactor shutdown is greatest to maximise the benefits from radioactive decay e.g. Berkeley, Hunterston A and Trawsfynydd;
- Sites for which achieving the quiescent C&M state would be most challenging e.g. Dungeness A, due to coastal related issues;
- Sites for which previous experience of reactor dismantling can most readily be applied i.e. steel pressure vessel sites;
- Sites suited to development of a near surface disposal facility as a specific enabler for reactor dismantling, for example as a demonstration project;
- Sites within National Parks, or sited near ecologically sensitive locations e.g. Trawsfynydd and Dungeness;

[25] The same timing assumption as for the GDF to enable consistent option comparison, noting that the timing for the availability of any such facility will be subject to the Scottish Government's Implementation Strategy.

- Sites with C&M Preps waste plants that could be made use of, or with significant surplus interim storage capacity, or where such storage capacity could be readily expanded e.g. Hunterston A;
- One or more sites in Scotland, possibly with development of a near surface disposal facility or facilities as an enabler, taking into account the supporting policy framework for near surface, near site disposal of HAW; and
- Sites not adjacent to EDF Energy sites, or planned Horizon sites, as the most progress toward a totally cleared site could be made, and issues associated with isolation for a deferred project during C&M would be avoided.

The above list of possible approaches to sequencing logic is not inclusive. It should also be noted that prioritisation decision making is unavoidably subjective as a consequence of the disparate range of drivers and factors to be taken into account.

A collation of site-specific information has been produced [xxviii], for use in assessing priorities for reactor dismantling. A summary on a site by site basis of information that could influence timing and sequencing is provided in Appendix J.

A list of strategic factors for eventual application to the identified strategic options has been formulated in accordance with the NDA's developing prioritisation process. This maps such factors to the NDA's Value Framework attributes [i] and pace and priority factors [ii], and the Magnox options assessment attributes [xxix]. The list of proposed factors is included as Appendix K.

Strategic options will be better defined and considered further at Gate A/ B.

14 Strategic opportunities

A number of strategic opportunities associated with key enablers that could make a significant contribution to the business case for a reactor dismantling project or programme have been identified:

- There is an opportunity to make use of available capacity in interim stores for operational wastes, as an enabler for reactor dismantling, either at Magnox sites or potentially at Sellafield;
- There is an opportunity to develop a near surface disposal facility [26], as an enabler for reactor dismantling, perhaps as a demonstration facility for this disposal concept for HAW; and

[26] For an immediate or early reactor dismantling option, an on-site disposal facility could be implemented to avoid the need for interim storage of reactor waste and to minimise lifecycle costs. Estimated timescales to develop such a facility are in the range 5 - 10 years.

- There is an opportunity for a continuous Magnox reactor dismantling programme, which could be implemented progressively based on available funding and potentially variable cash flows.

There is also a range of optimisation opportunities which could be considered to improve the efficiency of delivering a reactor dismantling programme:

- There is an opportunity for a demonstration reactor dismantling project at one or more sites, to develop approaches and technologies for possible use across the Magnox fleet;
- There is an opportunity to implement a "back-to-bioshield" strategy at some sites, perhaps as a contributor to a continuous decommissioning programme and to make best use of variable available cash flows;
- There is an opportunity to develop innovative organisational and supply chain models for the efficient delivery of a reactor dismantling project, or programme;
- There is an opportunity to consider alternative funding and contract models for a reactor dismantling project, to incentivise performance and minimise commercial risks;
- There is an opportunity to optimise the processing and packaging strategy for reactor dismantling wastes; and
- There is an opportunity to make use of and develop waste routes that support the waste management hierarchy, for example to metal melt facilities for suitable reactor wastes.

15 Consequences of pursuing the change of direction

This study is the first stage of a periodic strategic review of Magnox reactor dismantling timing strategy. Future strategy development to explore the merit for a change of direction would:

- Help to address the issues and concerns associated with the current strategy, for example those related to a long period of fleet wide quiescence;
- Support the development of mitigation strategies, for example for scenarios in which the availability of the GDF may be delayed;
- Promote a holistic approach at shared sites, and encourage operators to collaborate to make best use of resources, infrastructure and capabilities;

- Inform the development of reactor dismantling strategies for the Magnox site at Calder Hall, and for the fleet of EDF Energy Advanced Gas Cooled (AGR) reactor sites[27];
- Inform HAW strategy development with respect to treatment, interim storage and disposal of reactor wastes;
- Recognising the interdependencies, enable progress in development of an integrated approach to decommissioning and waste management; and
- Inform the development of a business case to inform a decision to either remain with the current strategy or to change to a different strategy.

Making progress with Magnox reactor dismantling planning and implementation would contribute to the maintenance and enhancement of the UK's capabilities and experience in decommissioning and waste management.

There are UK, European and international markets for such skills, with a large number of nuclear reactors across the world due to be decommissioned over the next couple of decades.

16 Stakeholder engagement

The NDA plans to share this strategic development reviewing the case for change for Magnox reactor dismantling timing and sequencing with representatives from Government, regulators and other SLCs at the NDA's Site Restoration Thematic Overview Group (SR-TOG).

This work could also be discussed at the Industry Group on Decommissioning.

This strategy paper or a summary of it could be published on the NDA's web site to seek stakeholder comments and input to the strategy review.

These are valuable opportunities to obtain early feedback from public and industry stakeholders to enable refinement of the strategy development work.

The NDA will use this study to inform the development of an updated position on strategy development for the timing and sequencing of Magnox reactor dismantling, and will feed into the preparation of the next update to NDA Strategy.

Given the significance of the subject matter to local communities, and the potentially considerable socio-economic implications associated with the current strategy (see Appendix L, as an example of the implications of Bradwell entering C&M), there may be merit in developing a structured programme of public and stakeholder

[27] Noting that EDF Energy has differing business drivers and the design differences between AGR and Magnox sites, although these are less significant for Oldbury and Wylfa.

engagement [28]. This could be used to elicit views on the relative merits of the current strategy and alternative options, and the factors that should be taken into account in determining a preferred strategy.

Engagement with the media may also be warranted to pro-actively communicate important messages about the aims of the review, as the subject matter will be of wider local interest, and is likely to attract media attention at some stage.

17 Plan for delivering the topic strategy

Subject to review of the outcomes of this paper, future strategy development could be carried out to identify credible and preferred options, and to develop a business case for possible implementation.

It is proposed that a Gate A/B credible and preferred options paper is produced in financial year 2015/16, followed by a Gate C paper setting out the business case in 2016, to support milestones specified in the NDA Client Specification [xxx] [29].

A programme of more detailed work to support and further underpin strategy development in this area is proposed:

- A simple high level cost model, building upon a recent and previous cost assessments, and which supports lifecycle base cost and NPV calculations, including sensitivity analyses, should be developed;
- The inventory data set and other analyses should be updated to take into account actual load factors at Magnox sites, to remove a known pessimism;
- Packaging options, including the numbers of packages needed, and an assessment of interim storage needs, taking into account available capacity in interim stores at Magnox and others sites, should be carried out;

[28] A programme could be designed to achieve a range of aims, for example: to communicate the reasons for the review, and its scope and boundaries, and to seek stakeholder input, for example through briefings to Site Stakeholder Group (SSG) Chairs, SSG meetings, and local community meetings; engagement with planning officials and elected councillors, possibly via groups that represent the interests of planning authorities, such as the Nuclear Legacy Advisory Forum (NuLeAF) and the Convention of Scottish Local Authorities (COSLA); and perhaps via more focused workshops with local community and industry representatives.

[29] This includes the following specified tasks to deliver site restoration strategic development support projects: Project SR2 – to determine the optimum period between shutdown and reactor dismantling, requiring an assessment of the impact on the programme that would result from this strategy change, and has an associated milestone (M117) for submission of a Gate C paper to the NDA by September 2016; and Project SR3 – to determine the feasibility of dismantling one Magnox site in order to demonstrate feasibility, with any waste requiring disposal in the GDF stored pending the availability of this waste route. SR3 would be commissioned by the NDA in accordance with the SLC call-off support procedure.

- Further summary level and site-specific analysis of waste data should be undertaken to support the next stage of the study;
- Supporting information and simple graphics should be produced to for use in any planned stakeholder engagement activities;
- Technical work could be undertaken to increase confidence in the outcomes of the feasibility assessments for the management and disposal of HAW streams from reactor dismantling[30]; and
- Further work could be undertaken to improve understanding of the interface between reactor dismantling and HAW strategy, including in relation to reactor wastes that will arise in Scotland.

A detailed list of data uncertainties and technical actions to address these is provided in Ref. [xxviii], and a concise summary of proposed technical actions to support future strategy development is set out in Appendix M.

This strategy development, and any future work on this topic, is likely to be of interest to EDF Energy in relation to final decommissioning strategies for the AGR sites, the second generation of graphite moderated reactors. High level engagement with other operators, particularly in relation to shared sites that might be affected by any future change of strategy, is recommended.

18 Recommendations

The following recommendations are made:

(1) The NDA should take into account the strategic context, the drivers for change and the strategic options identified in this paper for the development of an updated strategy position for the timing of Magnox reactor dismantling;

(2) Strategy development work should be carried out to identify credible and preferred options, and to develop a business case to enable a decision to continue with the current deferred reactor dismantling strategy, or to change to an alternative strategy; and

(3) A structured programme of public and stakeholder engagement should be designed, to support the next stages of strategy development.

[30] Specific options for further technical work to help to better underpin waste management and disposal opportunities are set out in [vi].

Appendix A Dismantling costs

Conclusions from a recent review of Magnox reactor dismantling costs for early and deferred timing strategies (from Ref. [iii])

"*Dismantling cost estimates have been generated for a single Bradwell reactor at 40 and 85 years after shutdown. The dismantling costs estimates are £145M and £124M respectively.*

For dismantling the main contributors to the cost difference of £21M are; waste containers at £12.5M due to the higher waste activity levels at 40 years; additional tooling development and operating times associated with the increased level of remote operations for the 40 year scenario at £8M." (See Table A1.)

"*The difference in dismantling costs at 16% is relatively small and is sensitive to dose rates. A small increase in the dose rates at 85 years could substantially erode the cost difference though at no time would the cost at 85 years exceed the cost at 40 years. Within the applicable estimate ranges it can be concluded that in current money values the cost for dismantling at 40 and 85 years are broadly similar.*

Timing sensitivity has been considered by applying +/- 10 years to each of the dismantling scenarios. In each case advancing dismantling has a higher cost impact than deferment. Some of the impact is from waste activity levels but more importantly increased dose rates require changes from manual to remote for some operations.

The timing sensitivity analysis emphasises the importance of the waste activity and dose rate predictions in developing the dismantling cost estimates. These predictions are based on models and reports supplied by Magnox. Although partially correlated with actual readings the acknowledged uncertainties in the predictions could swamp the marginal cost differences between the two dismantling scenarios.

No account has been taken of the costs associated with the care and maintenance for the period between the two scenarios or additional costs that may be incurred preparing the reactor structures for the extended deferment to 85 years. These costs could be significant when compared to the cost difference between the two scenarios. Further study would be needed to fully understand this impact.

When applying discounting it is of no surprise that the 85 year scenario is a substantially lower cost, though note comments above.

The study findings are broadly applicable to the steel RPV Magnox stations. For Oldbury and Wylfa the location of the boilers within the RPV are likely to add significant cost to the dismantling due to access restriction and potential activation levels. Further analysis of waste inventory predictions is required to decide if remote dismantling of the boilers would be necessary.

For AGRs the higher flux densities are likely to lead to higher waste activity and dose levels than for Magnox. It is therefore anticipated that very similar remote dismantling approaches would be required at 40 and 85 years with only marginal cost difference *driven by waste containers. Further consideration of predictive activation models held by EdF would be required to support this finding.*”

Table A1 Cost Estimates for Early and Deferred Dismantling

Major Cost Item	45 Year £’s	85 Year £’s	Delta £’s
Waste Treatment Facility Construction and Operation	£40,350,000	£40,350,000	£0
Pile Cap Containment, Ventilation and Cross-site Transfer	£23,250,000	£23,250,000	£0
Tooling development	£17,250,000	£13,750,000	£3,500,000
Create RPV top access	£866,667	£1,083,333	-£216,666
Core Dismantling	£15,680,000	£11,200,000	£4,480,000
Active Concrete Removal	£9,824,000	£8,382,400	£1,441,600
Conventional Demolition	£1,789,900	£2,421,300	-£631,400
Waste Containers	£36,220,000	£23,795,000	£12,425,000
Total	**£145,230,567**	**£124,232,033**	**£20,998,534**

Appendix B Packaging options

Summary of results of a preliminary assessment of packaging options

The impact of decay time on the number and types of waste packages needed for higher activity waste (HAW) to ensure adherence with limits for transport to a waste disposal facility is reported in Ref. [v] for the Bradwell site.

The results are set out in Table B1.

Table B1 Estimated Number and Type of Packages for Varying Decay Times

	Decay time (years)							
Box type	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**
4 m box, no shielding	8	44	127	139	158	171	194	201
4 m box, 100 mm shielding	36	83	12	19	13	25	7	7
4 m box, 200 mm shielding	83	18	19	14	26	5	7	3
4 m box, 300 mm shielding	12	13	13	23	4	7	3	4
3 m^3 boxes	218	116	85	28	20	13	10	4
Total boxes	**357**	**274**	**256**	**223**	**221**	**221**	**221**	**219**

After 20 years of decay, over 60% of the packages require more shielding than can be offered by any 4 m box variant to meet the necessary transport dose rate limits. Note that approximately 25% of the packages require the shielding afforded by a 200 mm shielded 4 m box variant.

The most significant change in the balance of required container types occurs between 30 and 40 years of decay as the proportion of 3 m^3 containers falls from ca. 60% to circa 40% to circa 33% of the total number of packages. In this period there is also a significant shift in shielding requirements for 4 m containers with the proportion requiring no shielding increasing from ca. 16% after 30 years to circa 50% after 40 years of decay.

Over the next 50 years the radioactivity gradually decays such that at 90 years 91% of the packages require no additional shielding, with only 6% requiring a 4 m box with shielding, and less than 2% requiring more shielding than can be offered by a 4 m box and as such requiring a 3 m^3 box.

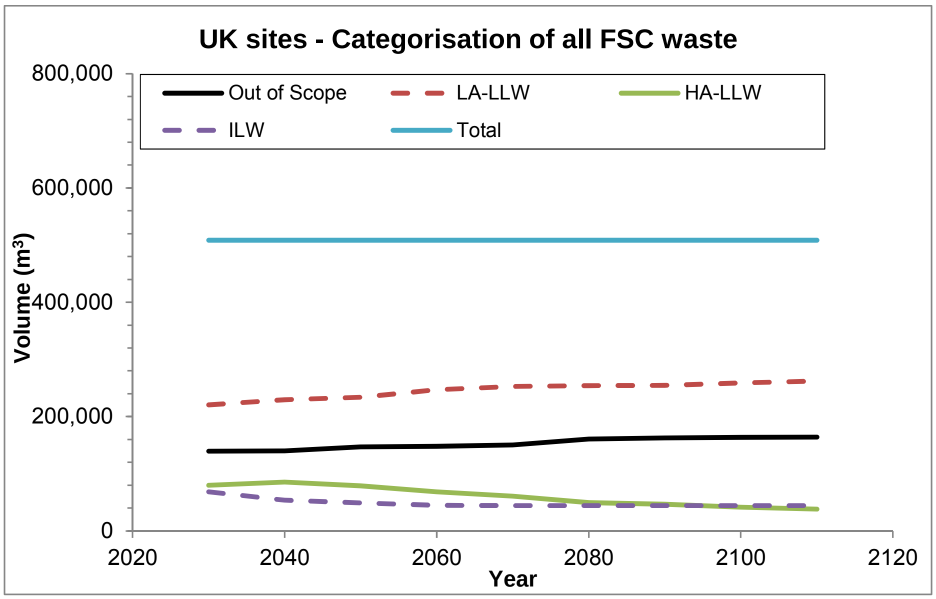
The simple approach used for the assessment provides approximate results which marginally under-estimate the total number of packages needed. The assessment of packaging options could be undertaken based on a more rigorous methodology to support future stages of the strategy development process, and potentially to enable comparisons on a site by site basis.

Appendix C Waste categorisation

An assessment of the categorisation of reactor waste is provided in Ref. [vi].

The evolution with decay time of the categorisation of reactor waste across 10 Magnox sites is illustrated in Figure C1.

Figure C1 Evolution of Waste Categorisation across 10 Magnox Sites



There is limited change in the waste categorisation as a function of time, mainly reflecting the decay of LLW into LA-LLW and Out of Scope categories.

A number of site-specific points were noted.

At the Oldbury and Wylfa sites a higher volume of mild steel is categorised as Out of Scope waste than at the other Magnox sites. This is because the heat exchangers at these sites are embedded within the bioshield and located behind a shield wall. At the other Magnox sites they are not included because they are outside of the bioshield and not part of the study inventory (experience suggests that such material would in any case be LLW and suitable for metal melting).

The estimated volume of Out of Scope concrete is much lower at Chapelcross, Hunterston A, Hinkley Point A, Sizewell A and Trawsfynydd compared with the other Magnox sites due to Ca-41 activity concentrations, and to a lesser extent those for Eu-152, being higher than the EPR values that define upper activity limits for Out of Scope waste not subject to permitting for radioactive waste.

Appendix D Feasibility for metals recycling

Summary of results of an assessment of the feasibility for metals recycling

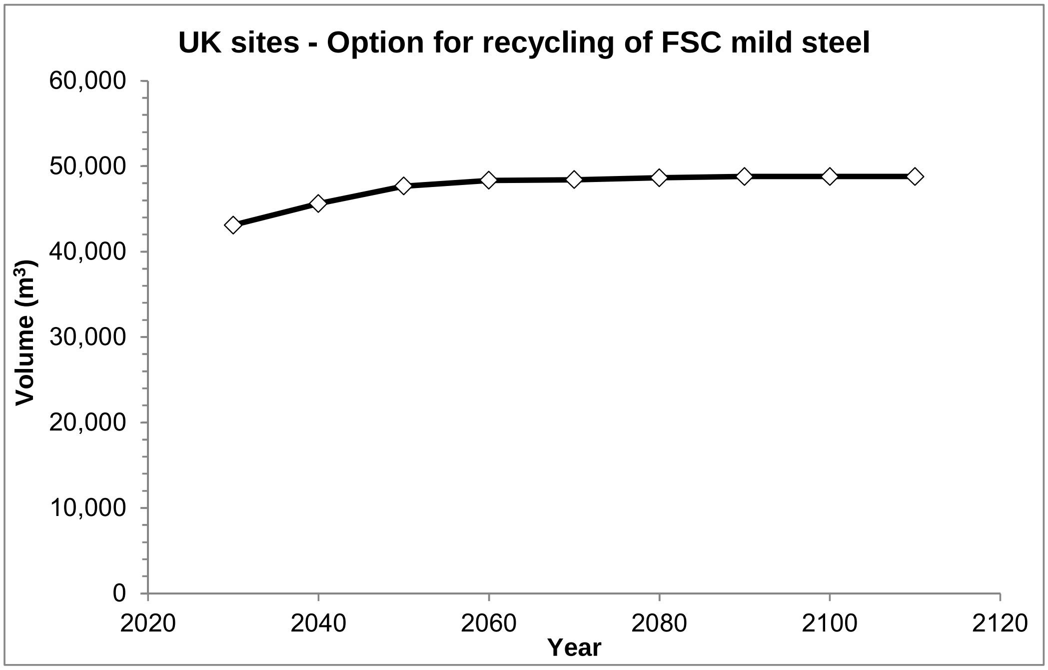
An assessment of the feasibility for application of the metal melt and recycling option to metallic wastes is provided in Ref. [vi], which includes results on a fleet wide and a site-specific basis.

The proportion of the total metallic waste volume assesses as being potentially suitable for the metals recycling option increases gradually with decay time from about 75% of the metallic waste inventory in 2030, to more than 80% in 2050 and to about 85% by 2080.

The maximum volume of metals (mild steel, stainless steel and other metals) potentially suitable for metals recycling therefore amounts to around 10% by volume of the total 500,000 m^3 reactor waste inventory.

The metals recycling opportunity applies primarily to mild steel wastes. Figure C1 illustrates the impact of decay time on the volume of mild steel waste potentially suitable for the metals recycling option across 10 Magnox sites.

Figure C1 Evolution of Recycling Option for Mild Steel across 10 Magnox Sites



A maximum of about 43,000 m^3 mild steel waste is assessed as being potentially suitable for metals recycling in 2030. This rises gradually to circa 48,000 m^3 in 2050 after which radioactive decay provides little further benefit.

The following site-specific conclusions were noted:

- The metals recycling option is primarily an opportunity for mild steel;
- The volumes of stainless steel and other metals potentially suitable for metals recycling is generally insignificant at the steel pressure vessel sites (less than 5% of such inventories);
- The exception is the pre-stressed concrete pressure vessel sites at Oldbury and Wylfa where up to 50% of the stainless steel inventory is potentially suitable for metals recycling;
- The largest volume of mild steel potentially suitable for metals recycling is at the Wylfa site, followed by the Oldbury and Chapelcross[31] sites;
- At the Oldbury and Wylfa sites about 27,000 m^3 of waste is assessed as being potentially suitable for metals recycling from around 2030 with limited further benefit to be achieved from radioactive decay; and
- The majority of sites have reached a plateau in the volume of metallic wastes potentially suitable for metals recycling by no later than about 2050.

The Wylfa and Oldbury sites yield the highest proportions of their total metallic inventories as potentially suitable for metal melting and recycling, with less benefit from radioactive decay than at the steel pressure vessel sites[32]. Berkeley, Bradwell, Chapelcross and Hunterston A also yield significant proportions.

It should be noted that the practical viability of the metals recycling option would require further consideration at the time of implementation, as the activity levels of the waste are generally at the higher end of those that might be considered suitable.

The melting process separates certain contaminants into slag and off-gas phases; however, certain activated radionuclides such as Co-60 are not separable and will remain in the product. Assessment against the capacity and waste acceptance criteria of metal melt facilities would be necessary, taking into account the amount of lower activity feed that would be required to ensure an acceptable product and that an end-use exists for such products.

[31] The Chapelcross site has 4 reactors, compared with 2 reactors at the other Magnox sites, and hence a greater volume of metals associated with the steel pressure vessel and reactor components. This likely contributes to it being assessed as having the largest volume of metals of the steel pressure vessel sites potentially suitable for metals recycling.

[32] It should be noted that the heat exchangers are within the boundary of the bioshield at the Oldbury and Wylfa concrete pressure vessel sites and hence within the reactor inventory, whereas at the steel pressure vessel sites the heat exchangers are located external to the bioshield and hence not within the defined reactor inventory. This in part accounts for the differences in results reported for concrete and steel pressure vessel sites.

Appendix E Feasibility for disposal

An assessment of waste categorisation and the feasibility for application of alternative waste disposal options to reactor wastes is provided in Ref. [vi], which includes results on a fleet wide and a site-specific basis.

It should be noted that all HAW is considered on technical grounds to be suitable for consignment to a geological disposal facility.

E1 Summary of results for feasibility of alternative disposal options

The total volume of reactor wastes in the study inventory across the 10 Magnox sites for which waste data were assessed amounts to a little over 500,000 m^3.

Based on the application of simple criteria, and on the expert judgement of specialists in developing environmental safety cases for waste disposal, the following conclusions were drawn for a 2030 assessment date:

- Up to 30% by volume of the reactor waste inventory can be categorised as Out of Scope and would be suitable for disposal as non-radioactive waste under the Environmental Permitting Regulations;
- About 40% is identified as LA-LLW potentially suitable for disposal to a permitted landfill;
- About 10% is identified as HA-LLW and would be potentially suitable for disposal to a specialised facility for radioactive waste located at the surface, for example the LLWR;
- Up to 20% is identified as HA-LLW but would be constrained by the presence of specific radionuclides such as C-14 and/ or Cl-36, or is identified as similar ILW, that would require disposal at > 5 m depth, either to a near surface disposal facility, or to a GDF; and
- Less than 0.001% by volume of the reactor waste inventory, amounting to about 2 m^3 of stainless steel and 1 m^3 of other materials[33], is identified as likely requiring geological disposal on safety case grounds[34].

Radioactive decay between 2030 and 2110 gradually reduces the 10% of the total reactor waste volume requiring disposal to a specialised facility at the surface to less than 1%, as waste that can be consigned as Out of Scope waste, or as LA-LLW suitable for disposal to permitted landfill, increases commensurately.

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[33] This consists mainly of lightweight absorbers from Bradwell, BBSD system parts from Chapelcross, Hinkley Point and Trawsfynydd, stainless steel pins from Trawsfynydd and control rods from Wylfa. Most sites also have neutron sources and core thermocouples which are considered likely to require disposal in a geological facility.

[34] If Ag-108m were taken into account, the volume assessed as likely to require disposal to a geological facility would potentially rise to circa 5 m^3 in total across the 10 Magnox sites.

For most sites, it appears that the benefits of LLW decaying into lower waste categories, such as LA-LLW and Out of Scope waste, is largely complete within about 40 years of reactor shutdown.

By contrast, disposal options for the Higher Activity Waste (HAW) from reactor dismantling are little affected by radioactive decay, as such waste contains large inventories of the long lived radionuclides C-14 and Cl-36, and is unsuitable for disposal to a facility at the surface.

The main potential waste route constraints identified in this study for an immediate or early reactor dismantling project are the lack of a near surface disposal facility or geological facility suitable for the disposal of HAW, although management in a purpose built store pending the availability of such a disposal facility is a possible option that could be considered.

The conclusions described above are based on some simple assumptions and are subject to uncertainty. In particular, site-specific work (taking disposal facility design, local geology, disposal depth horizon, etc. into account) would be required to develop an environmental safety case for a disposal facility, whereas simple criteria, based on current regulation and waste acceptance criteria, have been used to judge the potential acceptability of different waste disposal options.

Acceptability for a specific option could depend on some characteristic of the waste that has not been evaluated, for example the presence of discrete higher activity items. There is also uncertainty associated with estimation of the inventory, but it is unlikely that such uncertainties would significantly change these conclusions.

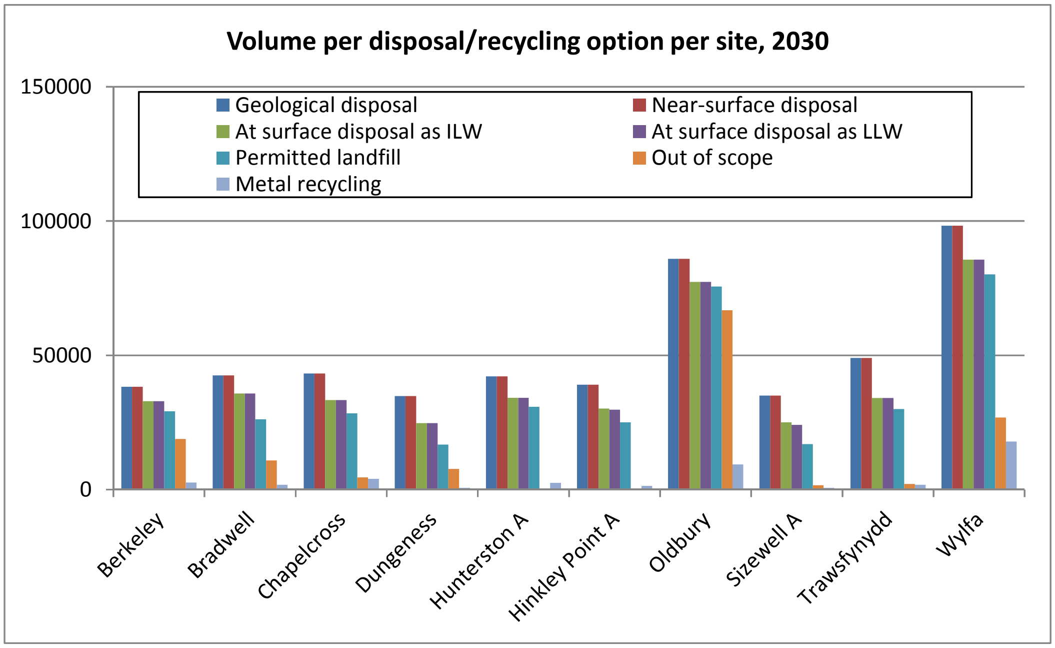
E2 Site-specific results for feasibility of alternative disposal options

Site-specific results describing the volume of reactor waste potentially suitable for consigning to alternative disposal options are illustrated in Figure E1 (results for the metals recycling option are included for comparison).

It should be noted that Figures E1 and E2 illustrate the volume of reactor waste that would meet the simple criteria used to assess feasibility of specific waste disposal options and include waste that could be managed using a less specialised disposal option. For example, all waste that is potentially suitable for disposal in a facility at the surface (e.g. LLWR), or in a near surface facility at > 5 m depth, could also be disposed of to a geological disposal facility.

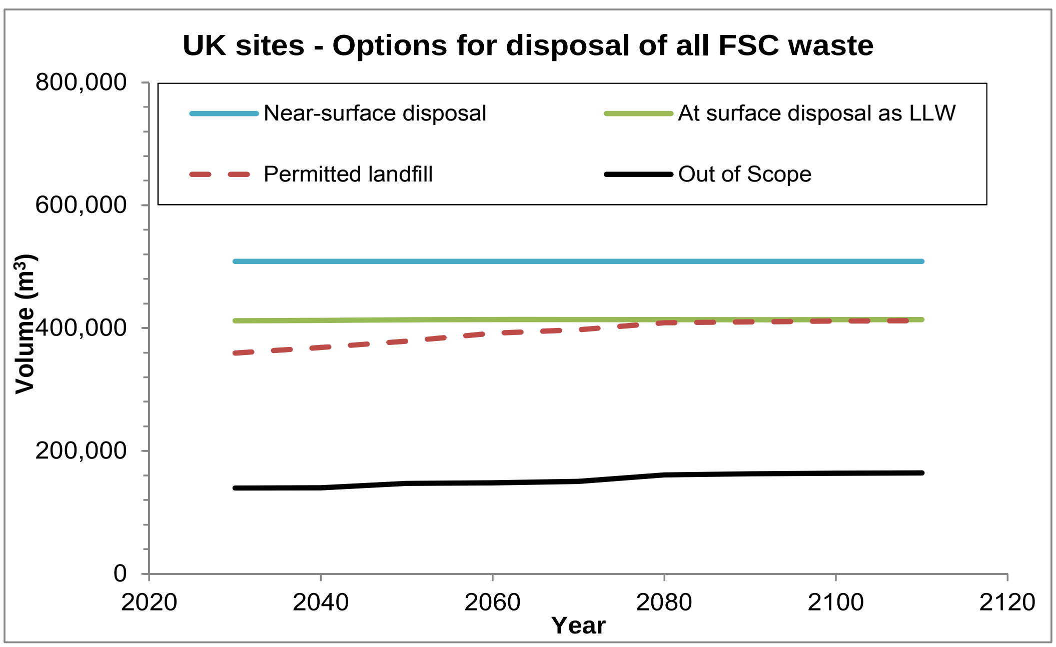
In practice, preference would be given to available waste options, consistent with facility waste acceptance criteria, and in line with national policy and waste hierarchy considerations i.e. in order, to an Out of Scope waste route, permitted landfill for LA-LLW, a specialised surface facility for LLW (e.g. the LLWR), or to a disposal facility for HAW (e.g. a near surface facility, or the planned GDF).

Figure E1 Waste Options on a Site by Site Basis in 2030



The evolution with decay time of potential disposal options is illustrated in Figure E2.

Figure E2 Evolution of Alternative Disposal Options across 10 Magnox sites



There is some benefit from LLW decaying into lower waste categories, such as LA-LLW and Out of Scope waste, generally over a period up to about 40 years following reactor shutdown, although the specific time period over which decay is most significant varies across the sites.

By contrast, there is very little benefit from radioactive decay of HAW, and potential disposal options for this waste do not effectively vary with decay time.

E3 Reactor Wastes with a High Inventory of C-14 and Cl-36

There is a significant inventory of C-14 and Cl-36 in certain reactor wastes, such as core graphite and some activated metallic components.

High inventories of these long lived radionuclides occur in 2,730 m^3 of graphite from Dungeness A, 2,520 m^3 graphite from Oldbury, 2,610 m^3 graphite from Sizewell A and 4,680 m^3 graphite from Wylfa.

The inventories of C-14 and Cl-36 have been compared with those currently acceptable for disposal to the LLWR based on the groundwater pathway radiological capacities for Cl-36 of 34 TBq and for C-14 of 380 TBq [xxxi].

The IAEA has calculated illustrative radionuclide capacities for generic near surface vault disposal models in different geologies [xxxii]. Whilst the radiological capacity for the disposal of C-14 to a facility located in a temperate climate to a sandy geology (70 TBq) is broadly similar to that for the LLWR (380 TBq for the groundwater pathway and 130 TBq for the gas pathway), the reported generic model capacity for C-14 disposal to a vault located in a temperate climate to a clay geology is several orders of magnitude higher (100,000,000 TBq), and is significantly in excess of the total inventory of C-14 associated with all the HAW streams arising at the Magnox sites (5,077 TBq), which includes core graphite waste streams and activated metallic wastes with a high inventory of C-14.The total inventory of Cl-36 associated with all the HAW streams across the Magnox sites is somewhat less than the groundwater pathway radiological capacity for the LLWR.

This suggests that it should be possible to make an environmental safety case for the disposal of Magnox reactor wastes with a high inventory of C-14 and Cl-36 to an appropriately designed near surface facility, provided such a facility is sited in a suitable geology and location. Although such wastes would not currently be suitable for disposal to the LLWR due its high C-14 content, even if ILW were acceptable for disposal at the LLWR, they could potentially be suitable for disposal to a near surface disposal facility sited in a more favourable environment.

The crude comparison with the LLWR radiological capacities serves to indicate that consideration in a site specific environmental safety case would be particularly important for these wastes.

Appendix F International experience

Summary of relevant experience from other countries

Experience has shown that the technological components of decommissioning are by no means sufficient to assure its satisfactory completion. Careful planning, organisation and management are essential. Until the mid-1990s decommissioning experience was scarce, but much has been learned since. Sometimes the magnitude of projects was over estimated. On other projects the tasks were under estimated, resulting in some mistakes being made. Planning or organisational shortcomings have often given rise to a slow-down, or even failure to start, or sustain, the decommissioning process. In some cases, obstacles to timely decommissioning were due to the lack of a clearly defined and rigorously maintained strategy.

Sufficient experience has been acquired to summarise state-of-the-art, current trends and developments in decommissioning strategies worldwide. Currently, of the many large nuclear installations permanently shutdown, only a fraction have been, or will in the near term, be completely cleared. Nevertheless, a trend towards immediate dismantling seems to be emerging in some countries, which is supported by the IAEA, but this appears to be driven mostly by country-, site- or plant specific circumstances. In recent years, and often as the result of international efforts, the situation has been evolving, and provisions and infrastructures including funding are being established. This seems in principle to encourage immediate dismantling. However, the worldwide overview of strategies does not offer a clear pattern. New factors have come into being, such as stakeholder opinions, in particular those of local communities, and now play a significant role in decision making.

The availability of, and plans for, disposal facilities for the radioactive wastes from decommissioning have to date been important enablers for reactor dismantling projects and have, at least in part, contributed to some countries changing course from a deferred to an immediate dismantling strategy.

Disposal facilities for low and intermediate level waste (L&ILW)[35] exist in many countries, or are under development. Examples include the facilities at Centre L'Aube in France and El Cabril in Spain, which both consist of above ground concrete vaults, the mined on-site disposal facilities at the nuclear power reactor sites at Olkiluoto and Loviisa in Finland at up to 100 m depth, the cavern type facility at about 50 m depth at Forsmark in Sweden, several facilities of differing design and at various depths for different types of waste in Japan, and a range of facilities in the US of varying design (trench, landfill and vault).

[35] The ILW component of the waste is in some countries referred to as short lived ILW although waste acceptance criteria almost always include an allowance for a certain inventory of long lived radionuclides, according to national criteria or the facility safety case. Most waste streams produced within the nuclear industry contain some long lived radionuclides. For example, many fission product waste streams contain long lived alpha emitting radionuclides, whilst most metallic activated wastes contain long lived beta emitters.

Such near surface disposal facilities have waste acceptance criteria that enable the safe disposal of much decommissioning waste that would be classed as either LLW or ILW in the UK. Further information on, and examples of, near surface disposal facilities for reactor waste are provided in Refs [xxxiii, xxxiv, xxxv and xxxvi].

There is also growing experience and interest in applying near surface disposal to graphite and other long lived wastes. The CarboWaste programme has considered a range of waste treatment and disposal options for core graphite.

There is also a programme in France for the disposal of core graphite wastes to a proposed national facility for long lived waste sited within a thick, low permeability clay formation [xxxvii].

A test cavern at 50 - 100 m depth has been excavated at Rokkasho in Japan, for a facility designed for the disposal of long lived reactor dismantling wastes.

Core graphite from the Brookhaven Graphite Research Reactor (BGGR) has been disposed of to a near surface disposal facility in Nevada in the US (as a specific benchmarking comparison, the C-14 activity levels of BGRR core graphite bricks was broadly similar to those for Hunterston A core graphite). There are also plans for the prompt decommissioning of the K-reactors adjacent to the Columbia River that include the disposal of core graphite to the Environmental Restoration Disposal Facility (ERDF), a large near surface landfill on the Hanford Site.

In the UK, the graphite moderated Windscale Advanced Gas-cooled Reactor (WAGR) has been largely successfully dismantled, demonstrating a range of dismantling, material handling and packaging techniques and approaches that could be applied to Magnox reactor dismantling. Reactor wastes were packaged in large robust concrete boxes then known as WAGR boxes. The waste is currently in interim storage within an ILW Store on the Sellafield site, pending future consignment to the planned geological disposal facility for wastes arising in England and Wales.

In France, to decommission its first generation gas cooled, graphite moderated reactors, EDF had initially selected a deferred reactor dismantling strategy commencing 50 years after shutdown. However, technological progress in reactor dismantling, the establishment of a VLLW disposal facility (and in the future, a disposal facility for graphite) and political factors (the desire to exhibit to the public a successful solution for decommissioning and waste management, and to develop its industrial capacity) led to a decision to change to an immediate reactor dismantling strategy, although progress has been slow, partly as a consequence of delays in siting a national disposal facility for graphite.

Japan also has a strategy for prompt decommissioning of its nuclear reactors which is mandated in legislation. It has a range of disposal facilities available for low and intermediate level wastes, and is planning a near surface facility at intermediate depth specifically for long lived radioactive wastes, such as irradiated core graphite and reactor components. As already noted, a test cavern for such a disposal facility has been excavated at the Rokkasho site.

The Zion project in the US is another case where decommissioning strategy evolved from safe enclosure to immediate dismantling. The project involves decommissioning of a twin 1040 MWe PWR station over a period of 10 years, and the return of the site in a green field state, except for a spent fuel pad. The strategy was changed as a result of a number of factors: the ability to transfer site ownership to a licensee with decommissioning experience; the availability of a waste disposal site (at Clive, Utah) to accept the vast majority of the radioactive wastes, excluding spent nuclear fuel; and certainty of available funding. The new operator took responsibility for the decommissioning fund and the site license, and bears the full risk associated with cost or schedule overruns.

Tangible benefits of the change of strategy for the Zion NPP include: site restoration for beneficial re-use by 2020, about 12 years earlier than planned; economic benefits for the state of Illinois, generating $100s Millions for the local economy, over one thousand man years of employment, and over $100 Million in employment compensation within the wider Illinois economy; significant overall cost savings, with no further financial costs or risks to Illinois residents; and early reduction and removal of hazards, leading to safety and environmental benefits. The Zion case shows that the occurrence of favourable factors may create the conditions to enable a change to an immediate dismantling strategy.

A major strategic change to waste management should be noted; previously, interim storage of the waste was not considered to be an alternative strategy to the utilisation of a disposal facility for decommissioning waste. The picture is now different, in that several countries lacking a disposal facility have resorted to, or are planning to resort to, interim storage of decommissioning waste. For example, at the Greifswald PWR site in Germany, all wastes resulting from facility decommissioning are being stored in large warehouses on-site pending availability of a disposal route. This strategy should be viewed in conjunction with an aggressive waste minimisation policy based on waste clearance which is legally enforced in Germany, and a particular driver at the site to support the socio-economic wellbeing of the local community at this site in the former East Germany. It should be noted that the volume of radioactive waste from the dismantling of a PWR is much less than that from a Magnox reactor, and the justification for storing large volumes of reactor wastes at a Magnox site pending availability of a disposal route would require careful examination.

Even countries having some waste disposal routes may not have disposal options for all types of decommissioning waste. For example, the large Magnox site at Vandellos in Spain is being kept in a 30 year safe enclosure, one of the arguments for this strategy being the unavailability of a graphite disposal route. Conversely, the Jose Cabrera PWR, also in Spain, that has a disposal route for the low and intermediate level wastes from reactor decommissioning to the El Cabril disposal facility, has been under active dismantling since soon after shutdown.

A new trend has also emerged over the last few years, sometimes called continuous decommissioning. It is a form of dismantling subject to restricted, year-by-year cash flows, and inevitably lasting longer than if the money were available at the beginning. In some cases, it has proven to be difficult to plan for the whole process and allocation of workforce and financial resources can be less than optimal. However, continuous decommissioning can be made so to adhere to a schedule, including for provision of funds and is a legitimate approach that could offer new prospects.

Selection of a strategy should take account of many factors, for example. A list of factors identified in the review is provided at the end of this section. Some factors are within the influence of the operator, others will set by the reactor type and site location, and others will emerge from the need to meet requirements and policies. It is recognised that, besides technical aspects, there are lots of non-technical factors that cannot be readily compared in any metrics. These include stakeholder involvement, international practices and site re-development aspects that reach far into the future. It is important to ensure that the two basic strategies, immediate and deferred dismantling, and typical variants thereof are taken into account and evaluated for the site as a whole rather than for individual facilities e.g. for multi-unit, or indeed multi operator sites. The choice between options, and the strategy timing, depends on a variety of factors. Many aspects must be addressed; the challenge is to achieve an optimal solution in a logical, structured and justifiable manner.

A key element of any analysis is likely to be its transparency so that stakeholders can understand the basis on which it was derived and the judgements made. In the most complex cases this may require the use of multi-attribute techniques. Factors such as stakeholder acceptance can be very difficult to quantify, as different stakeholders may hold very different or opposing views. As a result it is more important to identify and understand relevant factors and to consider their likely impact on strategy than it is to produce an apparently comprehensive numerical conclusion.

Transparency is closely related to auditability and the latter may encourage the use of numerical techniques in order to make conclusions based on an apparently numerical analysis. However, only a few of the relevant factors are explicitly expressed in numerical terms (e.g. cost, waste volumes). Even where they are expressible numerically their units are radically different; comparisons would be needed between dollars and m^3 as an example. In both of these cases, and in the case of other factors less inherently quantifiable, a form of scoring (e.g. from 1-very poor to 10-excellent) can be used to generate numbers for comparison. Even when an auditable, quantified approach emerges, it is likely to be dominated by subjective judgements, and uncertainties are likely to remain a challenge to decision makers.

Factors identified in the review of experience from other countries include: reactor type, size, operating history and location; legislative and regulatory requirements, and national policies; waste amounts and national waste management; spent fuel management; end state and post-decommissioning use of site; technology, human resources and other infrastructure; stakeholder involvement and socio-economic factors; decommissioning cost and funding; knowledge management; radiological and industrial safety, security; plant conditions; ethical factors; and multi-facility sites and programmes. A detailed discussion of these factors and their applicability to decision making for strategy selection is provided in Ref. [xiii].

Appendix G The NDA's prioritisation process

The NDA's approach is influenced by the level of risk to people or the environment. Where the risks are intolerable, urgent action is taken to reduce them. Where the risk is less significant the approach takes greater account of other factors. However, it is still focused on reducing risk and hazard as far as is reasonably practicable. The NDA monitors risk levels and acts proportionately to ensure that the net level of risk does not increase in the long-term. Where risks have been reduced, there is still work to be done. Decisions on further site restoration must balance the broad range of factors in the Value Framework.

The NDA's decisions consider the lifecycle impacts on people and the environment to ensure that the chosen strategic option does not compromise the needs of future generations. There are agreed site end states which define long-term restoration objectives. In addition, the NDA identifies interim states to focus delivery on nearer term restoration goals. These are measurable, demonstrable and could align to stepped risk or hazard reduction targets, decommissioning phases, contract delivery milestones or opportunities to release land for its next planned use.

NDA Strategy, in its strategic overview, states that:

"*At the heart of our Strategy is the priority we apply to delivering a reduction in risk and hazard across our estate.*"

This is followed with the statement that at a high level there are three priorities:

- "*Firstly, where risks to people or the environment are intolerable, making tangible, demonstrable progress on these national priorities is our priority…";*
- "*Secondly, where the risk is tolerable we will pursue hazard and risk reduction.*"; and
- "*Finally, where risks are broadly acceptable and hazards have been reduced, our attention turns to site restoration in line with our Site Interim and End State objectives.*

These priorities will drive the allocation of resources."

Within the section on site restoration of the document it further adds:

"*Where risks have been reduced, there is still work to be done. Decisions on further site restoration will balance the broad range of factors in our* Value Framework*.*"

It later goes on to state in the section on Decommissioning:

"*Decisions will take account of lifecycle risk to people and the environment, and other relevant factors to determine whether continuous or deferred decommissioning is the most appropriate strategic option.*"

This adds an additional condition that the rate or pace of decommissioning and remediation also needs to be included in the assessment of how the reduction of hazard should be considered and/or scheduled.

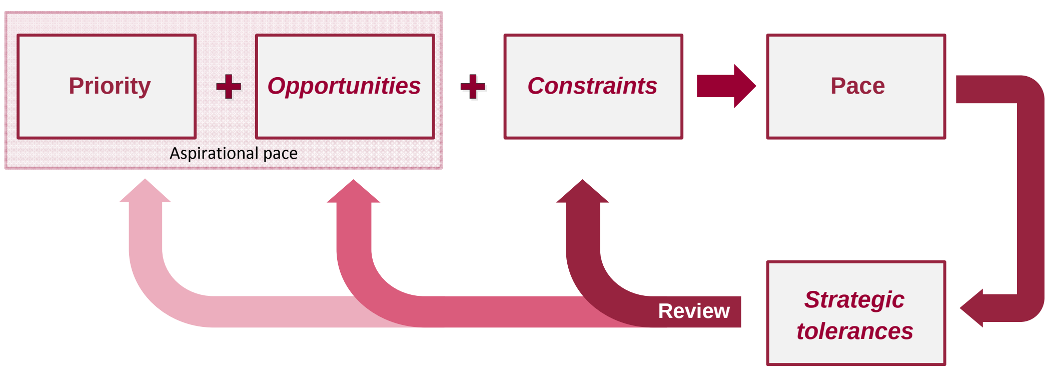
The prioritisation of activities is the ranking or ordering of those activities with reference to single or multiple factors.

The priority chosen is dependent on the relative balance and weighting of these factors. In the case of site restoration the priority represents an unconstrained order in which hazards and liability associated with the NDA estate should be removed or controlled. Note that in its broadest sense optioneering may also be assessed as a prioritisation (ranking or ordering) of options.

The pace of an activity is the timing (start and end date) and rate at which that activity is progressed and achieved.

The relationship between priority and pace is illustrated in Figure G1.

Figure G1: Relationship between Priority and Pace



While prioritisation may identify dates, the difference between pace and priority is that pace allows for the constraints associated with the factors which determine the priority. For example the hazard from an inventory may drive a high priority. The availability/capacity of the waste route to manage that inventory may cause a reduced pace in removal of the hazard and hence a potential change in the order in which the hazards are dealt with, i.e. a lower priority activity may be completed sooner using a different waste route.

As a result of this influence of constraints, pace is generally represented as a plan or schedule of activities as opposed to an order of activities. The pace of decommissioning and remediation for the NDA estate as a whole could simply be the combination of site plans. However there may be an additional layer of constraints added by the considerations at the estate level.

Appendix H Relevant policy factors

Relevant factors from UK Decommissioning Policy

The policy states that decommissioning strategy should take into account all relevant factors, assessing and presenting them in a transparent way underpinned by objective information and arguments.

These include:

- Ensuring worker and public safety;
- Maintaining site security;
- Minimising waste generation and providing for effective and safe management of wastes which are created;
- Minimising environmental impacts including reusing or recycling materials whenever possible;
- Maintaining adequate site stewardship;
- Using resources effectively, efficiently and economically;
- Providing adequate funding;
- Maintaining access to an adequate and relevant skills and knowledge base;
- Using existing best practice wherever possible;
- Conducting research and development (R&D) to develop necessary skills or best practice; and
- Consulting appropriate public and stakeholder groups on the options considered and the contents of the strategy.

Appendix I Risks

Identified risks associated with the current deferred strategy and for immediate and early strategy timings

I1 Risks more significant for deferred reactor dismantling strategies

- The threat of loss of skills, knowledge and organisational capability;
- The threat that long term records and information will be lost, or no longer be intelligible;
- The threat that adequate Suitably Qualified and Experienced Persons (SQEP) will not be available to deliver the programme;
- The threat that adequate Government and regulatory resources will not be available to support programme implementation;
- The threat that Safestore preparations are more costly than currently estimated e.g. for Safestore cladding;
- The threat of technical challenges to achieving a prolonged C&M phase at some sites e.g. structural integrity and water ingress issues.;
- The threat that the C&M Hub organisation will be more costly on an annual basis than current estimates;
- The threat that monitoring, maintenance and management costs escalate beyond estimates e.g. as a consequence of plant deterioration, or equipment obsolescence;
- The threat that coastal evolution and/ or climate change have impacts at some sites beyond those currently foreseen;
- The threat that security requirements change;
- The threat that ILW Stores or ISFs require additional maintenance beyond current assumptions [36];
- The threat of loss of institutional control due to unforeseen circumstances e.g. war, financial crisis, pandemic;
- The threat that legislation and/ or regulatory standards change, impacting the reactor dismantling programme;
- The threat that the cost of labour escalates beyond current estimating uncertainty;
- The threat that the cost of materials escalates beyond current estimating uncertainty e.g. steel for radioactive waste packages;
- The threat that funding is unavailable or inadequate for implementation at the planned time of reactor dismantling e.g. the real rate of return on investments over time is lower than assumed;

[36] A study [xl] produced for the NDA assesses the features and environmental factors that affect the performance of interim storage facilities particularly with respect to longevity.

- The threat that the WAC for currently available routes for radioactive wastes become more stringent, or the route becomes unavailable e.g. LLWR, permitted landfills for LA-LLW, metals recycling facilities;
- The threat that the WAC for currently available routes for inert, non-hazardous and hazardous wastes become more stringent, or the route becomes unavailable e.g. conventional landfill, asbestos routes.;

I2 Risks more significant for early reactor dismantling strategies

- The threat that the availability of resources and skills for reactor dismantling is limited as a consequence of competing demands e.g. from higher hazard work programmes, for example at Sellafield
- The threat that the GDF is not available at the time of planned reactor dismantling, necessitating delays to the reactor dismantling programme, or interim storage of reactor waste;
- The threat of difficulties in obtaining regulatory and planning permissions for any ILW Stores that may be required for the interim storage of reactor waste pending availability of a HAW disposal route;
- The threat that some stored waste packages degrade to a point where they might not be readily transportable to a disposal facility, necessitating over-packing and increasing programme costs[37];
- The threat of difficulties in obtaining regulatory and planning permissions for any new waste routes that may be required to support reactor dismantling e.g. for a near surface disposal facility for HAW[38]; and
- The threat that some radioactive waste may not be suitable for consignment to any available waste route, resulting in an orphan waste requiring ongoing management.

The identification of risks is not an indication of their magnitude, frequency or consequence, and that for some mitigations are already in place. Further quantification of risks will be undertaken in the next stage of strategy development.

[37] The Environment Agency has produced a review relevant to consideration of container lifetime which notes that risks to package integrity increase with time, given that package degradation mechanisms are progressive.

[38] A waste disposal opportunity for sites in England and Wales, and the proposed baseline waste disposal strategy for sites in Scotland.

Appendix J Site specific information

Potentially discriminating site-specific information

J1 Berkeley

Twin reactor site, heat exchangers previously removed from site, cylindrical steel pressure vessels (built using a particularly high cobalt content Inconel), circa 8 ft thick bioshield made of portland concrete.

No history of significant fuel failures or tramp fuel.

The reactors have steel pressure vessels and concrete bioshields which are similar to those which have been decommissioned in the past e.g. Fort St.Vrain and WAGR.

Railhead (Berkeley) is 2.5 miles from the site meaning some use of local roads (including through Berkeley town centre) for material import and waste export.

Berkeley has no adjacent nuclear site.

Berkeley was not identified by Government as a potential site for nuclear new build.

No significant asset management issues identified relevant to reactor dismantling timing.

Population of around 6 within 1 km of the site Detailed Emergency Planning Zone (DEPZ).

The sea defences are part of wider Severn Estuary defences that will likely be maintained for some considerable time.

Contaminated land zones are limited. Contaminated structures are on land at long term risk of inundation and/or increased erosion, especially under extreme global sea level rise scenarios.

Berkeley site is not particularly spatially constrained and could potentially have sufficient space available for the development of an on-site disposal facility.

The site also has plenty of space for currently planned FSC activities.

Development of an on-site disposal facility, either at the surface or at tens of metres, may be practicable.

Planned C&M entry date of 2021.

Berkeley is located in an area with a large number of other employment opportunities. Adjacent Oldbury site (and potential new nuclear build) offer similar skilled jobs.

Land has minimal agricultural value. Adjacent land use include agriculture and natural conservation.

Current planning constraints include designation as a Site of Special Scientific Interest (SSSI), a Ramsar site (a wetlands site of international importance designated under the Ramsar Convention), a Special Area of Conservation (SAC), a Special Protection Area (SPA) and an active Environmental Management System (EMS).

No B site present therefore significant visual impact.

Safestores are already developed.

J2 Bradwell

Twin reactor site, 12 mild steel heat exchangers (ca. 640 tonnes each), spherical steel pressure vessels.

No history of significant fuel failures, tramp fuel or contamination incident in reactor.

The reactors have steel pressure vessels and concrete bioshields which are similar to those which have been decommissioned in the past e.g. Fort St.Vrain and WAGR

Bradwell has no adjacent nuclear site.

A potential site for new nuclear build, although not currently being developed.

Boiler house roofs degradation being addressed by current Safestore cladding project.

Radioactive effluent discharge under threat due to silting in Cooling Water outlets, being addressed under the new discharge pipeline project.

Population of around 500 within 2.4 km of the site (previous DEPZ).

No disturbance issues identified specifically for Bradwell.

Land quality issues – North End, contamination possibly underneath ponds complex and reactor bioshield; potential of mobilisation.

Current engineered coastal defences present (part of the wider Estuary defences). Baseline plan assumes maintenance of the coast defences until final site clearance (85 years post-shutdown) - risk of inundation and/or increased erosion under extreme global sea level rise scenario.

Bradwell site is not particularly spatially constrained and could potentially have sufficient space available for the development of an on-site disposal facility.

The site also has plenty of space for currently planned FSC activities.

Bradwell is underlain by London clay which would be well suited to development of an on-site disposal facility, both at the surface and at tens of metres depth.

Planned C&M entry date of 2015. Unlikely to be able to halt current staff transition programme. No other requirements for nuclear skills in the vicinity. Possibly other employment opportunities in the South East of England.

Railhead (Southminster) is 8 miles from the site meaning some use of local roads for material import and waste export.

Land has minimal agricultural value. Adjacent land use includes agriculture and natural conservation.

Current planning constraints include SSSI, National Nature Reserve (NNR), Ramsar, Submerged Aquatic Vegetation (SAV), SPA & EMS.

Visual impact would be significant as lone site in a flat area visible from Mersea Island.

Unlikely to be able to halt current programme of work towards entry into Care and Maintenance.

J3 Calder Hall

Four reactor site, 16 mild steel heat exchangers (external to the reactor building), cylindrical steel pressure vessels, circa 7 ft thick bio-shield.

The reactors have steel pressure vessels and concrete bioshields which are similar to those which have been decommissioned in the past e.g. Fort St.Vrain and WAGR.

Railhead is on the site (Sellafield) and therefore transport by rail would involve no transport on the public road.

Calder Hall is located within the Sellafield site.

Sellafield was identified by Government as a potential site for nuclear new build and is being developed by the NuGen JV

Post operational clean-out (POCO) and asset management activities have continued at a pace commensurate with funding availability, following end of generation in 2003. Reactor and turbine hall buildings have significant issues with respect to failing cladding, glazing and roofs. Time at risk has been considered during development of the integrated decommissioning programme. Should funding not be prioritised for the optimum decommissioning programme (Safestore by 2034) significant interventions for roofs and cladding will be required in the next 5 years.

Calder Hall comes under the security provision for Sellafield.

Population of around 9 within 1 km of the site (DEPZ).

Space for on-site disposal cell would need to be considered. Potential for use of existing on-site disposal cell at the Sellafield site, or any future planned disposal cells at the Sellafield site.

Available land for FSC activities, laydown areas, contractor compounds etc. would need to be considered.

Suitability for on-site disposal, either at the surface or at tens of metres depth, would require assessment.

Planned Final C&M Entry date of 2034.

Calder Hall is located in an area with a large number of other employment opportunities (Sellafield).

The site is situated within the wider Sellafield site so will have some future land use to support Sellafield decommissioning.

Visual impact reduction particularly with external heat exchanger vessels. Positive sign of reinforcing that Sellafield is in a decommissioning phase due to Calder Hall skyline changes.

Costs developed for optimum decommissioning programme compared with deferred C&M Preps phase decommissioning to 2026. Cost savings of £65m are achievable by following the optimum plan. Affordability within the Sellafield Safety and

Environment Detriment (SED) priorities will determine the funding availability. Safestores developed to concept stage based on learning from experience from Berkley and Bradwell.

J4 Chapelcross

Four reactor site, 16 mild steel heat exchangers (external to the reactor building), cylindrical steel pressure vessels, circa 7 ft thick bioshield.

Fuel fire in one reactor of the four.

The reactors have steel pressure vessels and concrete bioshields which are similar to those which have been decommissioned in the past e.g. Fort St.Vrain and WAGR.

There is no railhead close to the site (fuel was historically transport of fuel to Sellafield was done by road). Waste export would either require re-establishment of a railhead or transport by road.

Chapelcross has no adjacent nuclear site.

Scottish Government policy does not support nuclear new build.

Pump house roof severe degradation, temporary repairs in progress until decommissioning can be carried out.

Reactor heat exchanger pipe work and associated fittings severely corroded, surveillance and essential repairs programme in force until decommissioning is completed.

Early dismantling may result in a larger release of tritium than a deferred strategy for the two tritium production reactors.

Population of around 50 within 2 km of the site (DEPZ).

Inland site, so no risk from coastal inundation and/or increased erosion. Gullielands Burn may be returned to a natural state at FSC, but in any case has insufficient flow to pose a risk of flooding the site.

Chapelcross site is not particularly spatially constrained and could potentially have sufficient space available for the development of an on-site disposal facility.

The site also has plenty of space for currently planned FSC activities.

Suitability for an on-site disposal facility would require assessment, both at the surface and at tens of metres depth (an inland site located above an important aquifer).

Planned C&M entry date of 2028.

Chapelcross is located in an area with minimal other employment opportunities. No presence of an adjacent EDF Energy site so no mitigation with respect to loss of jobs.

Adjacent land use include agriculture, light industry (e.g. scrapyard), landfill and peat extraction.

No planning restrictions on or adjacent to the site itself.

No B site present therefore significant visual impact.

Safestores yet to be developed, could avoid cost of development.

J5 Dungeness A

Twin reactor site, 8 mild steel heat exchangers (ca. 864 tonnes each), spherical steel pressure vessels, bio-shield thickness varies between 1.7 m and 2.1 m.

No history of significant fuel failures, tramp fuel or large scale contamination incident in reactor.

The reactors have steel pressure vessels and concrete bioshields which are similar to those which have been decommissioned in the past e.g. Fort St.Vrain and WAGR.

Dungeness A has a neighbouring EDF Energy site.

Dungeness was not identified by Government as a potential site for nuclear new build.

Beach feeding required on continuous basis to mitigate flooding risk from the sea.

Particularly harsh environment at Dungeness makes asset management more onerous than at other sites.

There is known water ingress into the basement of Reactor 1, which currently requires active management systems. This water is regularly pumped out and has been radiochemically analysed (it contains H-3). As such it is currently processed through the site's AETP.

There are a small number of properties close to the site on the Dungeness estate (ca. 50 properties within 1 mile of the site).

Railhead being close to the site would help to limit number of HGV movements for import and export of materials.

There are no significant zones of contamination at the site, but on longer timescales it is expected that a large part of the Dungeness peninsula may be inundated, so any contaminated structures on site are at significant risk.

Dungeness A site is not particularly spatially constrained and could potentially have sufficient space available for the development of an on-site disposal facility. The site also has plenty of space for currently planned FSC activities.

Dungeness would be unlikely to be suitable for the development of an on-site disposal facility at the surface due to likely coastal evolution. However, development of such a facility at tens of metres depth may be practicable.

Planned C&M entry date of 2027. Dungeness is located in an area with minimal other employment opportunities. The presence of the adjacent EDF Energy site offers some mitigation with respect to loss of jobs.

The site is situated in a SSSI and would likely be returned to its natural state. Parts of the site have been designated as part of the surrounding SSSI area.

No visual change as next to a B site. However it is in a visually attractive area and therefore would have more benefit than some other sites.

Could potentially share resources with EDF Energy.

Dungeness site is not particularly spatially constrained. There is anticipated to be plenty of land available on the current licensed site to enable reactor dismantling.

There is a cost associated with the likely need to 1) continue to manage the water entering Reactor 1 basement and 2) feed the site's shingle bank to protect against flooding during the C&M phase.

J6 Hinkley Point A

Twin reactor site, 12 mild steel heat exchangers (ca. 800 tonnes each), spherical steel pressure vessels, bio-shield thickness varies between 2.1 m and 3.4 m.

No history of significant fuel failures or tramp fuel.

The reactors have steel pressure vessels and concrete bioshields which are similar to those which have been decommissioned in the past e.g. Fort St.Vrain and WAGR.

Railhead (Bridgwater) is 11 miles from the site and located in the centre of Bridgwater. It is considered that this would not offer a suitable option for the transport of large number of waste packages.

Hinkley Point A has a neighbouring EDF Energy site.

Hinkley Point was identified by Government as a potential site for nuclear new build and is being developed by EDF Energy.

No significant asset management issues identified relevant to reactor dismantling timing.

Population of around 1300 within 3.5 km of the site (DEPZ).

Early dismantling could have a cumulative impact with nuclear new build.

The sea defences (concrete sea wall, etc.) are solely to defend the power stations.

Contaminated land zones are limited. Contaminated structures are not on land at significant risk of inundation and/or increased erosion (based on work done for on-site LLW disposal feasibility studies), and therefore coastal defences not relied on for radiological protection during C&M.

Hinkley Point site is not particularly spatially constrained and could potentially have sufficient space available for the development of an on-site disposal facility.

The site also has plenty of space for currently planned FSC activities.

Hinkley Point would be would be well suited to development of an on-site disposal facility, both at the surface and at tens of metres depth.

Planned C&M entry date of 2025.

Hinkley is located in an area with a large number of other employment opportunities (Hinkley Point B and C development).

Adjacent land use includes agriculture (& planned nuclear new build).

Current planning constraints include SSSI, NNR, Ramsar, SAC, SPA & EMS.

No visual change as next to a B site and C site.

Could potentially share resources with EDF Energy.

Safestores yet to be developed, could avoid cost of development.

J7 Hunterston A

Twin reactor site, 16 mild steel heat exchangers, spherical steel pressure vessels, bio-shield thickness circa 1.5 m.

A bottom fuelled reactor, differing pile cap design to other Magnox sites.

No history of significant fuel failures or tramp fuel.

The reactors have steel pressure vessels and concrete bioshields which are similar to those which have been decommissioned in the past e.g. Fort St.Vrain and WAGR.

Railhead is 1.5 miles from the site with minimal use of local roads for material import and waste export.

Hunterston A has a neighbouring EDF Energy site.

Scottish Government policy does not support nuclear new build.

A technical specification is being produced for repairs to the reactor building roofs to prevent further water ingress and restore the weather envelope.

Population of around 44 within 2.4 km of the site (DEPZ).

The sea defences (rip rap) primarily defend non-licensed land.

Contaminated land zones and contaminated structures are on land at long term risk of inundation and/or increased erosion, especially under extreme global sea level rise scenarios.

Hunterston A site is not particularly spatially constrained and could potentially have sufficient space available for the development of an on-site disposal facility.

The site also has plenty of space for currently planned FSC activities.

Development of an on-site disposal facility, both at the surface and at tens of metres depth, is potentially practicable (preliminary environmental safety case, engineered design and community engagement as part of NDA feasibility study demonstrates viability for facility at tens metres depth, and includes sensitivity study for core graphite wastes and steels).

Planned C&M entry date of 2022.

Hunterston A is located in an area with a moderate number of other employment opportunities. Adjacent EDF Energy site offers similar skilled jobs.

Adjacent land use is only agriculture.

Current planning constraints include SSSI, "Undeveloped coast" in Local Plan.

No visual change as next to a B site. However it is in a visually attractive area and therefore would have more benefit than some other sites.

Could potentially share resources with EDF Energy.

Existing cladding has a limited lifespan.

Safestores yet to be completed, could avoid certain costs. Cladding design done and planning permission granted.

J8 Oldbury

Twin reactor site, 8 mild steel heat exchangers (within the reactor pressure vessel), cylindrical pre-stressed concrete pressure vessels, pressure vessel thickness circa 4.5 m.

No history of significant fuel failures or tramp fuel.

The reactors have pre-stressed concrete pressure vessels which are not similar to previous reactors which have been dismantled.

Railhead (Berkeley) is 12 miles from the site meaning some use of local roads (including through Berkeley town centre) for material import and waste export.

Oldbury has no adjacent nuclear site.

Oldbury was identified by Government as a potential site for nuclear new build and is being developed by Horizon.

No significant asset management issues identified relevant to reactor dismantling timing.

Population of around 6 houses within 1 km of the site (DEPZ).

Early dismantling could have a cumulative impact with nuclear new build.

The sea defences are part of wider Severn Estuary defences that will likely be maintained for some considerable time.

Contaminated land zones are limited. Contaminated structures are on land at long term risk of inundation and/or increased erosion, especially under extreme global sea level rise scenarios.

Oldbury site is not particularly spatially constrained and could potentially have sufficient space available for the development of an on-site disposal facility.

The site also has plenty of space for currently planned FSC activities.

Development of an on-site disposal facility, both at the surface and at tens of metres depth, potentially practicable.

Planned C&M entry date of 2027.

Oldbury is located in an area with a large number of other employment opportunities. Potential new nuclear build offers similar skilled jobs.

Adjacent land use includes agriculture & informal nature conservation (and planned nuclear new build).

Current planning constraints include SSSI, NNR, Ramsar, SAC, SPA & EMS.

Intention is that Oldbury will have a B site so minimal visual impact.

Safestores yet to be developed, could avoid cost of development.

J9 Sizewell A

Twin reactor site, 8 mild steel heat exchangers (ca. 740 tonnes each), spherical steel pressure vessels.

No history of significant fuel failures or tramp fuel.

The reactors have steel pressure vessels and concrete bioshields which are similar to those which have been decommissioned in the past e.g. Fort St.Vrain and WAGR.

Sizewell A has a neighbouring EDF Energy site.

Sizewell was identified by Government as a potential site for nuclear new build and is being developed by EDF Energy.

No significant asset management issues identified relevant to reactor dismantling timing.

Population of around 470 people within 2.4 km of the site (DEPZ).

Early dismantling could have a cumulative impact with nuclear new build.

The sea defences form part of regional defences and defences for adjacent power station(s).

There are not significant zones of land contamination at the site, but on longer timescales this coastline is considered to be particularly susceptible to erosion, so any contaminated structures on site are at significant risk.

Sizewell site is spatially constrained and could potentially have insufficient space available for the development of an on-site disposal facility (particularly at the surface).

The site has sufficient space for currently planned FSC activities.

Sizewell would be unlikely to be suitable for the development of an on-site disposal facility at the surface due to likely coastal evolution. However, development of such a facility at tens of metres depth may be practicable.

Planned C&M entry date of 2027.

Sizewell is located in an area with a large number of other employment opportunities (Sizewell B and C development).

Adjacent land use includes agriculture (& planned nuclear new build).

Current planning constraints include SSSI, NNR, SAC, SPA, EMS & Area of Outstanding Natural Beauty (AONB).

No visual change as next to a B site and C site.

Could potentially share resources with EDF Energy.

Safestores yet to be developed, could avoid cost of development.

J10 Trawsfynydd

Twin reactor site, 12 mild steel heat exchangers (ca. 800 tonnes each), spherical steel pressure vessels, bioshield thickness varies between 2.1 m to 3.5 m.

No history of significant fuel failures or tramp fuel.

The reactors have steel pressure vessels and concrete bioshields which are similar to those which have been decommissioned in the past e.g. Fort St.Vrain and WAGR.

Heat exchangers have been cut in half and the sections are stored in the reactor basement/ circulator hall.

Avoidance of reactor height reduction works would minimise the exposure of workers to conventional safety risks.

Trawsfynydd has no adjacent nuclear site.

Trawsfynydd was not identified by Government as a potential site for nuclear new build.

The reactor buildings civil structures have recently been strengthened in order to make them wind loading code compliant.

Minimal population within 1.3 km of the site (DEPZ).

Inland site, so no risk from coastal inundation and/or increased erosion.

Under pond contaminated land and also an authorised conventional asbestos disposal facility present ongoing risks.

Trawsfynydd site is not particularly spatially constrained and could potentially have sufficient space available for the development of an on-site disposal facility.

The site also has plenty of space for currently planned FSC activities.

Feasibility to develop an on-site disposal facility, both at the surface and at tens of metres depth, would need to be determined; possible National Park issues and inland site so may not be well suited to a facility for long-lived waste.

Planned C&M entry date of 2016.

Unlikely to be able to halt current staff transition programme.

Trawsfynydd is located in an area with minimal other employment opportunities. Wylfa offers some requirement for nuclear skills in the vicinity.

Adjacent land use includes hill farming, forestry and wild country.

Current planning constraints include National Park, SSSI, SAC

Significant visual impact as in National Park and can be seen from a large distance away. Note that this visual impact would be mitigated by reactor height reduction works.

The current plan is to reduce the height of the Safestore building to improve the visual impact. When FSC is to be carried out, the height of the buildings will have to be raised to install the necessary equipment for dismantling.

Could potentially share resources with Wylfa.

Could avoid expenditure in reactor height reduction works.

J11 Wylfa

Twin reactor site, 8 mild steel heat exchangers (within the reactor pressure vessel) cylindrical pre-stressed concrete pressure vessels, pressure vessel thickness circa 3.35 m.

No history of significant fuel failures or tramp fuel

The reactors have pre-stressed concrete pressure vessels which are not similar to previous reactors which have been dismantled.

Railhead (Valley) is 12 miles from the site meaning some use of local roads for material import and waste export.

Wylfa has no adjacent nuclear site.

Wylfa was identified by Government as a potential site for nuclear new build and is being developed by Horizon.

No significant asset management issues identified relevant to reactor dismantling timing.

Minimal population within 1.6 km of the site (DEPZ).

Early dismantling could have a cumulative impact with nuclear new build.

There are some hard sea defences that may not need to be maintained as the natural form of coast provides bulk of protection.

There are not significant zones of contamination at the site, and contaminated structures are not on land at significant risk of inundation and/or increased erosion, except under extreme global sea level rise scenarios.

Wylfa site is not particularly spatially constrained and could potentially have sufficient space available for the development of an on-site disposal facility.

The site also has plenty of space for currently planned FSC activities.

Development of an on-site disposal facility, both at the surface and at tens of metres depth, potentially practicable.

Planned C&M entry date of 2025.

Wylfa is located in an area with minimal other employment opportunities. Potential new nuclear build offers similar skilled jobs.

Adjacent land use includes agriculture (and planned nuclear new build).

Current planning constraints include SSSI, NNR, SAC, SPA, EMS & AONB.

Intention is that Wylfa will have a B site so minimal visual impact.

Could potentially share resources with Trawsfynydd, or with Horizon if new build developed.

Safestores yet to be developed, could avoid cost of development.

Appendix K Assessment factors

Factors for assessment of reactor dismantling timing and sequencing

The factors set out in Table G1 have been identified and will be subject to further development at future stages of the assessment process.

Table G1 Relevant Factors for Future Stages of Assessment

<table>
<tr><th>Value Framework</th><th>Relevant factors with Value Framework *</th><th>Equivalent Magnox Ltd. Standard Attributes</th></tr>
<tr><td rowspan="12">Safety: Risk to health, safety and welfare of workers and public</td><td rowspan="3">Risk to workers from radiological, chemical and conventional hazards</td><td>Short-term risk to workers</td></tr>
<tr><td>Lifecycle worker dose</td></tr>
<tr><td>Conventional safety risk (workers)</td></tr>
<tr><td rowspan="4">Risk to public from radiological, chemical and conventional hazards</td><td>Short-term risk to public</td></tr>
<tr><td>Conventional safety risk (public)</td></tr>
<tr><td>Public dose (transport)</td></tr>
<tr><td>Public doses - discharges (gaseous and aqueous)</td></tr>
<tr><td rowspan="3">Level of institutional control (management and regulatory controls) required to maintain safety</td><td>Active/ passive management</td></tr>
<tr><td>Novelty/ prior use</td></tr>
<tr><td>Impact on future options (complexity of management)</td></tr>
<tr><td rowspan="2">Level of asset management required to maintain safety</td><td>Precautionary approach (safety)</td></tr>
<tr><td>Intrinsic safety risk</td></tr>
<tr><td>Security: Ability to keep nuclear material and associated records secure</td><td>Impact on security arrangements</td><td>Security</td></tr>
<tr><td rowspan="2">Hazard reduction: Reduction / passivation of inventory (radiological and chemical)</td><td>Hazard passivation</td><td>Rate of hazard reduction</td></tr>
<tr><td>Progress towards the end state by managing the inventory</td><td>Time to end of liability</td></tr>
</table>

Value Framework	Relevant factors with Value Framework *	Equivalent Magnox Ltd. Standard Attributes
Environment: Impact on natural environment air, water, ground, groundwater) including associated biota	Impact on the environment and associated biota from discharges to air, water and land	Radioactive discharges (gaseous and aqueous)
		Non-radioactive discharges (gaseous and aqueous)
	Impact on protected sites / sensitive habitats	Disturbances
		Precautionary approach (environment)
	Use of energy	Greenhouse gas emissions
	Use of natural resources	Use of materials
		Land use (impact on sensitive habitats/ environments)
	Category and volume of radioactive and non-radioactive waste generated	Volume/activity of LLW (primary & secondary)
		Volume of ILW (primary & secondary)
		Volume of conventional waste (primary & secondary)
		Availability of future waste disposal routes
Socio-economics: Ability to support and sustain social and economic well-being within the community	Impact on jobs in community	Employment and skills
	Release of land for reuse	Land Use (release of land for reuse)
	Impact on wellbeing of community	Burden on future generations

Value Framework	Relevant factors with Value Framework *	Equivalent Magnox Ltd. Standard Attributes
Opportunities to advance the programme ***	Level of visible progress	Level of visible progress
	Potential to test approaches / technologies	Implementation risk
		Development status
	Potential to maintain and grow skills Potential to maintain and grow knowledge	Impact of loss of corporate records and memory
	Release of resource for use elsewhere Release of land for reuse by SLC	Dependence on other sites and facilities
Cost: Cost of doing the work (discounted and undiscounted) and financial return **	Annual spend profile	Short-term costs
	Discounted cost of doing the work Undiscounted cost of doing the work	Lifecycle costs
	Expected financial return	Cash benefit

* For all factors, need to consider: the impact of doing the work; and impact of the work having been done (e.g. profile of risk to workers and public, profile of jobs, profile of impact on sensitive habitats)

** Note potential for double counting the cost attribute because other factors (e.g. waste arising) are frequently quantified in terms of cost

*** Could be treated as opportunities, rather than factors

Appendix L Bradwell socio-economic implications

Socio-economic implications of Bradwell entering C&M (extract from Ref. [xxxix])

"*1. Executive Summary*

1.1 In Summer 2012 Magnox Limited in partnership with Maldon District Council and the Nuclear Decommissioning Authority (NDA) commissioned a study which had two core objectives:

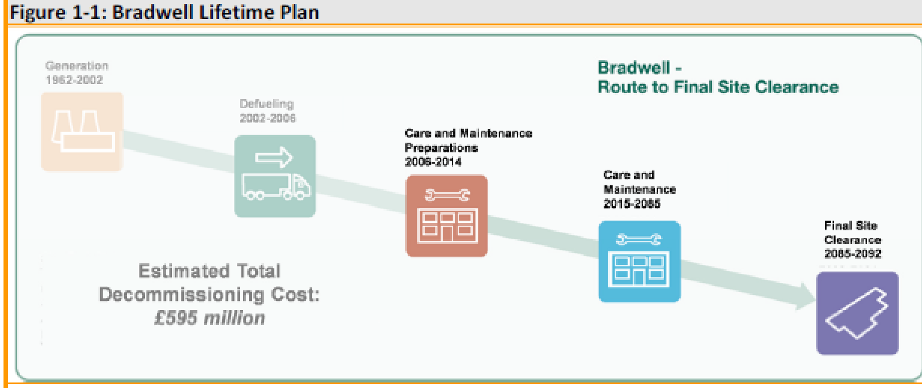
- *To ascertain the socio-economic impacts of the decommissioning process at Bradwell*
- *To develop an Action Plan setting out the possible interventions going forward to mitigate against the negative impacts of decommissioning*

1.2 This report focuses on the former of these two objectives, setting out the results of a detailed technical assessment of the current economic contribution of Bradwell and how this is likely to evolve in coming years

The Decommissioning Process at Bradwell

1.3 Bradwell Nuclear Power Station reached the end its scheduled power generation lifetime in 2002 and subsequently began decommissioning. Nuclear decommissioning in the UK is the responsibility of the Nuclear Decommissioning Authority (NDA), which provides the financial resource required to undertake decommissioning at each site. Each site is operated by a Site License Company – in the case of Bradwell, this is Magnox Ltd. As highlighted by the diagram below, decommissioning is both a lengthy and complex process – at Bradwell, the process is expected to last until 2092/93.

Figure 1-1: Bradwell Lifetime Plan



Source: Based on diagram set out in Bradwell Lifetime Plan (Magnox Ltd) and information from NDA

1.4 Different levels of activity on site at Bradwell (both in terms of expenditure and employment) are associated with each phase of decommissioning. Of particular significance is the impending transition from the Care and

Maintenance Preparations phase to the Care and Maintenance phase. This transition (in 2015) will see levels of activity on site decline to minimal levels. As such, this transition period is the primary focus for this study.

The Current Economic Impact of Bradwell

1.1 *Bradwell is currently an **important component of the local economy**. The site is currently in the Care and Maintenance Preparations phase of decommissioning and levels of activity onsite remain relatively high – in 2011/12, NDA funding for activities on site totalled £92 million.*

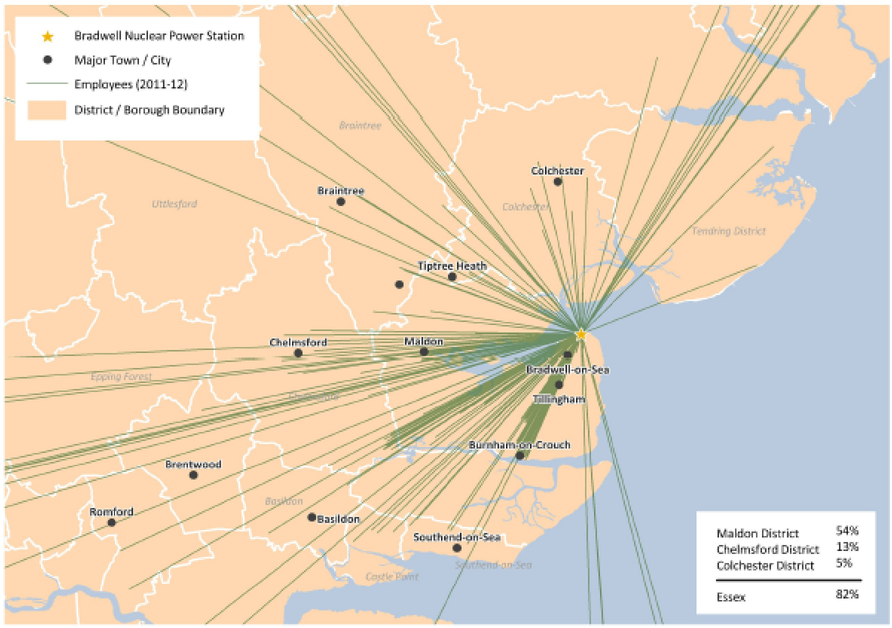
1.2 *It is estimated that Tier One activities at Bradwell directly support up to 900 jobs and GVA of £49.7 million. When taking indirect (supply chain) and induced (employee spending) impacts into account, it is estimated that Bradwell supports up to around 1,000 jobs and GVA of around £52.5 million at the Maldon level, around 1,100 jobs and GVA of around £54.9 million at the Essex level, and around 1,800 jobs and GVA of £90.71 million at the UK level.*

Bradwell: Summary of Current Economic Impacts				
	Tier One	Tier One, Indirect and Induced		
		UK	Essex	Maldon
Employment (inc sub contractors)	900	1,800	1,100	1,000
GVA	£49.7 million	£90.7 mil	£54.9 mil	£52.5 mil
* Note – Exchequer Benefits have only been calculated for Magnox activities – they do not take account for Tier One sub-contracting activities.				
Source: Based on Magnox Ltd information and Regeneris Consulting Calculations				

1.3 *The nature of jobs provided at Bradwell is also an important factor to consider. Over four decades, Bradwell has been a source of full time, year round positions. These are important factors and benefits to the local economy, given that rural and coastal areas are often characterised by industries which provide a lot of seasonal / temporary and part time work. It is also interesting to note that Magnox jobs at Bradwell cover a relatively broad occupational profile and are filled by employees with a relatively wide skills profile. This is significant as it means that jobs supported by the site are theoretically accessible to a wide profile of the local labour market.*

1.4 *The important role that Bradwell plays in the sub-regional labour market is highlighted by the map below [sic] which shows that over 80% of Magnox Employees at Bradwell (not including Agency workers) live within Essex. In total, Magnox and Agency jobs at Bradwell account for around 8% of all jobs on the Dengie Peninsula and around 2% of all jobs in Maldon District.*

Place of Residence of Current (2011) Workers Directly Employed at Bradwell by Magnox Ltd



Source: Information from Magnox Ltd

1.5 *Wider socio-economic benefits relating to Bradwell include the provision of training (and consequential up-skilling of members of the sub-regional labour market), and the provision of community funding to relevant local organisations and projects.*

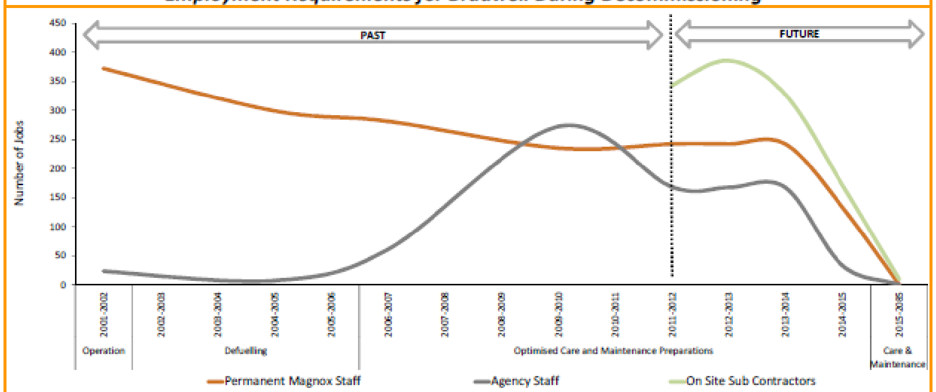
The Economic Impacts of Future Decommissioning Activities at Bradwell

1.6 *In 2015 Bradwell is due to enter the Care and Maintenance Phase of decommissioning. The transition to the Care and Maintenance phase will see the level of* ***economic impact supported by Bradwell reduce to minimal levels****:*

- *In the remainder of the Care and Maintenance Preparations phase up to 2015, levels of activity on site are expected to remain strong. During this period, the site will receive average funding of £79.9 million per annum from the NDA. As such, during this period current levels of economic impact are likely to be largely sustained – with around 800 Tier One jobs and £40 million Tier One GVA supported*
- *After 2015, levels of funding will immediately drop to minimal levels. In 2015/16, funding of £3.3 million from the NDA is projected – a decline of 97% from 2011/12 levels. Levels of funding (and hence activity on site) are then projected to remain low over the remainder of the Care and Maintenance period (to 2085). As such, after 2015, the level of economic impact supported by Bradwell is projected to decline to negligible levels – both in terms of employment and GVA*

Bradwell – Changes in Economic Benefits during Decommissioning						
	Passage of Time		Tier One	Tier One, Indirect and Induced		
				UK	Essex	Maldon
Employment	2011/12	↓	900	1,800	1,100	1,000
	Average 2012-2015		800	1,700	900	800
	Average 2015-2085		<10	50	20	15
GVA	2011/12	↓	£49.7	£90.7	£54.9	£52.5
	Average 2012-2015		£39.9	£86.3	£44.2	£42.2
	Average 2015-2085		£1.6	£3.2	£1.8	£1.7

Employment Requirements for Bradwell During Decommissioning



NOTE: Data not available to calculate sub-contractor headcount pre 2011/12

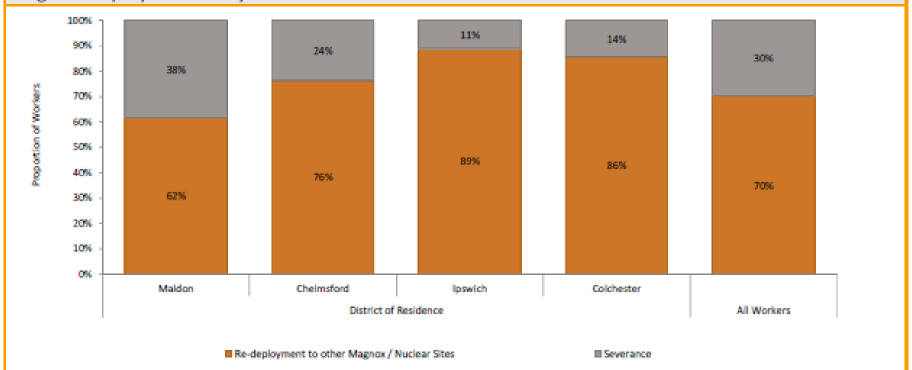
Source: Based on Magnox Ltd Information and Regeneris Consulting Calculations

The consequences of future decommissioning activities

1.7 *The likely consequences of these projected trends are numerous and multi-layered. Some of the most important implications include:*

- ***Implications for Magnox Employees*** *– Magnox has suggested that three options exist for employees after 2015 – re-deployment to other Magnox sites elsewhere in the UK; re-deployment to other nuclear sites in UK; or severance. Early indications of how these options might ultimately play out suggest that around 70% of employees (up to 180 people) will be looking to take the 'redeployment' option. Under this option, workers would move to other sites elsewhere in the UK, with detrimental impacts for the sub-regional labour market. Around 30% of employees are likely to take the severance option – around 70 workers in total. It will be important that steps are taken to assess the characteristics of those who are taking the severance option, and in those instances where workers are looking to remain in the labour market, provide assistance where necessary (particularly around transferability of skills)*

Magnox Employees – Likely Destination Post 2015



Note: this chart only includes around two thirds of current Magnox employee

Source: Based on Magnox Ltd Information

- ***Implications for Agency Workers*** *– There are currently around 170 Agency workers at Bradwell. This is a significant number and it is important to note that Agency workers will not have access to the same rights or opportunities post 2015 as those available to Magnox employees. Clearly, it will be important to engage with these workers at an early stage where possible. The focus should be placed on understanding the skills which have been gained whilst working at Bradwell and the extent to which these are transferable to other industries.*
- ***Implications for Local Businesses*** *– Evidence suggests that there are some parts of the local economy which are reliant on the activities of Bradwell – in particular, the local guest houses, restaurants and a range of other local service businesses which currently benefit year round from the high number of sub-contractors / temporary workers staying in the area. Going forward, it will be important to engage with these businesses to assess the extent to which they understand the forthcoming implications of decommissioning for their business and assess any instances where the provision of support might be beneficial.*
- ***Implications for Supply of Local Accommodation*** *– Concerns currently exist within Maldon District Council that Bradwell sub-contractors are having a negative influence on the local housing market and the local tourism sector by saturating the supply of local accommodation. However, analysis suggests that the current distribution of Bradwell sub-contractors (clustered in accommodation relatively close to the site) is perhaps more of an issue than the absolute supply of accommodation. As such, in the short term, efforts to address the local supply of accommodation should focus on achieving a more even distribution of Bradwell subcontractors within the sub-region. This might be achieved through closer dialogue between the NDA, Maldon District Council and Magnox, and subsequently between Magnox and sub-contractors. A second option which has been suggested to address the local supply of accommodation is the provision of funding to convert several vacant premises locally into accommodation for workers (subsequently reverting to accommodation for residents in housing need). We conclude that this is a less appropriate solution to the*

issue, given the level of investment required, the absence of an appropriate funding stream and the timescales involved (given that sub-contracting activity will all but disappear after 2015)."

Appendix M Actions to support future strategy development

Discussion points and list of potential technical actions to support future strategy development

- Clarify terms and conditions of the DRS lease of the railhead - Stage A;
- Clarify availability of the railhead for use for decommissioning wastes (cranes etc.) - Stage B/C;
- Further site specific analysis of preferred package type for different decommissioning timing scenarios - Stage A;
- A number of plant items requiring improvement on asset management: confirmation of completion of these items prior to C&M entry - Stage B;
- Alignment with Land Quality Strategy and plan, and Areas of Potential Concern - Stage A;
- Clarification of long-term Estuary & Coastal Defence Plans - Stage B;
- No significant further work identified to further refine component inventory, except for correcting for load factors - unlikely to be value-for-money to revisit as-built drawings;
- Opportunities to obtain material samples of good provenance are to be encouraged to add to statistical significance of samples already analysed - long-term. However, it is unlikely to be value-for-money to initiate a re-sampling campaign - as opportunity arises;
- No further work identified to refine neutron flux - unlikely to have better validation than the RPV safety case;
- Further dose measurements to validate the predicted dose rates - as opportunities arise;
- Further samples from bioshield to reduce uncertainties on the calculated activation within the concrete - as opportunities arise; and
- Note that unless a systematic statistically significant sampling programme is carried out, the uncertainties in the activation inventory is likely to remain, however these are unlikely to be significant for strategy development purposes.

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