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Re-defining the Dounreay Site End State

Gate B Paper – Preferred Site End State Option

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Issue 01	04/03/2022	First formal issue to DNSEC and SSC for comment
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EXECUTIVE SUMMARY

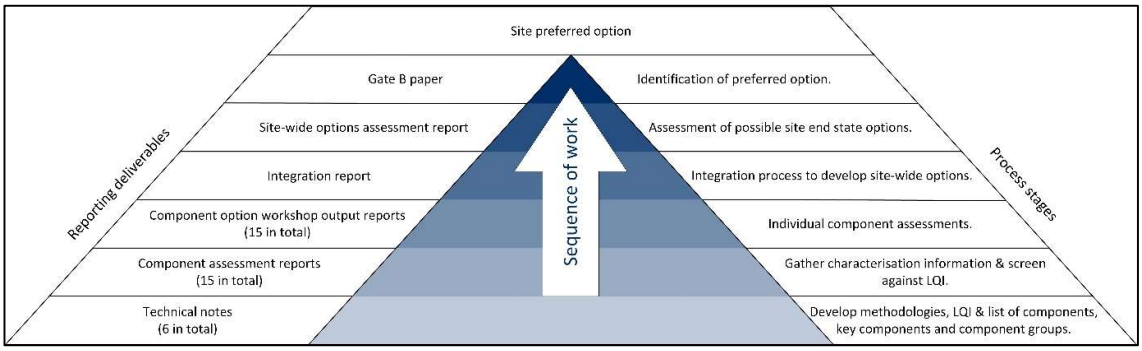
Aim and Scope

The NDA is responsible for the decommissioning and clean-up of the UK's historical nuclear sites and the safe management of the radioactive and non-radioactive waste. DSRL is undertaking this work for NDA at the Dounreay nuclear site in Scotland. The aim of the work at Dounreay is to reach the "site end state" – the condition to which the site (land, structures, etc.) will be taken to at the end of decommissioning and remediation. In turn, the site end state helps inform how the waste and contamination in the ground will need to be managed and the condition and controls which may be in place once all planned work is complete.

The current Dounreay site end state was defined in 2009 [NDA, 2009a]. In 2016 DSRL and NDA initiated a programme of work to review this. A "Gate 0" Paper was produced in 2018 [King, 2018] which highlighted the benefits of reviewing the site end state. The paper recognised that new regulatory guidance provides a clear approach to dispose of building substructures and leave contaminated ground *in-situ*, provided a successful regulatory case can be made. Following this, in 2019 a "Gate A" Paper [King and Proverbio, 2019] set out the credible options for the site end state. A total of four options and two sub-options were developed. These have been used as the basis of work to produce this Gate B Paper. This document summarises the work undertaken, the preferred site end state, key uncertainties and recommended next steps.

Reviewing the Site End State

The review of the end state is founded on best practice and uses the most recent information for Dounreay, including data on waste, contamination, land use and climate projections. It has followed a systematic and structured process, which has been informed by the IAEA 'Definition of Environmental Remediation End State' project, through dialogue with the NDA 'Site Decommissioning and Remediation Theme Overview Group', and the NEA 'Holistic Decision Making on Complex Sites Group'. The process, shown below, is designed to address both regulatory requirements and NDA's needs. The work involved engagement with a range of stakeholders from the site's community, regulators, and those with wider interests, such as local residents.



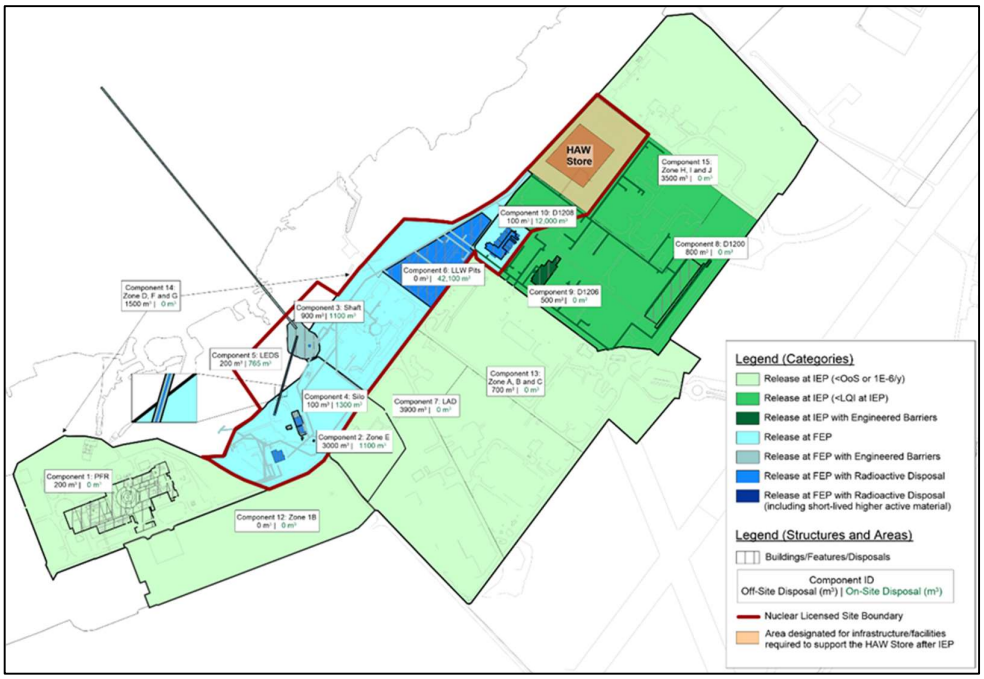
Dounreay has a wide range of facilities and areas of land contamination (radioactive and non-radioactive). In order to make the site more manageable it has been sub-divided, with those facilities or areas of contamination considered to influence the site end state designated as components. Parts of the site deemed to be of particular significance in shaping the overall site end state were defined as "key components" and each 'characterised' through a description of their radiological and non-radiological contamination, potential future use, etc. In addition to making a complex site more manageable, this approach was chosen to simplify the addition of new components should they be identified as data is collected, or in the event that the scope of work changes (for example the potential addition of the Vulcan site to DSRL in the future).

The key components include geographical areas (e.g., “Zone E”), disposal facilities (e.g., the LLW Pits) and plants (e.g., PFR). For each component, a range of potential end state options were considered including removing contamination or managing it *in-situ*, potentially with an extended period of control and/or using engineered barriers. The use of basements and sub-surface voids for disposal for a purpose (backfilling) with slightly radioactive waste was also considered. This could comprise material such as demolition low-level waste where this is appropriate based upon any non-radiological contaminants present. The re-use of non-radioactive waste was not considered explicitly since this is already integrated into the site’s management.

For each end state option, clean-up criteria (“Land Quality Indicators”) were used to estimate how much waste would be generated. This and other information informed a comparison of the options for a range of criteria such as sustainability[1], cost, nuisance and worker safety. The options were then combined to generate self-consistent whole-site strategies. These were presented to stakeholders, with a view to identifying which best addressed their priorities. The findings were used by DSRL to inform its selection of a preferred end state option.

Preferred Site End State

The preferred option involves the remediation of the majority of the site to enable it to be released shortly after decommissioning is complete (areas shown in shades of green, below). In the remainder (areas shown in shades of blue), *in-situ* contamination would remain under control for up to 300 years, during which time it would decay to meet regulatory guidance levels. The area shown in light brown shows the footprint of the Higher Activity Waste Store[2]; HAWS, (which was excluded from the Gate B process but is assumed to share a similar end state to the areas shown in blue). This option was selected as it best fulfils stakeholder’s priorities for restoring the site and has the best balance of benefits and detriments. It delivers the most optimised strategy for the individual components and reduces by three quarters the amount of waste that would otherwise be generated and need to be disposed of off-site.



[1] Sustainability was applied broadly and included economic sustainability, featuring current and future employment opportunities and intergenerational equity, in addition to environmental sustainability which encompassed elements such as resource use, greenhouse gas emissions etc.
[2] The fate of the materials within the HAWS is currently under review, with possible options including nearby disposal or transfer to another suitable site.

	End State of Zones E, F, G and D1208	End State of Rest of the Site
Remediation	Further characterisation decommissioning and remediation. Verify disposals and contamination will achieve the radiological and non-radiological site reference state criteria by the FEP.	Further characterisation and remediation synchronised with decommissioning. Verify GRR criteria met by IEP. Retain beneficial infrastructure needed for future use.
Waste Management	Waste removed from the Shaft and Silo. Waste remains in LLW Pits (subject to regulatory approval) with added engineered barriers. Large voids infilled with slightly radioactive waste, sending the rest to D3100. Non-radioactive waste not suitable for re-use sent to off-site landfill.	Effluent management maintained as required to support decommissioning. Infill large voids with uncontaminated material. In general, radioactive material sent to D3100, non-radioactive waste not suitable for re-use sent to off-site landfill.
Land Use from IEP – FEP	Clean-up to standard allowing release from control at FEP(Zone F could be released at IEP if required). No further remediation work but monitoring and control of the area (extending to Higher Activity Waste store) to gain benefit from *in-situ* decay of residual activity.	Clean-up to standard allowing release from control at IEP. Make case to release from regulatory controls for alternative use, assumed to be industrial.
Remaining services and structures	Clean-up to standard allowing release from control at FEP. Retain services (roads, drains, power, etc.) and buildings required to deliver FEP. Other buildings demolished to floor slab level.	Clean-up to standard allowing release from control at IEP. Where required by site's next users retain and sell as site assets. Retain services such as roads, drains, power, etc. where valuable to future site occupants.

Key Issues

Some significant assumptions and uncertainties have been identified by this work that need to be addressed. The most important are as follows:

- The final site decommissioning and clean-up will be implemented under Proportionate Regulatory Control (PRC) rather than under current regulations. PRC will allow the site to be delicensed through an alternative route than the ONR 'no danger' criterion;
- The end state of the LLW Pits: The characteristics of some historical waste is uncertain, which may make it difficult to demonstrate that it can be managed *in-situ*. The end state for the LLW Pits has the potential to influence end state decisions for other key components, most notably those in close proximity such as D1208. Further work to try to resolve the uncertainties is required;
- The duration of the period of monitoring and control after decommissioning has been completed: The mixture of contaminants present, and their natural rate of decay, determines how much benefit there is in applying a period of control. For some of the site, optimisation may suggest a reduction from the currently assumed 300 years, whilst in areas like the Fuel Cycle Area (FCA), assumed to be suitable for release shortly after decommissioning, a period of control may be added due to the potential benefits it could bring. Additional characterisation to understand the mixture of contaminants across the site, followed by more accurately informed optimisation assessments are required;
- Future Use of the Site: The next use of the site once released from control, together with future uses that could be reasonably foreseen, will influence practical decommissioning decisions such as whether to leave infrastructure in place. Changes in the next use may also drive clean-up targets for some non-radioactive contamination where pollutant linkages have the potential to affect the health of the site's next occupants. By considering what comprise credible foreseeable future uses of the site for both the decommissioning scope and clean-up criteria means that 'unrestricted

release' is not the proposed end state. It would not be optimised to deliver a site that is suitable for a use that will never be realised;

- Capabilities: The work to deliver the end state will require extensive characterisation of suspect contaminated ground and subsurface structures. In addition, areas believed to be clean will be subjected to a detailed desk study and, where appropriate, randomised verification sampling. This, and any required remediation work, needs to be integrated with decommissioning plans.

Implementation

The preferred site end state is recommended for adoption in Dounreay's Lifetime Plan. Details for its implementation will be developed. Key priorities for the next five years include:

- Updating the site's plans and ensuring that the management systems, capabilities, and resources are in place to deliver the site end state;
- Ensuring that work to implement the site end state includes consideration of the principles of the waste hierarchy as part of the decision making process;
- Communicating the site end state and its implications to the decommissioning project teams, regulators, and other stakeholders;
- Where necessary, identifying, tracking, and resolving key issues, including:
    - the inventory uncertainties that may affect the end state of the LLW Pits;
    - Better understanding the mixture of radionuclides and non-radiological contaminants, to optimise the post-decommissioning period of control;
    - Developing the plans for the future use of the site, in particular for those parts that will be released shortly after decommissioning;
    - Establishing and agreeing the process for deciding what contamination can remain *in-situ*, including practical clean-up criteria; and
- Beginning to apply the end state to the site's facilities in practice, building on experience gained so far from pilot projects carried out in Zones 1B and H2. Integration of the end state into the decommissioning process ensures that the facility decommissioning project's plans can take account of the end state.

The review also identified some existing assumptions that would benefit from being tested. The most significant is the retrieval of wastes from the Shaft. This should be confirmed to remain the best strategy, given the potential benefits of *in-situ* management of waste highlighted in this work, and given that near surface disposal of some higher active waste is being considered elsewhere in the UK and complies with Scottish policy. Another assumption to test relates to groundwater contamination. Given its coastal location, groundwater beneath the Dounreay site is affected by the sea and, as such, may not be appropriate for all uses and it may be possible to make a case for exemptions from groundwater regulations under specific circumstances. Finally, there is scope to integrate the end state of adjacent sites, including the neighbouring Vulcan site, into Dounreay's strategy in the future.

An implementation strategy for the Dounreay site end state will be developed to take the findings from this paper and turn these into a programme of prioritised activities.

CONTENTS

1. INTRODUCTION

1.1 The Site End State

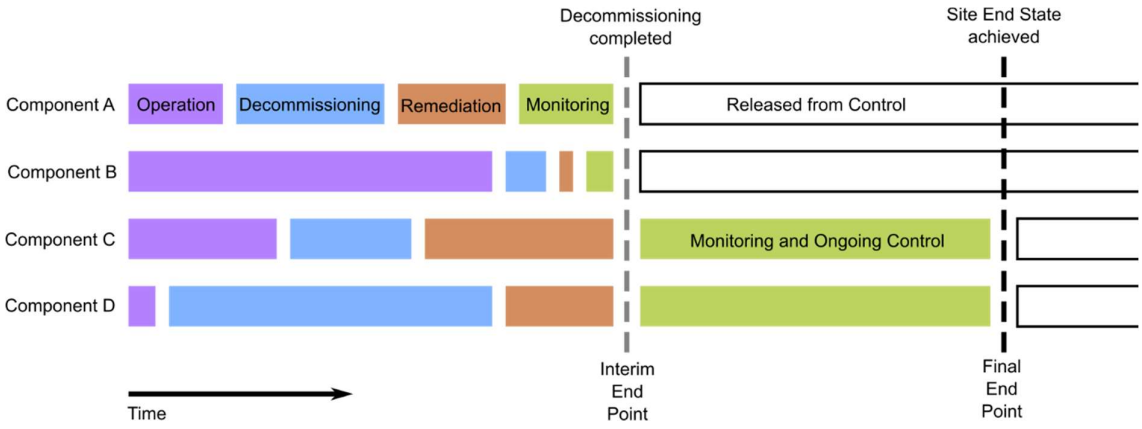
The scope of work that the Nuclear Decommissioning Authority (NDA) is responsible for at Dounreay is to take the site to a condition where it is suitable for its next use and returning it to society, de-designating the site from its current regulatory controls. In addition, NDA is responsible for defining the scope for decommissioning and clean-up in order that Dounreay can reach the “site end state” – a term used to describe the condition to which the site (land, structures, and infrastructure) will be taken to at the end of the decommissioning process. A defining characteristic of the site end state is how the waste and any residual contamination in the ground is safely dealt with and the condition and controls which may be in place once all planned work is complete. Once the site end state has been reached, there may be a period of monitoring and control, before the final ‘site end state[3] is reached such that it may be released from regulatory control. It is assumed that this will take place under Proportionate Regulatory Control (PRC) rather than the ONR’s current ‘no danger’ criterion.

The site reference state is the condition of the site that should allow it to be safely released, for any foreseeable future use, from a radiological substances permit issued under the Environmental Authorisation (Scotland) Regulations 2018 by the Scottish Environment Protection Agency (SEPA). To achieve this, the site must meet, amongst other things, several regulatory requirements as stated or inferred by the ‘Guidance on Requirements for Release from Radioactive Substances Regulation’ (the GRR) [SEPA et al., 2018]. A clearly defined end state that will allow the site to meet the relevant requirements is therefore an essential part of planning and delivering the decommissioning programme.

Figure 1 provides more detail on how Dounreay expects to achieve the site end state. As the site has a range of different facilities, areas of the site will be closed, decommissioned, and remediated at different times, according to the Lifetime Plan. The end of all decommissioning work is designated the Interim End Point (IEP). Beyond this, some parts of the site will remain under passive controls (stewardship, access controls, monitoring, and surveillance). This will be for a planned period of time, during which contaminants will decay to levels that will meet targets in the GRR by the Final End Point (FEP) when the site end state will be achieved. Other parts of the site will be remediated to meet GRR targets at the IEP and would be released for other uses after that point.

[3] SEPA et al. [2018] refer to the "Site Reference State" as the condition of a nuclear site when it is fully compliant with the requirements for release of the site from Radioactive Substances Regulations. For the purposes of this document, the final Site End State is considered equivalent to the Site Reference State.

Figure 1: Activities to Deliver the Site End State and Enable Other Uses of the Site



1.2 Need to review the site end state

Dounreay has an existing site end state definition which was developed in conjunction with the site stakeholders and approved by NDA in 2009 [NDA, 2009a]. Since 2009, plans for the site's decommissioning mission have been progressed and developed, and new information has been gathered. The GRR, published in 2018, gives guidance on the optimisation principles that should be applied when developing the programme of work to reach the site end state. Specifically, the guidance provides the opportunity to consider a broader range of options for the site end state than was considered in 2009.

An end state review has been undertaken to take account of the changes since 2009. The review aims to provide a more detailed site end state definition which will be used as a tool to aid the optimisation of the future decommissioning programme of work. The review has followed a systematic and structured process and has been informed by the International Atomic Energy Authority (IAEA) 'Definition of Environmental Remediation End State' project. It has also been informed by dialogue with the NDA 'Site Decommissioning and Remediation Theme Overview Group', and the Nuclear Energy Agency (NEA) 'Holistic Decision Making on Complex Sites Group'. The work also addresses the regulatory requirements [SEPA et al., 2018] and NDA guidance [NDA, 2016], and meets NDA's expectation that an end state definition shall be progressively refined, developed, and optimised. A list of all the committees and groups that the work to develop the site end state was shared with as the work progressed is shown in Appendix A.

This document is the conclusion of the review of the end state for the Dounreay site [Penfold, 2022]. It summarises the work undertaken, describes the preferred site end state, and highlights the key uncertainties associated with it. The work to be undertaken to resolve the key uncertainties is summarised. Should NDA accept the site end state recommended by this document, an implementation programme based on its findings will be developed.

Several terms and acronyms are used in this document that have a particular meaning; these are given in a glossary at the end of this document.

1.3 Background and Context

The NDA owns the assets and liabilities of 17 nuclear sites across England, Wales, and Scotland. Their mission[4] is to '*deliver safe, sustainable and publicly acceptable solutions to the challenge of nuclear clean-up and waste management*'. The NDA role is strategic; it establishes objectives, allocates budgets, sets targets, and monitors progress. The NDA is

[4] Details from https://www.gov.uk/government/organisations/nuclear-decommissioning-authority/about

responsible for ensuring the decommissioning and clean-up of its sites, and the safe management of all radioactive and non-radioactive waste as it arises and for the long-term.

The site end state is a fundamental part of NDA's expectation for management of a nuclear site since it defines the objective of the decommissioning and clean-up work. This, in turn, enables budgets, schedules and resource requirements to be established for the successful achievement of NDA's mission. The end state is also very important to the site's stakeholders, particularly the local community, and needs to be determined through consultation with them. It provides a clear understanding of what work will be undertaken to make the site safe, and what will be delivered.

The end state is also important to the site's regulators. The Office for Nuclear Regulation (ONR)[5] regulates nuclear and conventional safety, security of the operations, and decommissioning work at nuclear sites including the regulation of land contaminated with radioactivity on such sites. Currently the ONR is responsible for regulation of the site until such time as it has been delicensed (through a demonstration of 'no danger from ionising radiation).

The Scottish Environment Protection Agency (SEPA) regulates the safety of the public and the environment from radionuclides and other contaminants in the environment[6] and in particular is responsible for regulating the management of wastes on or from such sites (radioactive and non-radioactive).

The Highland Council (THC) also has an important role as it applies the planning process, through which development and use of the land is regulated. Different aspects of the site end state will be regulated by SEPA, ONR and THC. The end state sets out the strategy for how all regulatory requirements will be optimised in a sustainable and publicly acceptable manner.

A defining characteristic of the end state is how the waste and contamination on the site is ultimately dealt with in its decommissioning and clean-up, with both ONR and SEPA having key roles in this, with SEPA's role expanding as PRC rolls out. SEPA will need to authorise all the activities concerned with waste management and land contamination and, at the site end state, be satisfied that it can be demonstrated that the site can be released from its radioactive substances regulation (RSR) permit'. The conditions to be satisfied at that point have been published in the GRR in 2018.

1.4 Key Assumptions and Constraints

The work to develop the site end state has been based on several assumptions and constraints. The key assumptions and constraints affect the overall scope of the study and all site end state options considered. These are summarised below.

The key assumptions are:

- The work is based on current information on the condition of the site, recognising there are uncertainties in some areas;
- Further characterisation work will be required to resolve uncertainties associated with land quality and data relating to subsurface structures across the site. It is assumed that this work will not significantly change the volumes of waste generated by implementing the preferred site end state option;
- The current regulatory guidance will continue to apply in the future. However, the site end state will be implemented under Proportionate Regulatory Control (PRC) rather than the ONR 'no danger' criterion;
- The radiological condition of the site end state is assumed to permit any foreseeable future use of the site;

[5] From https://www.onr.org.uk/documents/2014/onr-strategy-2015-2020.pdf
[6] From https://www.sepa.org.uk/about-us/

- The non-radioactive condition of the site is assumed to comprise a standard consistent with the next planned use (currently assumed to be for industrial purposes) and in line with regulatory guidance for receptors such as groundwater;
- Site decommissioning will remove all redundant above-ground infrastructure by the IEP. Retained infrastructure includes that required to ensure the safety and security of the site during monitoring and control, the Higher Activity Waste (HAW) store, and any demonstrated as a beneficial asset to the next use. All remaining infrastructure will be remediated to a safe state;
- Finances, resources, and skills will be available as required to implement the preferred option; and
- The waste present in the Shaft will be retrieved, packaged, and placed in the HAW Store pending a decision on its final disposal.

The key constraints applicable to the proposed end state solution are:

- It must be legally compliant;
- It is applicable to the authorised site;
- It should be consistent with elements of the Lifetime Plan already accomplished;
- DSRL should be able to demonstrate that optimisation has been applied to the site end state strategy;
- It should align with the anticipated requirements of the proportionate regulation (PRC) of decommissioning nuclear sites;
- It should align with NDA strategy and other NDA guidance;
- DSRL should be able to demonstrate that the site end state is safe and sustainably delivered; and
- DSRL should be able to demonstrate that the work required to reach the site end state represents good 'value' for taxpayers.

1.5 Work Done to Date

The site end state defined in 2009 was based on work led by the Dounreay Stakeholder Group (DSG). The preference was for a "restored site with early release of land" [DSG, 2007]. DSRL developed a plan to deliver this, within the context of the regulations and guidance available at the time. Since then the GRR has been published. This places emphasis on an optimised approach, which SEPA defines as seeking to "keep the radiation exposure of people as low as possible, while ensuring that the costs and other detriments of doing so are not disproportionate" [SEPA et al., 2018].

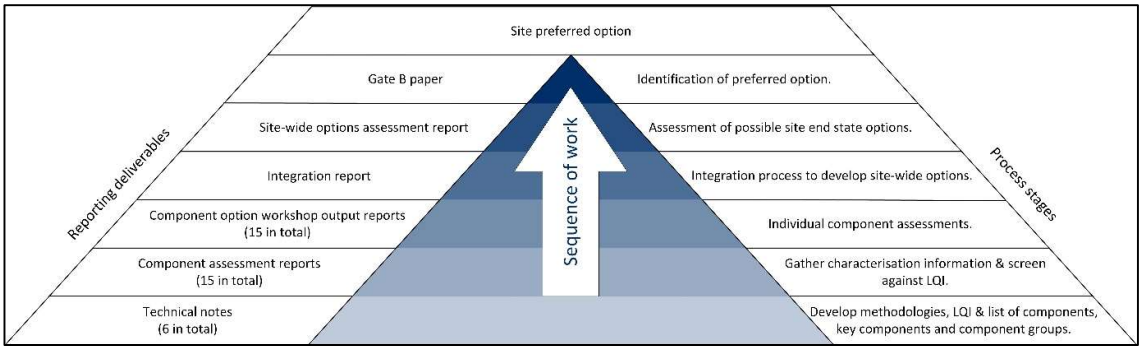
By applying the guidance there are opportunities to leave some radioactively contaminated ground and structures below the surface, provided it can be demonstrated that the process of optimisation has been applied and that people and the environment will be protected. In doing so there is the opportunity to consider a more sustainable approach to decommissioning and clean-up which avoids unnecessary generation of waste and waste movements. It provides the opportunity for slightly radioactive waste, such as that generated from demolishing buildings, to be reused on the site (for example, to fill voids) rather than being sent for disposal elsewhere and other materials being imported to site. (Note that any such reuse would only take place if this were shown to be the optimal use of the waste, ensuring that people and the environment are protected and subject to appropriate authorisation).

The NDA has asked DSRL to undertake an "unconstrained" review of the site end state and to identify a set of credible strategic options, compare them, taking account of stakeholders' views, and to identify the optimised site end state. The review follows NDA's "Gate" process for strategy development [NDA, 2009b]. The first stage (Gate 0) was completed in 2018 and sets out the "case for change", highlighting the potential benefits that could result from reviewing the existing strategy. Gate A then involved an unconstrained review which identified a long list of options. These were filtered down to four credible options, with two sub-options. This was completed in 2019 and the credible options have been carried into this, the Gate B stage of the work.

2. APPROACH USED TO IDENTIFY THE PREFERRED OPTION

The work to identify the preferred site end state has been done in discrete phases. At each phase, documents have been produced to capture the key outcomes and to provide an auditable trail which demonstrates how the preferred option has been arrived at. The key process stages are illustrated on the right of Figure 2, with the associated key deliverables produced shown on the left of the figure. A list of all key documents produced is provided in Appendix B.

Figure 2: Process and document outputs contributing to this Gate B paper



The main aspects of the approach followed are summarised below.

2.1 Site Components

To simplify the process of determining a preferred site end state and to make the options study more manageable, the site was considered in terms of 'components' [Lansdell et al., 2020]. These are facilities or areas of the site whose individual end state would have an *influence* on the overall site end state. The list of components was analysed, and a sub-set of 'key components' was identified. These key components were defined as facilities or areas whose individual end state would *impact* the overall site end state (i.e. the end state of each of the individual key components would have the potential to drive the overall site end state decision).

The key components were selected by considering several factors including their physical size, the amount and extent of any contamination present, and the presence of any underground voids or structures. The groundwater beneath the site was treated as a single key component due to the characteristics of the diffuse contamination associated with it. A total of eleven key components were identified, and end state options were assessed for each one.

To ensure that the influence of the remaining site components was also considered, four areas termed 'balance of site' were identified. An options assessment was also carried out for each of the balance of site areas, to ensure that the whole of the site was considered as part of the process.

The key components and balance of site areas are shown in Table 1 and Figure 3.

Table 1: Key Components Considered in the Development of the Site End State Options

Key Component	Description
PFR	Prototype Fast Reactor complex, located in Zone D
Zone E	Liquid Effluent Treatment facilities and historical ground contamination
Shaft	Historical disposal facility for around 800 m^3 of ILW, located in Zone F
Silo	Historical store for ILW, located in Zone E
LEDS	Liquid Effluent Discharge System, pipework and associated structures leading from Zone E under the seabed for approximately 600 m
LLW Pits	Historical disposal facility authorised for around 30,000 m^3 of LLW, located in Zone G
LAD	Low Active Drain network, serving a wide range of facilities on site
D1200	Active laboratory complex, located in the southeast of Zone J
D1206	Reprocessing plant, located in the middle of Zone J
D1208	High-active liquid waste storage facility which includes sub-surface effluent storage tanks, located in the northwest of Zone J
Groundwater	Water present beneath the licensed site

Figure 3: Key Components and Component Groups (considered in the site end state review

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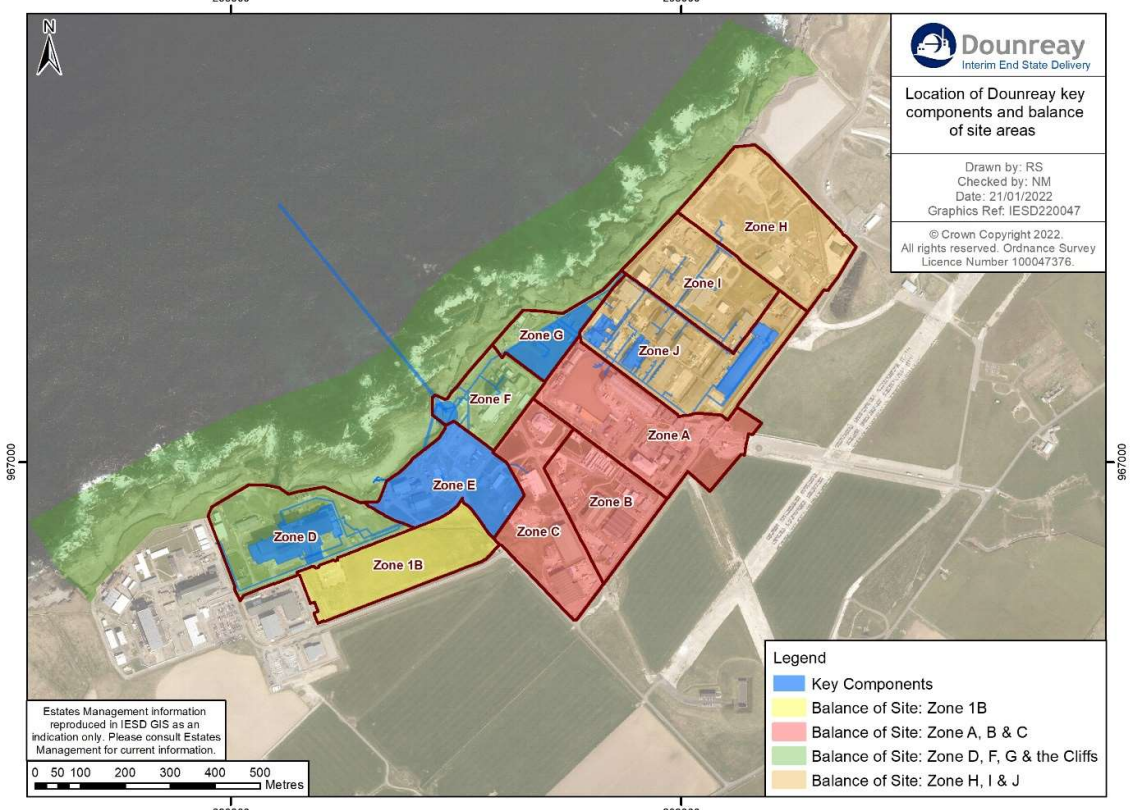

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2.2 Land Quality Indicators

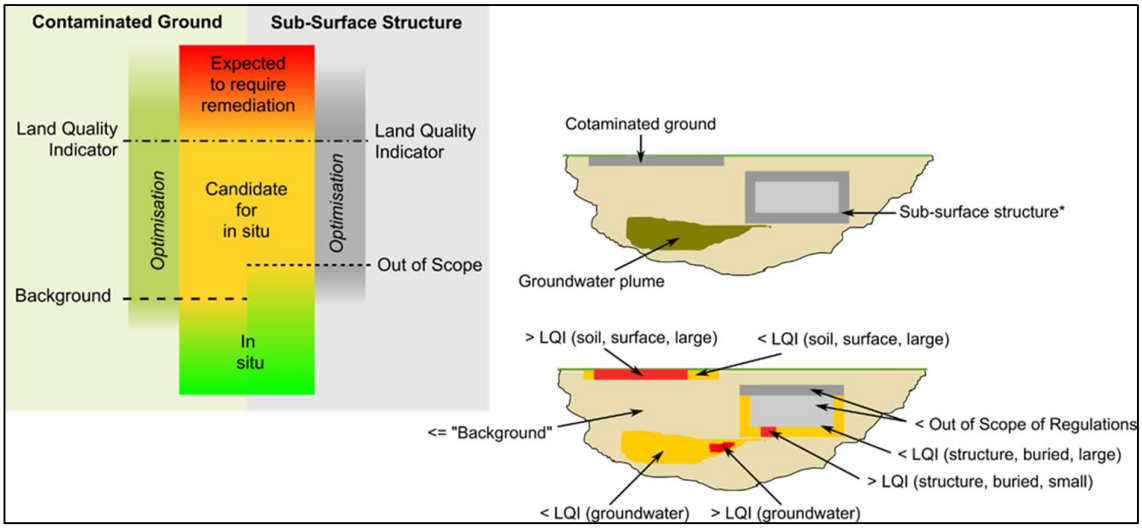
Once the key components and balance of site areas had been defined, the next step was to undertake an assessment of the characterisation data available for each, with the aim of establishing the extent to which *in-situ* management of some ground or structures may, in principle, be appropriate.

To simplify this process guideline values, termed Land Quality Indicators (LQIs), were established [Dowle and Penfold, 2020]. The LQIs were developed, based on published values and existing work, for radioactive material, non-radioactive material, and groundwater. They are defined contaminant concentration values intended to be used as a coarse indicator along with detailed monitoring and characterisation information to estimate the amount of material associated with each component that:

- is expected to require some remediation (exceeds the LQI);
- could be a candidate for management *in-situ* without requiring remediation (below the LQI).

Figure 4 illustrates the principles associated with LQIs and shows a cross-section of their application for a hypothetical area of the site.

Figure 4: Illustration of the application of LQIs



2.3 Generic end state options for components

Once the key components and balance of site areas were assessed against the LQIs, the next step was to determine the possible end states that could be applied to each. To aid this process a set of generic end state options were developed [Paulley, 2020], based on the options described in the GRR [SEPA et al., 2018], and included:

- No action (contamination is, or will become, out-of-scope of radiological substances regulations or compliant with applicable non-radiological criteria);
- Disposal of waste or leaving contamination *in-situ*;
- Disposal of waste or leaving contamination *in-situ* with an engineered closure;
- Disposal of waste for a purpose, within an existing void or structure;
- Removal and transfer off-site for disposal.

Similar generic options for contamination in groundwater were also developed. In some instances, it was deemed appropriate to apply a mixture of options to a given component.

2.4 Assessment of component end state options

An individual set of credible end state options was developed for each of the eleven key components and four balance of site areas. These end state options were developed based on the available characterisation data for each key component/balance of site area, comparison of this data with the LQIs, and the generic options.

Fifteen separate workshops were undertaken for each of the key components and the balance of site areas in turn. Workshop participants included DSRL staff and members of the Project Team, and included subject matter experts, and persons responsible for the key component/balance of site area being assessed.

The approach at each workshop involved assessing the main pros and cons of the credible options against a set of criteria developed from the NDA Value Framework [Cairns et al., 2020]. The aim of each workshop was to clarify which end state options were relevant and proportionate and what the positive and negative aspects of each was. The Value Framework criteria applied at each workshop are shown in Table 2.

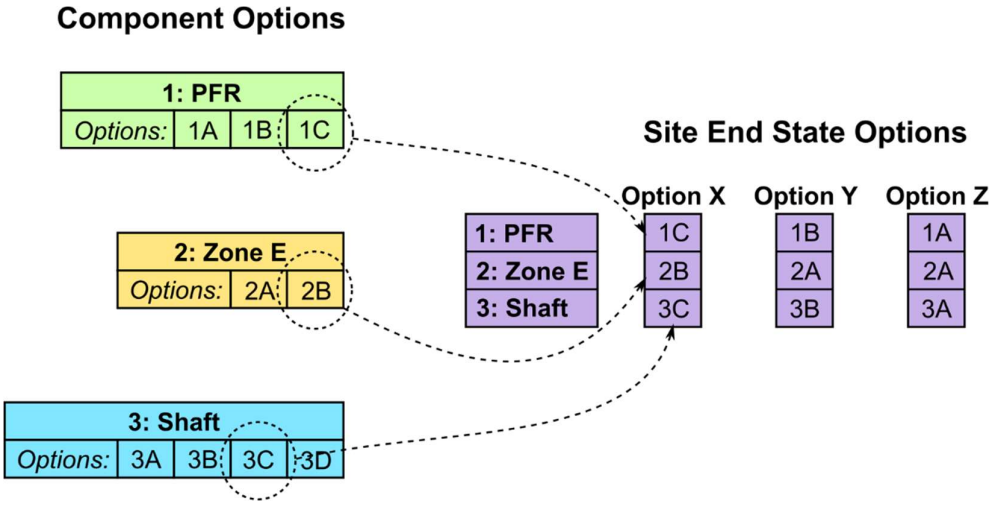
Table 2: Selected "Value Framework" Criteria used to Assess the End State Options

Workers – radioactive	Materials	Costs
Workers – non-radioactive	Environmental sustainability	Resources
Public – radioactive	Water environment	Technology
Public – non-radioactive	Radioactive risk reduction	Regulation / robustness
Nuisance		

2.5 Integration

The integration stage involved taking the credible options for each of the eleven key components and the four balance of site areas and assembling them in different ways to 'build' each site end state option [Penfold and Cairns, 2022]. The integration process is illustrated in Figure 5.

Figure 5: "Integration" – selecting options for each component that will deliver different end state strategies



Following the integration work a final list of site end state options was arrived at. A summary of the key characteristics for each option is provided in section 3.2, with further details in Appendix C. Detailed information for each is provided in the Options Assessment Report [Penfold, 2022].

The next stage involved working through the list of generated site end state options with stakeholders to establish their priorities for the restoration of the Dounreay site, and to examine how well the site end state options deliver them. This information was used to identify a preferred option, which is being recommended to NDA in this paper. This stage is described in the next section.

3. ASSESSMENT OF SITE END STATE OPTIONS

3.1 Site End State Workshop

A workshop was undertaken in October 2021 to evaluate the developed options with the aim of identifying a preferred site end state. A key element of the workshop was the involvement and input of a range of stakeholders whose interests could be affected by the chosen site end state.

The workshop process involved presenting each of the site end state options in turn and capturing stakeholder feedback on how they aligned with their views. This included capturing their views on their priorities with respect to what should be achieved by the site end state. Desirable outcomes of both the process of delivering the site end state (e.g., minimising wastes to be disposed of off-site) as well as what would be delivered (e.g., the resulting land quality and time at which it would become freely accessible) were discussed. Implicit in this process was a recognition that there was often a trade-off between positive and negative outcomes. For example, the site end state could be delivered quickly with the attendant socio-economic benefits, but this would inevitably lead to more waste, cost, exposure of workers to radiological and non-radiological hazards, etc.

In terms of stakeholder priorities, the first important point reached was that all site end state options needed to meet safety and environmental protection standards. The other main priorities identified by stakeholders during discussions were:

- Environmental sustainability (e.g., pollution prevention or minimisation, minimise emissions (including greenhouse gases), encourage biodiversity, etc.);
- Minimisation of risks to people (e.g., resulting from an accident or unanticipated conditions);
- Minimisation of natural resource usage (e.g., energy, raw materials, water, etc.);
- Minimisation of waste (i.e., application of the Waste Management Hierarchy); and
- Maximisation of future use opportunities for the site and its community both in terms of future land use and the development of key skills and the provision of local employment.

It was also noted that it is essential that there is the capability for DSRL to be able to successfully implement the option.

Although it was recognised that no single option is likely to fully meet all the priorities of all the stakeholders, the discussions helped to highlight the trade-offs stakeholders considered to be reasonable to provide an overall “best” outcome. Together, these priorities will tend to favour site end state options that could enable early release of parts of the site in a form that would be suitable for a broad range of economically and environmentally beneficial uses. The priorities also favour options involving the generation of less waste and less use of imported material for the restoration of the site (i.e., the smallest materials balance). In relation to environmental and safety factors, the view was all options would be undertaken in line with the required regulatory framework.

3.2 Summary of Presented Options

The following options were presented at the stakeholder workshop for discussion:

- Option D
    - Aligns with the current site strategy
    - Assumes ground and structures would be remediated to a level that would pose a health risk of less than 1 in a million even in unlikely circumstances
    - Certainty of the condition of the land at IEP, making it relatively straightforward to make the case for land to be released
    - Potential to release most of the site at IEP except Zones E, F and G. Does not involve removal of contamination at depth and in rock
    - Generates approximately 64,600 m^3 of waste for offsite disposal to D3100 (LLW) and landfill (non-radioactive waste)
    - Costly, with lots of nuisance and disturbance

- Option D Variant
  - Variant to deliver more clean-up in Zones E, F and G
  - Would involve extensive excavations to remove very low levels of contamination at depth and dispersed in the ground
  - Enables the whole of the site to be released at the IEP
  - Generates approximately 103,000m3 of waste for offsite disposal to D3100 (LLW) and landfill (non-radioactive waste)
  - More costly, with more nuisance and disturbance than Option D
- Option F
  - Involves *in-situ* management of contamination where a robust Environmental Safety Case (ESC) can be made. Clean-up targets based on GRR criteria, with optimisation applied
  - Would facilitate release of Zones A, B, C, 1B, potentially Zone D and a south-eastern part of Zone E, at IEP
  - Assumes that a case could be made for the LLW Pits to remain *in-situ*, with additional engineered barriers
  - Requires good understanding of potentially contaminated ground and structures across the site. May be uncertainties to deal with when making the case, due to limits on the ability to characterise contamination in the ground
  - Generates approximately 12,900 m^3 of waste for offsite disposal to D3100 (LLW) and landfill (non-rad waste), with 22,100 m^3 of waste for on-site disposal (volume that could be used for slightly radioactive demolition wastes)
- Option F Variant 1
  - Involves applying the principles of Option F, but with the application of some additional clean-up work focussed on Zone D and a large area of the FCA (Zones I and J)
  - Would facilitate release of Zones A, B, C, 1B, potentially Zone D, H, and a south-eastern part of Zone E, and large parts of the FCA (Zones I and J) at IEP
  - Assumes that a case could be made for the LLW Pits to remain *in-situ*, with additional engineered barriers
  - Requires good understanding of potentially contaminated ground and structures, with more material likely to require removal (particularly in the FCA) and so greater waste volumes
  - Generates approximately 15,400 m^3 of waste for offsite disposal to D3100 (LLW) and landfill (non-radioactive waste), with 15,500 m^3 of waste for on-site disposal (volume that could be used for slightly radioactive demolition wastes)
- Option F Variant 2
  - Involves applying the principles of Option F, but with more emphasis on placing engineered barriers around contamination to facilitate its management *in-situ*, further reducing the volumes of waste requiring disposal elsewhere
  - Would facilitate release of Zones 1B, A, B, C and potentially Zone H, at IEP
  - Requires good understanding of potentially contaminated ground and structures
  - Installation of engineered barriers may be technically challenging in places
  - Generates approximately 11,000 m^3 of waste for offsite disposal to D3100 (LLW) and landfill (non-radioactive waste), with 22,100 m^3 of waste for on-site disposal (volume that could be used for slightly radioactive demolition wastes)
- Option H
  - Involves maintaining the current Nuclear Site Licenced site boundary until the FEP. Keeping controls over the whole site up to the FEP could reduce the

amount of ground requiring excavation, by enabling more areas to benefit from radioactive decay
  - Requires good understanding of potentially contaminated ground and structures to make case to manage *in-situ* until FEP
  - No areas of the site would be released before FEP
  - Generates approximately 9,900m3 of waste for offsite disposal to D3100 (LLW) and landfill (non-radioactive waste), with 22,100 m^3 of waste for on-site disposal (volume that could be used for slightly radioactive demolition wastes)

- Option J
  - This is an extension of Option F that examines the potential for managing some short-lived higher activity contaminated material *in-situ*, provided it could still be shown to meet safety targets by the FEP
  - Key facilities where this strategy may be beneficial are the empty D1208 high-active liquor tanks and potentially the Shaft wastes
  - Potential technical challenges associated with making the case for the higher activity waste
  - Would facilitate release of Zones 1B, A, B, C and H, at IEP
  - Generates approximately 9,700m3 of waste for offsite disposal to D3100 (LLW) and landfill (non-rad waste), with 9,000 m^3 of waste for on-site disposal (volume that could be used for slightly radioactive demolition wastes)

3.3 Options Assessment

The sections below summarise the stakeholder discussions in relation to their identified main priorities. A more detailed narrative is presented in the Site Wide Options Assessment Report [Penfold, 2022].

3.3.1 Sustainability

Sustainability is the principle of meeting the needs of the present generation without compromising the ability of future generations to meet their own needs [NDA, 2021]. Sustainability can be measured in terms of when land is finally released for alternative uses and, in the intervening time, the responsibilities placed on future generations to manage the site.

The site end state option that best addressed sustainability in terms of releasing the site back to the community is the variant of Option D. This option could release the whole of the site shortly after decommissioning was completed. However, this would involve a very large amount of excavation work and would generate a very large amount of waste, thus failing to deliver other priorities. The other options offer varying degrees of balance between the amount of work involved and the social and environmental benefits associated with the early release of parts of site. Option F *(in-situ* management of radioactivity and early release) has the most nuanced approach of balancing the amount of excavation work undertaken with the benefits that can be accrued by maximising the area of site available for early release. Option F (Variant 1) would release the most land early and would also generate a much smaller amount of waste than other options that could achieve this.

3.3.2 Risks to People and the Environment

All site end state options will have to be shown to meet regulatory guidance levels for environmental safety. The differentiator is the risks associated with the way the contamination is managed – whether it is excavated or managed *in-situ*. For contamination that is removed, the risks are to workers and local residents, in the present-day and disturbing the material introduces a potential risk of contamination spread and consequential harm in the event of an

incident or fault. If contamination is managed *in-situ* the risks are to future users of the site and to environmental receptors that may be impacted after practicable mitigation measures are employed (such as the loss of groundwater resource between the site and the coast).

Risks from the removal of contamination are likely to be dominated by industrial accident risks, transport, and radiation exposures of workers. Risks from *in-situ* contamination are most likely to be dominated by the risk of accidentally unearthing contamination or through human exposure should the contamination be subject to erosion in the future (e.g., resulting in contamination presented on a future beach). Present-day risks from waste management can be managed and controlled but will increase with the amount of excavation and volumes of materials to be managed. Consequently, provided *in-situ* management meets environmental standards, minimising the work to remove contamination is preferable. Option D (the existing end state strategy) involves a much larger scope of physical work than others (five to six times more waste is generated) and so is least attractive on this measure. There is less difference between other options, and so less distinction in terms of risk.

3.3.3 Future Use Opportunities

All options will lead to the whole site being released from RSR controls for other uses after a period of monitoring and control, which could last up to 300 years. The distinction between the options is therefore the amount of land released earlier (shortly after decommissioning is completed) and the condition of the land that is released. As noted, one option would enable the whole site to be repurposed shortly after decommissioning but would involve great cost, both financially and in terms of waste generated.

Option D and Option F (Variant 1) are the most favourable in terms of releasing large areas of the site early. Option D would have the least constraints on future use but would involve the greatest disruption of the ground by widespread excavations requiring substantial landscaping to reinstate the ground condition to enable its use. Option F (Variant 1) would have some constraints on land use where *in-situ* contamination is capped, but efforts would be made to keep capping to a minimum, to maximise the use of land released in these areas.

3.3.4 Resources and Jobs

In relation to employment opportunities, work to excavate contamination and prepare it for disposal will largely involve conventional skills. Earthmoving will be mechanised but may still involve a considerable number of workers as large volumes are involved and imported resources would be needed for landscaping. If there are larger amounts of radioactive waste than currently planned for, then there will also need to be additional construction work at D3100 to accommodate its disposal. *In-situ* management of contamination will require sampling and surveying skills to demonstrate contamination meets radiological and non-radiological targets. It will also involve some specialist construction work if engineered barriers are required. DSRL already has these capabilities, but the scope of work would be likely to be increased and may be more demanding. There may therefore be opportunities for investment and innovation.

The largest use of resources is associated with Option D and its variant. The least resource use is likely to be associated with Option H, where the whole site remains under control for up to 300 years; this involves the least amount of clean-up work. Options F (including its variants) and Option J would both require more technically skilled employment to characterise the site and make arguments for regulatory submissions for *in-situ* contamination. These are the most attractive options from the perspective of resources and jobs.

3.3.5 Waste Management Hierarchy

The volume of waste that would be generated by each of the site end state options has been estimated in this study, based on currently available information. Options that involve keeping the largest area of site under control will minimise the amount of waste most effectively, mainly

through making most use of radioactive decay to reduce the risks associated with contamination thereby avoiding the need to excavate it as waste. However, this strategy is only effective where short-lived (with a half-life of approximately 30 years or less) radionuclides dominate risks. Consequently, selective control of some parts of the site, with some removal of waste from the rest of the site, would allow the majority of the site to be released shortly after decommissioning without greatly increasing the waste volumes. The biggest impact on waste volumes would be the retrieval of the LLW Pits, which is estimated to generate an additional 30,000 m^3 of waste, which would require repackaging and disposal. For this reason, Option D would lead to significantly larger amounts of waste than other options.

3.3.6 Implementability

Well-established land remediation techniques are most implementable, and most of the equipment required is readily available. It would be relatively straightforward to make the case to regulators for strategies that extensively use established techniques to allow the land to be released from control by removing contamination down to very low levels, such as Option D. The biggest challenge, however, is likely to be the retrieval of the waste in the LLW Pits, which would involve managing worker risk and the resulting waste and discharges.

Option F and its variants differ by relying more on comprehensive site characterisation data to show that much of the contamination can be safely managed *in-situ*. Where there is some uncertainty in the implementation of such an approach, engineered barriers and caps could be applied (although planning and design work would be required) or the particular area of contamination could be removed as a precautionary action. The most challenging approach, in terms of implementation, would be to manage short-lived higher active material *in-situ*, mainly because it may be difficult to make the case to regulators.

3.4 The Preferred Option

The preferred option is that which best satisfies the principles of optimisation and the use of Best Practicable Means (BPM). The GRR [SEPA et al., 2018] states that the optimisation of waste management options on a decommissioning nuclear site must balance many considerations including worker safety, waste generation, environmental effects, use of resources, best practice and public acceptance. The purpose of this study has been to reveal how credible site end state options compare on these terms, to enable the balance that best fulfils the priorities for restoring the site to be identified.

Overall, Option F and its variants are most balanced, performing relatively well for all priorities. The options involve targeted action to deal with contamination based on more characterisation of the ground and structures. Where the risks can confidently be shown to be lower than the GRR's guidance levels the contamination would be managed *in-situ*, unless there are other factors such as practicality, impacts on other facilities, or wider objectives for the site (such as a desire to release land from control without an extended period of monitoring and control).

Option F (Variant 1) offers the greatest benefits and fewest disbenefits. This would involve more effort to release land from control shortly after decommissioning (enhancing land use and socio-economic benefits) at the expense of additional clean-up work in the FCA and not using the PFR voids for disposal of slightly radioactive waste (as otherwise assumed for Option F). The option is shown in Figure 6 with a summary of key characteristics in Table 3.

Figure 6: The Preferred Option – In-situ Management of Radioactivity and Early Release

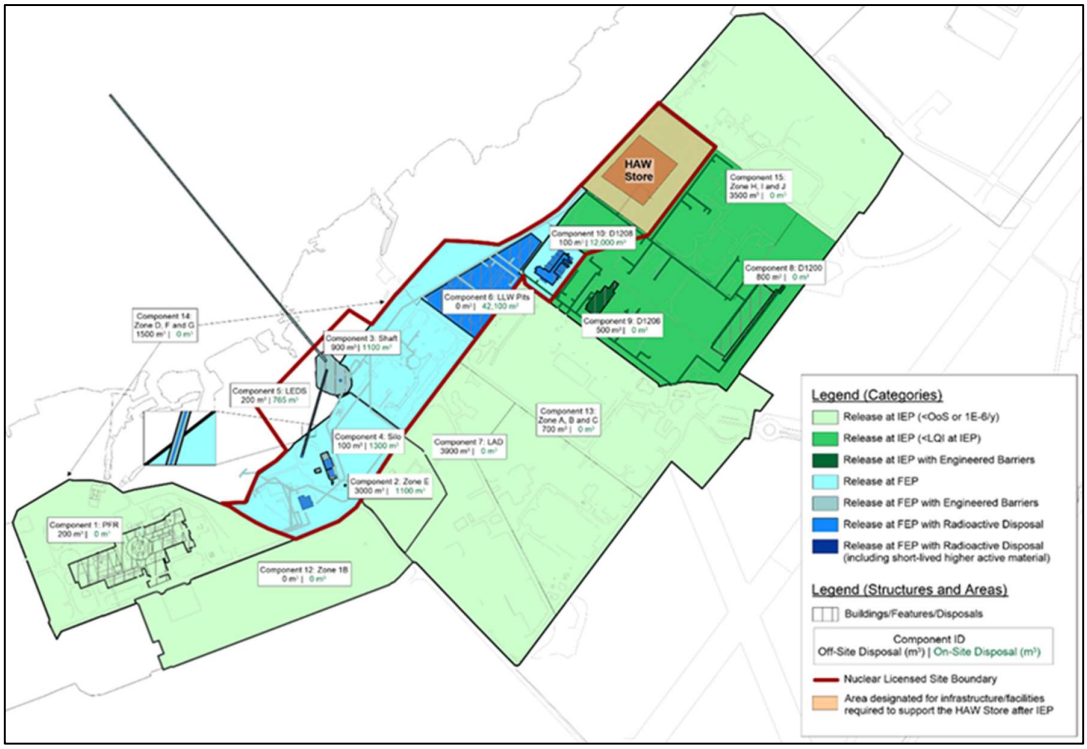


Table 3: Key Characteristics of Option F (Variant 1) (More Early Release)[7]

Waste Volume	Off-site* disposal: 15,700 m^3	On-site disposal*: 16,800 m^3
Advantages	Focuses the use of *in-situ* management of contamination and on-site disposals on those areas that most benefit from decay *in-situ* and are not located around the perimeter of the site. Some extra remedial work in areas such as the FCA will enable their release at the IEP. Opportunity for Dounreay to act as a 'lead and learn' site for other nuclear sites in the UK and worldwide.	
Disadvantages	Requires good understanding of potentially contaminated ground and structures. Will also require considerable innovative technical work to make the case for leaving contamination *in-situ*. Specialist resources required by all parties to deliver this option. May involve use of some engineered barriers (e.g., caps) to build confidence in the safety of areas subject to early release.	
Early release	Potential to release all of the site except for Zones E, F, G and a small part of the FCA, subject to detailed characterisation and decisions on strategy.	
Comments	Where measurement uncertainties mean that it is difficult to make an *in-situ* case precautionary excavation may be needed. *In-situ* management is less applicable where alpha contamination dominates.	

Note: * Wastes from land restoration only. Wastes for "Off-site" disposal be sent to Dounreay's D3100 disposal facility and some to landfill. "On-site" disposal would be for backfilling voids, subject to permitting by SEPA.

[7] Volumes may differ slightly from those within the source material due to rounding differences and ongoing data collection.

More details on the implementation of Option F (Variant 1) for key components and a breakdown of the waste volumes from each are shown in Table 4. Option F (Variant 1) is most closely aligned with the optimal end state strategy for each of the individual key components and therefore best reflects the optimisation requirements of the GRR. This approach has the potential to deliver benefits in terms of sustainability and future use opportunities (by releasing some land early) without incurring substantial amounts of physical works (with the associated risks to workers, resource use and other impacts) and the resulting waste. However, there is a degree of reliance on the capabilities to characterise and measure contamination in the ground. If it is difficult to adequately characterise contamination in the ground there may be a need for precautionary action to excavate greater volumes of material (i.e., leading to a similar approach to the site end state as assumed for Option D).

The most important site key component from the perspective of making the case for *in-situ* management is the LLW Pits. An options study [Kirkby et al., 2021] and provisional ESC [Wilmot et al., 2015] indicate that the optimal strategy is *in-situ* management and that a case could be made, but further work will be required to confirm this. Even if it were concluded to be necessary to retrieve the waste from the LLW Pits, the Option F (Variant 1) approach could still be applied at other parts of the site.

Table 4: Description of the Implications for Key Components of the Preferred End State

Component	Description	Off-site disposal* (m^3)	On-site disposal* (m^3)
PFR	Contaminated structures and ground surveyed, removed, and sentenced. Limited radiological contamination – hydrocarbons are the main issue. Radiological contamination remediated to meet GRR targets early. Infill voids with clean material. Make case for release from control shortly after the end of decommissioning.	200	0
Zone E	Contaminated structures and ground surveyed and characterised. Remediate to enable pumping schemes to cease operations by the end of decommissioning. Calculate local targets to meet GRR criteria by the end of a period of control of up to 300 years. Utilise voids for some slightly radioactive demolition waste. Monitor and limit access for a period of control, then release.	3000	1100
Shaft	Finalise Shaft retrievals plans. Retrieve wastes, surveying contamination levels when Shaft emptied. Apply simple remediation to inner surface, backfill with slightly radioactive demolition waste and seal. Monitor groundwater and limit access for a period of control, then release.	900	1000
Silo	Remove Silo waste, monitor internally and decontaminate. Backfill with slightly radioactive demolition waste. No anticipated ground contamination. Timing may need coordination with other work in Zone E. Monitor and limit access for a period of control, then release.	100	1900
Liquid Effluent Discharge System	Working around effluent management requirements, survey and remediate upper sections to meet GRR criteria by the end of the period of control. For deeper sections, survey and grout pipes. Backfill the adit with slightly radioactive demolition waste and seal. Remove structures from the seabed. Monitor and limit access for a period of control, then release.	200	800

Component	Description	Off-site disposal* (m^3)	On-site disposal* (m^3)
LLW Pits and Zone G	Survey LLW Pits and develop closure engineering scheme. Implement engineered barriers (walls, cap). Characterise and monitor surrounding ground. Remediate the ground to reach GRR targets by the end of a period of monitoring and control. Monitor and limit access for the control period, then release. Since this does not represent new backfilling, the onsite disposal volume is 0 m^3.	0	0
Low Active Drain	Characterise LAD and identify sections requiring removal. Contaminated sections in Zones E, F and G managed *in-situ* to the FEP, but remediate sections in zones to meet GRR targets at the IEP. When effluent system is no longer needed to support decommissioning remove new LAD then remove any sections of old LAD identified as exceeding GRR targets at the end of decommissioning.	4700	0
Fuel Cycle Area (except D1208)	Contamination mainly dominated by long-lived contamination assumed to be present. Survey and remove as necessary to meet GRR targets by the end of decommissioning and release from control then.	1300	0
10: D1208 Effluent Tanks	Survey tanks and determine if they can be disposed of *in-situ* to meet GRR criteria after a period of monitoring and control. (If not, dismantle and remove.) Backfill with slightly radioactive demolition waste. Monitor and limit access for the control period, then release.	100	12000
12: Zone 1B	Further monitoring and site controls to manage any current or future contamination issues. Make case for release from control shortly after the end of decommissioning.	0	0
All other zones	Ground and subsurface structures not expected to be substantially contaminated. Survey and characterise. Remediate to meet GRR targets at the IEP. Schedule work around site activities. Make case for release from control shortly after the end of decommissioning although may retain control of Zone F due to its location between Zones E and G.	5200	0
Total		**15,700**	**16,800**

Note: * Wastes from land restoration only. Wastes for "Off-site" disposal be sent to Dounreay's D3100 disposal facility and some to landfill. "On-site" disposal would be for backfilling voids, subject to permitting by SEPA.

Based on these arguments, Option F (Variant 1) is considered to be the preferred site end state option for Dounreay. The approach summarised in Table 4 will require further development to integrate into decommissioning plans and to reflect the approach for specific areas of contamination and sub-surface structures. There are uncertainties in the extent and level of contamination in the ground that will need to be systematically reduced in an iterative way. This will require a progressive programme of characterisation and risk assessment for the specific areas of contamination and sub-surface structures. Where the uncertainties can be reduced sufficiently, a risk-based case will be developed for *in-situ* contamination and material that cannot meet risk targets would be removed. Where the uncertainties cannot be sufficiently reduced DSRL may need to adopt a precautionary approach and remediate the suspect ground.

3.5 Key Issues

3.5.1 The End State of the LLW Pits

As noted in the previous section, one of the most significant decisions in the site end state study concerns the future management of the waste in the LLW Pits. The preferred site end state option is for the waste to remain *in-situ*, but it has been recognised that there is significant uncertainty as to whether an ESC can be substantiated for this approach. DSRL has commissioned a provisional ESC and supporting studies [Wilmot et al., 2015] which indicated that a case could be made. However, this work has highlighted some key issues that need to be addressed. If these cannot be resolved to the satisfaction of DSRL, the regulators and other stakeholders, the waste will be removed.

A key uncertainty is the inventory of waste that has been consigned to the facility. The inventory analysis previously undertaken for the LLW Pits Complex [Baldwin and Smith, 2015] indicates that the bulk waste is LLW, although it is recognised that there may be a small amount of waste with higher specific activity. It is also recognised that there is a level of uncertainty around the exact inventory due to the varying quality of disposal records across the lifetime of the LLW Pits facility. It was also known that large amounts of material with little or no contamination were added to the LLW Pits as it was deemed to be “suspect” contaminated waste.

There are other uncertainties that affect the ESC relating to the understanding of the environment in which the wastes have been disposed. Of these, the most important relates to the potential for coastal erosion to affect the LLW Pits. The phenomenon is well known at Dounreay, with evidence of erosion being clear in the coastline. However, there are uncertainties in the rate of erosion, which varies according to the strength of the rock and other factors. These factors could affect the timing that erosion starts to affect the LLW Pits, which is particularly important in relation to shorter-lived wastes in the facility. There is ongoing work to better understand the effect of coastal erosion at the Dounreay site.

Finally, the closure engineering that would be installed around the LLW Pits will be a significant benefit to its long-term safety but at this stage only high-level concept designs for the engineering have been developed [Kirkby et al., 2021]. The existing provisional ESC cautiously assumed there was minimal closure engineering, but a recent options study [Kirkby et al., 2021] showed that the preferred option was closure with the wastes *in-situ* and the addition of a cut-off wall surrounding the facility and an engineered cap. These features would provide additional containment and isolation of the wastes, and there is also the scope for some form of engineered defence against coastal erosion.

These uncertainties were considered in the 2015 ESC and supporting studies, which took the approach of adopting conservative assumptions where uncertainties were present. On this basis Wilmot et al. [2015] suggested that an ESC could be made for the *in-situ* option. However, there has yet to be detailed dialogue with SEPA concerning the long-term safety of the *in-situ* option. Further work will be needed to manage the uncertainties and show with confidence that the wastes will not pose an unacceptable risk in the future.

3.5.2 Characteristics of the Contamination

One of the largest areas of uncertainty in the site end state is the period of monitoring and control between the completion of all decommissioning and remediation works (IEP) and the site end state (FEP) being reached. The period of monitoring and control confers various benefits which offset the detriment of preventing or constraining alternative use of the land. These are, chiefly:

- Building further confidence, through monitoring, that remediation activities have achieved their planned targets;

- Building confidence that any engineered barriers are performing as planned; and
- Continued active management of hazards while the source term is reduced by natural (i.e., radioactive decay) or enhanced attenuation.

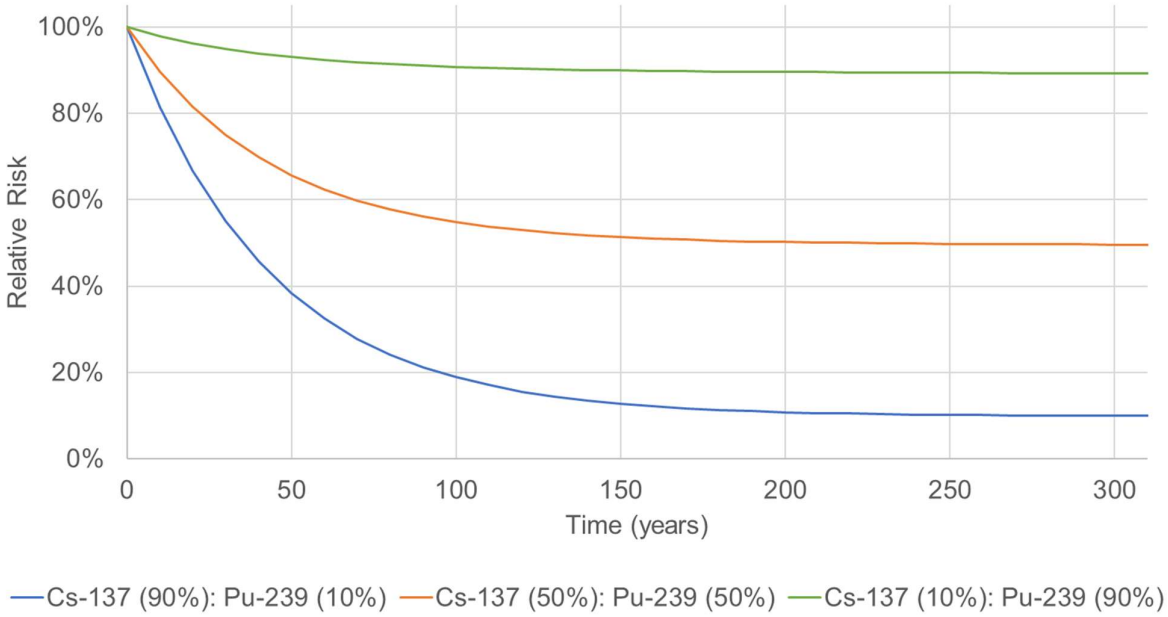
Experience with non-radioactive hazardous landfills suggests that the first two objectives are likely to be achievable within a period of a few decades. The length of time that is optimal for reducing radiological risks is, however, more uncertain because the mixture of radioactive contaminants is not known in detail in some parts of the site. For this reason, DSRL has not selected a specific date, but has assumed that it would be the maximum period specified in regulatory guidance (300 years). However, if a significantly shorter period can be achieved there will be obvious benefits in terms of releasing the land for other uses, as well as avoiding unnecessary costs.

The main uncertainty that needs to be resolved to enable an appropriate period of control to be chosen is the mixture of radionuclides in the contamination that would be managed *in-situ*. As shown in Figure 7, if short-lived radionuclides (like Cs-137) dominate the risks, there is considerable benefit from a period of control during which the risks reduce significantly. If there is a significant contribution to the risk from long-lived radionuclides (like Pu-239) there is less benefit, and the best option is likely to be to remediate the ground with a view to enabling it to be released earlier, shortly after decommissioning is completed. This rationale is key to the preferred site end state strategy, with the various parts of the site essentially falling into four categories:

- Very little contamination – clean-up and release shortly after decommissioning is complete (not shown in Figure 7);
- Risks from contamination dominated by long-lived radionuclides – clean-up and release shortly after decommissioning is complete (Figure 7; green line);
- Risks from contamination comprising a mix of short- lived and long-lived radionuclides – depending upon the activity present, this may need to be cleaned-up with release shortly after decommissioning is complete, or a case could be made that the benefit from radioactive decay would be sufficient to meet the release criteria after a period of control (Figure 7; orange line); and
- Risks from contamination dominated by short-lived radionuclides – take benefit from radioactive decay and release after an optimal period of control (Figure 7; blue line).

Better understanding the characteristics of the contamination in each part of the site, including the mixture of radionuclides present and their activity concentrations, is therefore very important in both deciding which areas could be released shortly after decommissioning is complete, and how long the period of monitoring and control should be for other areas.

Figure 7: Illustration of Decreasing Risks Due to Radioactive Decay of Contamination with Different Amounts of Short-lived (Cs-137) and Long-lived (Pu-239) Contamination



The characteristics of the contamination present varies across the site due to the different operations and activities that took place. Consideration of the historical uses of areas of the site together with the currently available characterisation data have been used to make a judgement on whether some areas are best released shortly after decommissioning is complete or after a period of control. The quality and level of detail for available characterisation data across the site is variable, so further work will be required to underpin the current assumptions made regarding which areas of site could be suitable for early release.

3.5.3 Future Use of the Site

The preferred end state option presented in this paper gives an indication of which areas of the site are expected to be suitable to be released for future use shortly after decommissioning is complete. In addition to confirming the areas suitable for early release, there is a need to determine the physical condition of the land required to facilitate its future use. To date, the fate of the large amount of embedded infrastructure that may be of use, including utilities, roadways and drains, is undecided. These assets will require maintenance but could have value if the future of the site involved some form of industry. Alternatively, if the agreed future use were to be focused on farming or conservation then roadways and the subsurface infrastructure would need to be removed, generating a considerable additional volume of waste. For both industrial or agricultural use, maintaining site drainage is important; if not maintained it is expected that some parts of the site would become boggy and be of limited practical use, but they may still be appropriate for rough grazing or as a natural environment.

The future use of the site remains undecided although some assumptions have been made. The Highland Council's [2015] most recent planning framework envisages the Dounreay Site as being redeveloped for employment uses as far as this is practicable. In the process of planning alternative uses for the site it will also be necessary to consider the potential impacts of climate change. The Highland Council has stated that it intends to continue to review potential options for the re-use of the site with DSRL and NDA, regulators, the local public and stakeholder groups. The designated future use of the site is important to as it influences the clean-up targets that need to be achieved when dealing with non-radioactive contamination.

This issue needs to be better resolved soon as the fate of the site's infrastructure and the final ground condition will need to be coordinated with the decommissioning and clean-up plans. For example, the removal (or maintenance) of in-ground utilities will need to be done so as not to negatively impact the remediation work.

3.5.4 Capabilities Needed to Achieve the Site End State

The site end state options considered in this work have been developed at a high-level based on currently available information and assumptions. Details of their practical implementation, beyond the key risks and challenges this would present, have not been developed in this study, and will be examined in subsequent phases of work. As decommissioning proceeds, and the uncertainties associated with the site end state are reduced, there will increasingly be a need to underpin the strategy with a programme for implementing the end state at each facility. Alongside this there will be a need for the required capabilities, some of which DSRL has, some of which need to be expanded, and some of which may be new.

As noted above, one of the key aspects required to implement the preferred approach is sufficiently detailed characterisation of the contamination, and this has been identified as an important uncertainty. Sampling and analysis capabilities exist but may need to be expanded to support a programme to characterise parts of the site where key uncertainties exist (noting that this would not be a single campaign of characterisation, but progressive, to synchronise with decommissioning work).

Developing the capability for understanding low levels of dispersed contamination across the site would be extremely beneficial, as would the capability to better characterise the LLW Pits wastes without intrusive measurements. A related aspect is the application and potential further development of appropriate screening and assessment tools, such as the LQI values (including the previous work that underlies them). The LQIs are simplified and coarse values which, whilst useful in initial screening, are not appropriate to make final assessments or to specify remediation targets. This development of the assessment tools for such applications will be an ongoing, iterative process in the site's management systems.

The physical aspects of implementing the site end state strategy are generally unlikely to provide a challenge to DSRL and the supply chain. There is demonstrable capability to remediate contaminated land and deal with the resulting waste in an appropriate way. This capability may need to be expanded, however, and certainly will benefit from further development and integration into the site's decommissioning planning and management aspects. There is some experience at Dounreay with the installation of engineered barriers, and there is already experience in, for example, capping landfills and areas of contamination. Nevertheless, there soon will be a need for significantly more detailed designs for closure engineering to be established to provide confidence that the planned end state conditions will meet anticipated targets.

There are greater challenges in the retrieval of waste from the LLW Pits and the Shaft. The retrieval of Shaft waste has been planned for a considerable period of time and there is an ongoing programme of work to determine the optimal retrieval and processing approach for the wastes. However, there remain considerable challenges and risks associated with retrieving the Shaft waste and it will be a complex and very costly project. Retrieving the LLW Pits wastes will in some respects be simpler, as the wastes are more accessible, but there are very large amounts of material involved, 30,000 m^3, and the work will be hazardous and time consuming.

Planning and managing the wide range of projects needed to achieve the site end state will itself be a key task for DSRL, and this will require new procedures to be developed and integrated with the existing management system arrangements. The work needed, and the reasons why, will need to be clearly communicated across the site and beyond (e.g., to enable other NDA sites to benefit from experience). The site's regulators are a key stakeholder and

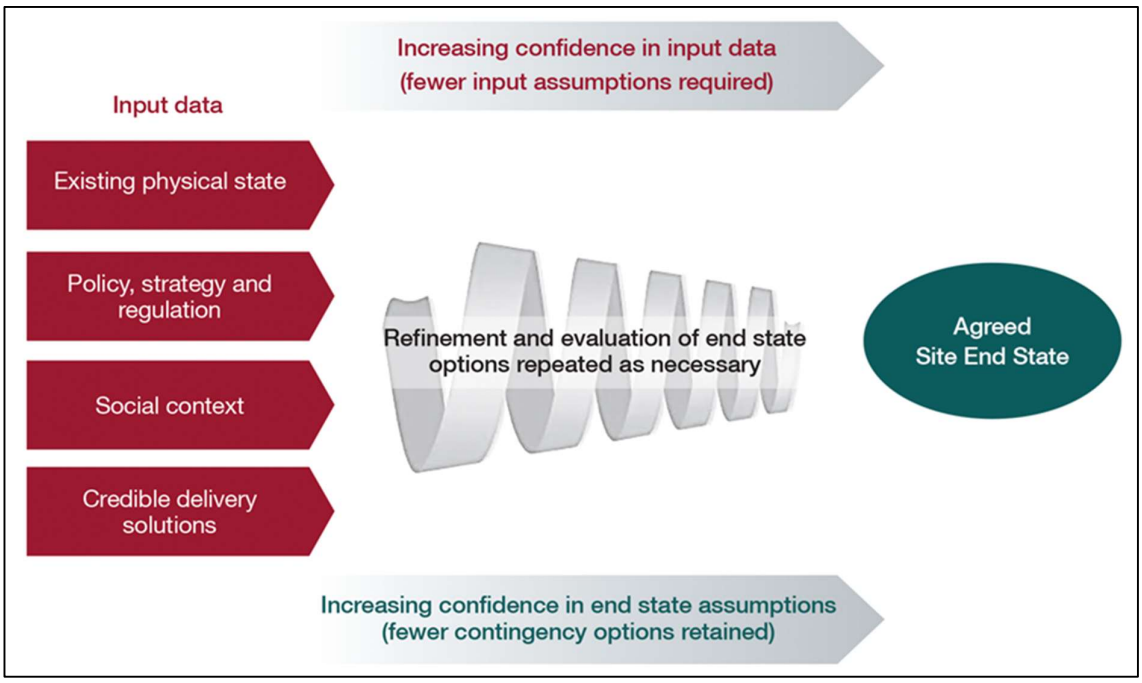
making the case to the regulators for specific facilities and the end state strategy as a whole is also a capability that will need to be further developed by DSRL.

DSRL has developed an initial SWESC [DSRL, 2021a] and associated WMP [DSRL, 2021b] to address the GRR requirements. In due course, these documents will need to reflect the adopted site end state. Furthermore, the GRR is relatively new and there will be a period of learning to understand how best to respond to the requirements it contains. The regulations may themselves also develop and be refined. It is noted, for example, that the GRR assumes that there will in due course be changes to the Nuclear Installations Act 1965 (the so-called "proportionate regulatory control" (PRC) initiative [BEIS, 2018]) which have yet to be enacted.

4. IMPLEMENTING THE PREFERRED SITE END STATE OPTION

The preferred site end state is presented in this paper, which summarises its key characteristics, the process followed to select it, and the reasons that it is recommended to NDA. The optimisation of the end state is an ongoing process, and it will be subject to further refinement in the future. The ongoing and iterative nature of the work required to reach the site end state is illustrated in Figure 8.

Figure 8: Illustration of the iterative process to reach the site end state



Over the remainder of the period of decommissioning, the implementation of the preferred site end state will be an iterative process which will involve:

- Updating the site's plans and ensuring that the management systems, capabilities and resources are in place to deliver it;
- Where necessary, identifying and resolving key issues in order to clarify assumptions and uncertainties in important aspects the site end state;
- Progressively applying the end state to the site's facilities in practice, through detailed characterisation and assessment, optimisation, regulatory submissions, implementation and verification; and
- Providing the decommissioning projects with greater clarity over their project end points, and how they link with the work to deliver the overall site end state.

Presuming NDA is satisfied with the case presented in this document, and endorses the site end state, the near-term next steps in its implementation are to embed it in the site's plans, and to address the issues for which there are the most important remaining uncertainties. These are priorities associated with the site end state to be addressed in the next five years. The main components of a programme of work to develop and begin to implement the site end state over the next five years are presented in more detail in the remainder of this section.

4.1 Embedding the Site End State within DSRL and with External Stakeholders

The highest priority is to embed the site end state in the site's decommissioning plans and activities. It is essential that those involved in planning and executing decommissioning and clean-up at the site have a clear understanding of what work is required to address contamination in the ground or associated with subsurface structures, why it is needed and when it needs to be done by. Without this, there is a risk that the benefits of the site end state strategy will not be fully realised.

4.1.1 Communicating the End State within DSRL

The preferred site end state needs to be communicated to DSRL's staff in an appropriate and effective way. The key messages that need to be communicated include:

- A meaningful and clear description of the site end state;
- Implications of the site end state on the decommissioning programmes of specific facilities and areas of site.

This will be achieved through the development of a summary datasheet which provides an overview of the developed site end state, and more detailed datasheets for specific facilities/areas of the site. The datasheets will initially be developed for the key components, and then for the balance of site areas and selected components within them as required. These datasheets will be used as a tool for initial discussions with the project teams on the implications of the site end state on their own decommissioning programmes. Through those discussions, specific issues for the decommissioning and clean-up work for the key components will be identified and prioritised.

4.1.2 Consideration of the waste hierarchy in End State decisions

As noted in section 3.1, one of the main priorities identified by stakeholders in relation to the programme of work to reach the site end state was the minimisation of waste. The strategic objective of the NDA Integrated Waste Management Strategy [NDA, 2019] is *'to ensure that wastes are managed in a manner that protects people and the environment, now and in the future, and in ways that comply with government policies and provide value for money'*.

Work to develop the preferred site end state included consideration of the waste hierarchy during each of the fifteen key component and balance of site workshops, and during the site end state workshop. Options which involved prevention of waste generation at source, and an overall minimisation of waste volumes were generally deemed the most favourable by stakeholders.

During implementation of the preferred option it is important that the principles of the waste hierarchy are used to help drive end state decisions regarding the key components and balance of site areas. The process to apply the preferred option will require further assessments to be undertaken to determine the specific nature of the end state, at the facility level. These assessments will provide further opportunities to ensure that the waste hierarchy is applied to the end state decision making process. Key considerations during these assessments will include:

- Characterisation information for subsurface structures and areas of contaminated land (including radiological and non-radiological inventory);

- Identification of opportunities to leave subsurface structures and contaminated land *in-situ*, where it can be demonstrated to be the optimal solution, leading to a reduction in the volumes of waste generated;
- Opportunities for the segregation of waste streams;
- Decision-making based on considerations relating to the waste hierarchy, in conjunction with conventional health and safety, radiological safety, cost, and programme considerations; and
- Ensuring that the waste disposal approaches applied protect people and the environment.

4.1.3 Updating the Lifetime Plan

The proposed change in the site end state will require aspects of the site's Lifetime Plan to be updated. To enable this, the site will develop their programmes of work to include more detailed consideration of end state requirements. This may include the addition of new activities such as early characterisation sampling to aid the understanding of the contamination present in a particular area or facility. A clearer understanding of the conditions may also allow facilities to identify opportunities to optimise their decommissioning end points.

The work to update the Lifetime Plan to reflect the preferred site end state will initially focus on the key components that will have a major impact on the site's closure (like the LLW Pits). Subsequently, the plans associated with the remaining areas of the site will be reviewed and updated. An example of a significant change to the Lifetime Plan is the proposal that some areas previously planned to remain under control to the FEP are instead prepared for release at the IEP (this includes most of the FCA). While this remains subject to confirmation with detailed studies, the additional activities (e.g., characterisation work, optimisation studies) will be identified and integrated into the plan. This in turn will highlight any changes to resource and capability needs, as well as any implications for other parts of the Lifetime Plan.

4.1.4 Management System Updates

The purpose of the management system will be to provide the decommissioning projects with the information they need to ensure the activities they undertake deliver what is required from an end state perspective. Some aspects may therefore need to be updated to reflect the change to the site end state.

An important requirement will be to ensure that detailed decisions on the fate of contaminated ground and subsurface structures follows a structured process with a clear audit trail. A key outcome of the site end state review has been increased understanding of the importance of contamination targets for clean-up work. Processes and procedures will need to ensure that suspect contaminated ground and subsurface structures are sufficiently characterised, decisions made can be demonstrated to be appropriately optimised, and the required remedial work (which might include engineered barriers) is properly undertaken and verified.

In parallel with the work to develop the site end state, DSRL has commenced work to establish an uncertainties tracker, which will also be embedded into the management system. The purpose of the tracker will be to recognise and manage uncertainties in the understanding of the site description, decommissioning, remediation, and closure programmes. It will be populated with uncertainties identified during the site end state review. The tracker will capture, prioritise, and monitor progress on the uncertainties as work to develop the site end state progresses and will ultimately enable DSRL to demonstrate that a sufficient understanding of the site has been achieved.

4.1.5 Engaging with External Stakeholders

The site end state – in terms of the implications for the condition of the site and its potential use, and the reasons for the decision – must also be shared with those outside of DSRL. The review of the site end state has paid considerable attention to the environmental regulator's principles and requirements, as expressed by SEPA in the GRR [SEPA et al., 2018]. These are also addressed in regulatory submissions by DSRL (the SWESC and WMP). There are also significant implications which will need to be conveyed to other regulators such as ONR (in respect of the safety of the clean-up work) and Highland Council (in respect to planning and the future designation of the land). Beyond this, the implications of the site end state and the benefits that will arise need to be presented and discussed with wider site stakeholders, including the local community and the supply chain.

As part of the next phase of work to implement the site end state, the project Stakeholder Management Plan will be updated and developed. This will identify the key stakeholders and their interest and will include details of engagement activities, including the frequency of updates. These activities will be included in the forward programme of work.

4.2 Addressing Key Uncertainties

The review has shown which components and parts of the Dounreay site are most significant in terms of the site end state. The approach taken to their decommissioning could also have significant knock-on effects for other facilities. This work has, in addition, highlighted where there are important uncertainties which could affect the end state of key components. These issues need to be addressed to enable the site end state to be progressively firmed-up and integrated into the site's Lifetime Plan. The most important uncertainties to be addressed in the next five years are discussed below.

4.2.1 The End State of the LLW Pits

The most significant uncertainty concerns the closure strategy for the LLW Pits, and whether this involves managing them *in-situ* or removing the waste. The current baseline in the Lifetime Plan is for the wastes to be removed and disposed of to the Low-Level Waste Facilities (D3100). However, an Options Study, involving internal and external site stakeholders, on the closure of the LLW Pits [Kirkby et al., 2021] concluded that the preferred option is for the wastes to remain *in-situ*, additional engineered barriers to be installed, and the facility closed. The Options Study made the key assumption that a regulatory case can be made for leaving the LLW Pits *in-situ*, based on a provisional ESC developed in 2015. As discussed in Section 3.5.1, there are several important uncertainties that could affect this conclusion. The most important of these relate to uncertainties in the inventory of wastes and the potential for coastal erosion to affect the LLW Pits, and its timing.

These uncertainties will need to be reduced to a satisfactory level for an ESC for the wastes to remain *in-situ* to be made by DSRL. This is very important because the alternative approach to the closure of the LLW Pits involves the considerable challenge of retrieving the wastes. In addition to the risks to workers, the technical challenges and costs, this will lead to around 30,000 m^3 of waste which will need to be packaged and disposed of to the vaults to be constructed at D3100. A programme of work is therefore required to review these uncertainties and make recommendations for the work that could be credibly undertaken to reduce them. DSRL will then determine whether there is scope to reduce the uncertainties sufficiently to make the case for *in-situ* disposal to the regulators. It is acknowledged that the work required to make the *in-situ* disposal case will require a significant amount of work.

The strategy for closing the LLW Pits could influence decisions made for other key components and areas across the site. For example, if the LLW Pits remain *in-situ*, the controls required after the IEP (such as access restrictions and monitoring) may also be of benefit to other parts of the site. Conversely, if the wastes were retrieved this may weight other decisions

towards excavation of contaminated land and subsurface structures where there are similar uncertainties.

4.2.2 Release of Areas where Long-lived Alpha Emitters are Present

During the work to identify the preferred site end state, it has been assumed that in some parts of the site, long-lived alpha-emitting radionuclides dominate the risk from contamination. The most significant of these areas is the FCA, although long-lived alpha-emitting radionuclides will also be encountered in other areas such as Zone E and the Active Drainage System. As discussed in Section 3.5.2, where long-lived alpha-emitting radionuclides are dominant there is no benefit from a period of control after the IEP as the risks from the contamination will not meaningfully decrease. Therefore, it will be necessary to meet the safety criteria for release of the site by IEP, by remediating and excavating contamination where required.

For this reason, the areas of the site where long-lived alpha contamination is understood to dominate are assumed to be suitable for release at the IEP rather than the FEP. This includes a large part of the FCA. However, as alpha contamination can be challenging to measure, it has typically been assumed to be dominant based on the nature of the historical activities in a given area. This is a major assumption and needs to be confirmed by further characterisation of the contamination.

A series of desk studies are currently being prepared for each of the site zones, including those within the FCA. These will give an improved view of the key areas of contamination across the site, including the presence of long-lived alpha emitters. Based on these desk studies, further investigations can be prioritised. Where possible, these will be integrated with individual facility decommissioning programmes. Furthermore, it is recognised that the in-field characterisation of alpha-emitting radionuclides presents some challenges, and further work is required to identify opportunities to improve the methods available.

4.2.3 Optimisation of the Period of Control after IEP

The site end state study, and previous work, did not consider a specific duration that the site should be controlled after the IEP, but assumed that it would be a period of up to 300 years. This is the maximum period stated in regulatory guidance. However, as explained in Section 3.5.2, there may be little benefit from such a long period during which the site will need to remain under surveillance and with limited scope for other uses.

Optimising the duration of a period of control requires more information on the significance of short-lived radionuclides in those areas intended to remain under control after the IEP. Previous estimates have indicated it may be possible to bring forward the date of the FEP to much less than 300 years hence. An improved understanding of the short-lived radionuclides across the site is therefore required. As noted above, a series of desk studies are being prepared for each of the site Zones. These will enable further investigation of key areas to be prioritised to constrain the significance of short-lived radionuclides more accurately. As well as enabling the end state plans to be refined this will indicate whether there are opportunities to reduce the duration of the period of control.

4.2.4 Assumed future use of the site

The GRR requires it to be shown that the site will be suitable for any foreseeable future use for it to be released from radioactive substances regulation. However, greater clarity on a feasible and desirable future use is needed to inform other aspects of the site end state which need to be further developed soon. The criteria for non-radioactive contaminants depend on the next planned use of the site in addition to the risk they pose to groundwater, so a clear position is needed to define suitable targets for the clean-up of these contaminants. Furthermore, there is a need to consider the fate of infrastructure, in particular surface-water drainage, in planning the work needed to reach the IEP. Therefore, greater clarity is needed on a feasible and desirable future use.

As discussed in Section 3.5.3, this remains uncertain. The most recent planning framework [Highland Council, 2015] envisages the site being redeveloped for employment uses as far as this is practicable (e.g., supporting other industrial applications). To further refine these plans the preferred site end state option will be used as a tool for dialogue with the Highland Council and SEPA. As part of the planned dialogue, the Phase 3 Planning Approval will be reviewed to determine if there are any changes required as a result of the work to update the site end state. This dialogue will also seek to resolve, if possible, the difference in assumed future use for radioactive and non-radioactive contaminants.

4.2.5 Establishing Clear and Robust Assessment Criteria

For the LLW Pits and some other key components, the characteristics of the contamination mean that a specific risk assessment study is needed to demonstrate that the planned end state will meet environmental safety targets. But for more general cases of contamination (base-slabs, patches of contamination in the ground, some sub-surface structures) simpler screening values will be valuable. These can provide a simple and clear indication as to whether the contamination can be expected to be safe to remain *in-situ* or not although they may not be appropriate to make final assessments. This study used LQIs to estimate volumes of contamination that could be suitable for *in-situ* management. It may be useful to develop similar assessment tools for such applications and this will be an ongoing, iterative process in the site's management systems.

4.3 Gaining Experience with the Implementation of the Site End State

Practical experience in the various aspects of the implementation of the site end state will be very important to develop, particularly ahead of the need to address the more significant components on the site.

During the past five years, DSRL has undertaken work in two specific areas of the site (Zone 1B, and Zone H2) with the aim of developing and testing the processes required to implement the site end state. These pilot studies have provided practical examples similar to the type of assessment required under GRR and formed the basis for discussions with SEPA on the work required. Further work will now be undertaken on the Zone 1B and Zone H2 projects, with the aim of securing SEPA endorsement that the site end state criteria for these areas have been met. The lessons learned from these projects will then be applied to other facilities and areas of the site. This will make use of an important window of opportunity to prepare the site's operational capabilities, including the aspects discussed in Section 3.5.4. This, and the work to resolve key uncertainties, can be undertaken before more significant parts of the site move towards the final stages of decommissioning, building confidence that the processes and procedures in place to deliver the site end state are sound.

Decommissioning progress means that there are a range of facilities and parts of the site for which the process of decommissioning and removing above-ground structures is largely complete, or where there were no such structures. These provide further opportunities for DSRL to develop the expertise and experience in practice in preparing the ground to meet the site end state. For example, further experience is needed in the process of applying suitable end state targets and demonstrating they are met, building on the lessons learned from work undertaken in Zone 1B and Zone H2 and identifying where new or improved capabilities are needed.

In a similar way, gaining further understanding of SEPA's requirements in respect of radioactive disposals will be very important. Although there is a provisional ESC for the LLW Pits, and some of the other key components, DSRL has not been in a position to hold detailed dialogue with SEPA and others concerning these cases. This is now necessary to confirm some key assumptions in the preferred site end state strategy.

4.4 Exploring Emerging Opportunities

This review has identified a preferred site end state option which can be used as a baseline from which further opportunities could be explored. At the outset of this project a number of important assumptions were made and as the work has progressed it has been acknowledged that some of these assumptions merit revisiting to confirm that they remain appropriate.

One such key assumption which is highly significant for the site is that all of the wastes present in the Shaft are retrieved, assayed, conditioned, packaged and stored pending a decision on their long-term management. This assumption was made because the current site strategy, agreed with stakeholders, is to retrieve the wastes. However, the reappraisal of the benefits of the *in-situ* management of radioactivity during this study has raised the question of whether the retrieval of all the wastes from the Shaft remains optimal. Consideration should be given to reviewing the strategy for the closure of the Shaft, recognising that the principle of disposing of some short-lived higher active waste in near surface disposal facilities is now being considered elsewhere within the UK but that any change in approach may be contentious. Similar considerations apply to some of the key components located in the FCA, such as D1206 and D1208.

Another potential opportunity identified during discussions relates to the application of groundwater exemptions to the site and the different approaches to historical contamination and ongoing processes. DSRL is aware of other Scottish industrial sites which hold SEPA licences or permits where the regulator has agreed that contamination demonstrated to predate the Water Environment (Controlled Activities) Regulations 2011 (CAR) are deemed to be historical, since the CAR standards could not be applied retrospectively. At Dounreay, the majority of waste disposals and contamination known to be affecting groundwater are from the site's early history. Ongoing dialogue between DSRL, NDA and SEPA is required to explore the issues associated with this opportunity. There is also an opportunity for the scope of work to, in the future, extend to the end state of the neighbouring Vulcan site. Dialogue between DSRL and Vulcan is already ongoing with respect to the site end state for Dounreay, and also on the development of the respective SWESCs and WMPs for each of the sites. If the site end state were extended in scope to include Vulcan End State, it can be incorporated as an additional key component if required.

5. APPROVAL AND FORWARD PLAN

5.1 Approval

DSRL is seeking endorsement via this Gate B Paper for the following items from NDA:

- The process followed to determine the preferred site end state has been demonstrated to be robust;
- The identified preferred site end state represents the best option based on currently available information;
- The identified preferred site end state is used as a basis for the development of future plans and decommissioning strategies; and
- The key uncertainties identified in the paper will be used as a basis for prioritising further work to develop and refine the Dounreay site end state.

5.2 Forward Plan

Subject to NDA endorsement of this Gate B Paper, DSRL will prepare a site end state implementation strategy. The strategy will take the findings from this paper and turn these into a programme of prioritised activities.

The forward plan will include consideration of the following:

- Communication of the key aspects of the preferred site end state to the decommissioning projects. This will include the development of summary 'plan on a page' documents which describe the end state requirements for key components and site components across the site;
- Dialogue with the decommissioning projects to allow the integration of site end state requirements into facility decommissioning programmes across the site. This will include identification of opportunities to optimise the scope of the decommissioning to be undertaken from an end state perspective;
- Review of the key uncertainties associated with the option to leave the waste in the LLW Pits *in-situ*, and the development of a plan of work to assess the implications of these uncertainties with respect to making an in-situ disposal case;
- Regulatory dialogue to explore the possibilities associated with securing groundwater exemptions for areas of the site impacted by groundwater contamination;
- Population and development of the site end state uncertainties tracker which will capture, prioritise, and monitor progress on the uncertainties as work to develop the site end state progresses;
- Incorporation of the principles of the waste hierarchy as part of the decision making process;
- Identification of the key decisions that need to be made from a site end state perspective, including details of any work required to inform the decision;
- Consideration of the mechanisms to be applied to allow decisions impacting the overall site end state to be agreed and foreclosed, as work to reach the end state progresses;
- Opportunities to optimise the duration of the period of monitoring and control between the IEP and FEP;
- Potential future uses of the Dounreay site footprint; and
- Implications on the preferred site end state option if the neighbouring Vulcan site is to be added to the scope of work for the decommissioning of the Dounreay site.

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7. GLOSSARY

ALARA	As Low As Reasonably Achievable, taking into account social and economic factors. A way of expressing the objective of "optimisation", a key principle of radiological protection.
Balance of Site	Areas of the site not considered to be a 'key component'. The balance of site areas include components and the land between them, divided using the site zones. These areas may include a key component (e.g., PFR lies within the Balance of Site – North) but these key components are considered separately.
Component	Buildings, facilities, or areas of ground which are considered likely to be significant in terms of the clean-up work needed to achieve the Site End State and the resulting condition of the ground. The individual end state of a Component will *influence* the overall site end state.
Criterion	A quality or property of an option that enables different options to be compared with one another.
DNSEC	Dounreay Nuclear Safety and Environmental Committee
DSG	Dounreay Stakeholder Group. An independent body whose role is to provide public scrutiny of the Dounreay site, by providing an active, two-way channel of communication between the site operators, the Nuclear Decommissioning Authority (NDA) and local stakeholders
DSRL	Dounreay Site Restoration Limited. The site licence company responsible for the clean-up and demolition of Britain's former centre of fast reactor research and development.
End State	The condition of the site (or part thereof), following all physical decommissioning and clean-up activities required to conclude the NDA's mission.
ESC	Environmental Safety Case, A documented set of claims, made by the developer or operator of a disposal facility, to demonstrate achievement of the required standard of environmental safety in accordance with Radioactive Substances Regulations, regulated by SEPA.
FCA	Fuel Cycle Area. A segregated part of the site that comprised facilities where materials were examined, irradiated material was processed, and nuclear fuel was fabricated.
FEP	Final End Point. The time at which the Site End State is achieved, and the site is suitable to be released from Radioactive Substances Regulations for an alternative use, without any further clean-up work or controls.
GRR	Guidance on Requirements for Release from of nuclear sites from radioactive substances regulation. Guidance published by environmental regulators that describes what is required to transition a nuclear licensed site from decommissioning to an agreed Site Reference State (considered here to be achieved by the Site End State).
HAW	Higher Activity Waste
IAEA	International Atomic Energy Authority

IEP	Interim End Point. The time at which all physical decommissioning and clean-up activities required for the next planned use of the site have been completed. The site may remain under control and regulated beyond the IEP, but no further decommissioning work would be planned.
ILW	Intermediate Level Waste, with radioactivity levels exceeding the upper boundaries for LLW, but which does not generate enough heat for this to need to be taken into account in the design of storage or disposal facilities.
Interim End State	Interim End State is taken to be the condition the site reaches where all planned active decommissioning and remediation work has been completed at the Interim End Point.
In-situ	Any subsurface structure or contaminated ground remaining on the site after the FEP.
Key Component	Key components are sub-surface facilities and areas of radioactive/chemical contamination deemed to be of particular significance in terms of the End State definition, and are defined in terms of physical characteristics, nature of contamination, location, and adjacencies. The individual end state of a key component will *impact* the overall site end state.
Lifetime Plan	The schedule of activities required to decommissioning the Dounreay site in order to achieve the Interim End Point
LLW	Low-level Waste, radioactive waste having a radioactive content not exceeding four giga-becquerels per tonne (GBq/te) of alpha or 12 GBq/te of beta/gamma activity.
LQI	Land Quality Indicator. Concentration values for contaminants that indicate whether the material (ground or sub-surface structures) could meet GRR criteria to remain *in-situ* without further remediation.
NDA	Nuclear Decommissioning Agency, as a Non-Departmental Public Body under the Energy Act (2004) whose purpose is to clean up the UK's earliest nuclear sites safely, securely and cost effectively.
NEA	Nuclear Energy Agency
Off-site	Anywhere beyond the Dounreay site boundary.
ONR	Office for Nuclear Regulation
Optimisation	The principle of ensuring that all exposures to ionising radiation of any members of the public and of the population as a whole are ALARA. Optimisation is one of the basic principles of radiation protection.
Option	A potential means of achieving a specified objective (in this case, achieving the Site End State).
Period of control	A period after all active decommissioning is complete but during which the site (or part thereof) remains subject to a Radioactive Substances Regulations permit. It is assumed that only passive management of any residual radioactivity would be required, such as monitoring, maintenance and access controls. The period would cease when SEPA is satisfied the requirements of the GRR have been fulfilled such that the permit may be removed. Some, controlled, reuse of the site may take place provided that the conditions of the permit are met.

PFR	Prototype Fast Reactor. The third and largest reactor to be built on the Dounreay site.
PRC	Proportionate Regulatory Control. PRC is a UK government led initiative created to identify opportunities to improve current arrangements that apply to the regulation of final stages of nuclear decommissioning and clean-up. It is anticipated that this initiative will enable a more flexible approach to site clean-up that takes account of a range of possible end states and opportunities to optimise waste management. PRC is intended to align with the guidance provided in the GRR.
RSR	Radioactive Substances Regulation
[Dounreay] Site	The land at Dounreay delineated by the environmental permit as constituting the authorised premises. The authorised premises may not always be identical to the nuclear licensed site, for example it may include extensions to include pipelines and drains.
SEPA	Scottish Environment Protection Agency, Scotland's environmental regulator. SEPA has a duty to protect members of the public and the environment from harm from radioactive substances. As part of this duty, SEPA regulates radioactive waste at nuclear sites.
Site End State	In this work the final Site End State is considered to be equivalent to the Site Reference State, defined by SEPA et al., [2018] as the condition of a nuclear site when it is fully compliant with the requirements for release of the site from Radioactive Substances Regulation.
SSC	(Dounreay) Site Strategy Committee
SWESC	Site-wide Environmental Safety Case. A documented set of claims, made by the operator of a nuclear site, to demonstrate achievement by the site as a whole of the required standard of environmental safety. The SWESC is a requirement of the GRR, regulated by SEPA.
Value Framework	A list of factors that NDA considers during decision making in nuclear decommissioning strategy.
WMP	Waste Management Plan, A documented plan, prepared by the operator of a nuclear site, which provides a comprehensive description of the current intent for dealing with all radioactive substances on or adjacent to the site and demonstrates how waste management has been optimised. The WMP is a requirement of the GRR, regulated by SEPA.

8. APPENDICIES

Appendix A

List of Groups and Committees the Strategy to Develop the Site End State was Shared with

Group/Committee	Description	Date
Nuclear Industry Group for Land Quality	Overview of the planned approach to development of the Dounreay site end state	25/05/20
Dounreay Senior Strategy Committee	Overview of the process and schedule of work associated with the site end state review	11/08/20
Dounreay Stakeholder Group – Business sub-committee	Overview of the process and schedule of work associated with the site end state review	18/08/20
Joint Industry – Regulator GRR Task Group	Progress update and overview of work being undertaken for the site end state review	28/01/21
Dounreay Nuclear Safety and Environment Committee	Progress update and overview of work being undertaken for the site end state review	25/03/21
NDA Site Decommissioning Theme Overview Group	Progress update and overview of work being undertaken for the site end state review	18/05/21
Dounreay Environmental Review Committee	Progress update and overview of work being undertaken for the site end state review	26/05/21
SEPA Site Inspector	Progress update and overview of work being undertaken for the site end state review	02/06/21
Nuclear Industry Group for Land Quality	Progress update and overview of work being undertaken for the site end state review	22/06/21
NDA Integrated Waste Management Programme Committee	Progress update and overview of work being undertaken for the site end state review	05/10/21
SEPA Site Inspector	Progress update and overview of work being undertaken for the site end state review	26/10/21
Nuclear Energy Authority – Committee on Decommissioning Nuclear Installations and Legacy Management – Holistic Decision Making on Complex Sites Group	Progress update and overview of work being undertaken for the site end state review. Dounreay site being adopted as a case study.	09/12/21
Dounreay Senior Strategy Committee	Progress update and overview of work being undertaken for the site end state review	11/01/22
Dounreay Executive Committee – Lifetime Plan workshop	Overview of work being undertaken for the site end state review and development of work to integrate findings from review into the Lifetime Plan	19/01/22
Dounreay Environmental Review Committee	Presentation and review of the 'Site Wide Options Assessment – Final Report'	26/01/22

Appendix B

Site End State Options Assessment Documents

Document	Title and Description	Authors, Reference and Date
Gate B Paper	Re-defining the Dounreay Site End State – Gate B Paper (This document)	Penfold JSS, Short RS. IESD(20)P157, Issue 02, May 2022
Site Wide Options Assessment – Final Report	Site Wide Options Assessment – Final Report	Penfold JSS. IESD(20)P156, January 2022.
Integration Report	Integration of Component Options and Development of Site End State Options	Penfold JSS and Cairns EL. IESD(21)P260, December 2021.
Component Options Reports	Prototype Fast Reactor	Paulley A. IESD(21)P215, November 2021.
	Zone E (including D1211)	Cairns EL. IESD(21)P150, April 2021.
	Shaft (D1225)	Penfold JSS. IESD(21)P203. January 2022.
	Silo (D9882/ D9833)	Penfold JSS. IESD(21)P212, January 2022.
	Liquid Effluent Discharge System	Paulley A. IESD(21)P206, December 2021.
	LLW Pits (D1212)	Penfold JSS. IESD(21)P218, January 2022.
	Low Active Drain	Paulley A. IESD(21)P209, December 2021.
	D1200 and associated components	Cairns EL and Penfold JSS. IESD(21)P211, November 2021.
	D1206 and associated components	Cairns EL and Penfold JSS. IESD(21)P224, November 2021.
	D1208 and associated components	Paulley A. IESD(21)P224, January 2022.
	Groundwater	Dowle J. IESD(21)P236, January 2022.
	Balance of Site: Zone 1B	Cairns EL and Penfold JSS. IESD(21)P150, December 2021.
	Balance of Site: Zones A, B and C	Cairns EL. IESD(21)P152, June 2021.
	Balance of Site: Zones D, F and G	Cairns EL. IESD(21)P230, January 2022.
	Balance of Site: Zones H, I and J	Cairns EL. IESD(21)P233, January 2022.
Component Assessments	Prototype Fast Reactor	Melville J and O'Brien G. IESD(21)P213, November 2021.
	Zone E (including D1211)	Lai W and O'Brien G (2021). IESD(21)P149, November 2021.

Document	Title and Description	Authors, Reference and Date
	Shaft (D1225)	Lansdell A, Dowle J and Melville J. IESD(21)P201, November 2021.
	Silo (D9882/ D9833)	Hipkins A and Lansdell A. IESD(21)P210, November 2021.
	Liquid Effluent Discharge System	Lai W and Lansdell A. IESD(21)P204, August 2021.
	LLW Pits (D1212)	Lunnon N, Hipkins E and Lansdell A. IESD(21)P217, November 2021.
	Low Active Drain	Dowle J, Melville J, O'Brien G and Tony Lansdell A. IESD(21)P207, November 2021.
	D1200 and associated components	Lansdell A and Melville J. IESD(21)P219, November 2021.
	D1206 and associated components	O'Brien G and Melville J. IESD(21)P225, November 2021.
	D1208 and associated components	Lunnon N, Melville J, Lansdell A. IESD(21)P222, November 2021.
	Groundwater	Melville J. IESD(21)P234, July 2021.
	Balance of Site: Zone 1B	Dowle J and Melville J. IESD(21)P187, November 2021.
	Balance of Site: Zones A, B and C	Dowle J, Lai W, Melville J and O'Brien G. IESD(21)P189, November 2021.
	Balance of Site: Zones D, F and G	Lansdell T and Lynch E. IESD(21)P228, July 2021.
	Balance of Site: Zones H, I and J	Herbas M and Lynch E. IESD(21)P231, December 2021.
Scoping and Process	Options Study Process	Penfold J. IESD(20)P166, December 2020.
	Options for the End States of Facilities and Areas associated with Components of the Dounreay Site	Paulley A. IESD(20)P145, October 2020.
	Assessment Criteria	Emma Cairns, James Penfold, Alan Paulley. IESD(20)P146, August 2020
	Proposed Approach to Community and Stakeholder Engagement	Collier GD and Love J. IESD(20)P167, October 2020.
	Proposed "Land Quality Indicators" for Dounreay	Penfold J and Dowle J. IESD(20)P165. October 2020.
	Review of the Proposed Key Components	Lansdell A, O'Brien G, Heathcote J and Penfold J. IESD(20)P148, November 2020

Appendix C

Summary of Key Characteristics for Site End State Options

Site End State Option	Key Characteristics
Option D Existing site strategy	Aligns with the current site strategy Assumes ground and structures would be remediated to a level that would pose a health risk of less than 1 in a million even in unlikely circumstances Certainty of the condition of the land at IEP, making it relatively straightforward to make the case for land to be released Potential to release most of the site at IEP except Zones E, F and G. Does not involve removal of contamination at depth and in rock Generates approximately 64,600m^3 of waste for offsite disposal to D3100 (LLW) and landfill (non-radioactive waste) Costly, with lots of nuisance and disturbance
Option D Variant Maximise land released at IEP	Variant to Option D would involve more clean-up in Zones E, F and G Would involve extensive excavations to remove very low levels of contamination at depth and dispersed in the ground Enables the whole of the site to be released at the IEP Generates approximately 103,000m^3 of waste for offsite disposal to D3100 (LLW) and landfill (non-radioactive waste) More costly, with more nuisance and disturbance than Option D
Option F *In-situ* management of radioactivity and early release	Involves *in-situ* management of contamination where a robust Environmental Safety Case (ESC) can be made. Clean-up targets based on GRR criteria, with optimisation applied Would facilitate release of Zones A, B, C, 1B, potentially Zone D and a south-eastern part of Zone E, at IEP Assumes that a case could be made for the LLW Pits to remain *in-situ*, with additional engineered barriers Requires good understanding of potentially contaminated ground and structures across the site. May be uncertainties to deal with when making the case, due to limits on the ability to characterise contamination in the ground Generates approximately 12,900m^3 of waste for offsite disposal to D3100 (LLW) and landfill (non-rad waste), with 22,100m^3 of waste for on-site disposal (volume that could be used for slightly radioactive demolition wastes)

Site End State Option	Key Characteristics
Option F (Variant 1) More early release	Involves applying the principles of Option F, but with the application of some additional clean-up work focussed on Zone D and a large area of the FCA Would facilitate release of Zones A, B, C, 1B, D, H, a south-eastern part of Zone E, and large parts of the FCA (Zones I and J) at IEP Assumes that a case could be made for the LLW Pits to remain *in-situ*, with Generates approximately 15,400m^3 of waste for offsite disposal to D3100 (LLW) and landfill (non-radioactive waste), with 15,500m^3 of waste for on-site disposal (volume that could be used for slightly radioactive demolition wastes)
Option F (Variant 2) More use of engineered barriers	Involves applying the principles of Option F, but with more emphasis on placing engineered barriers around contamination to facilitate its management *in-situ*, further reducing the volumes of waste requiring disposal elsewhere Installation of engineered barriers may be technically challenging in places Generates approximately 11,000m^3 of waste for offsite disposal to D3100 (LLW) and landfill (non-radioactive waste), with 22,100m^3 of waste for on-site disposal (volume that could be used for slightly radioactive demolition wastes)
Option H No early release of site	Involves maintaining the current Nuclear Site Licenced site boundary until the FEP. Keeping controls over the whole site up to the FEP could reduce the amount of ground requiring excavation, by enabling more areas to benefit from radioactive decay Requires good understanding of potentially contaminated ground and structures to make case to manage *in-situ* until FEP No areas of the site would be released before FEP Generates approximately 9,900m^3 of waste for offsite disposal to D3100 (LLW) and landfill (non-radioactive waste), with 22,100m^3 of waste for on-site disposal (volume that could be used for slightly radioactive demolition wastes)
Option J In-situ Management of Short-lived Higher Activity Material	This is an extension of Option F that examines the potential for managing some short-lived higher activity contaminated material *in-situ*, provided it could still be shown to meet safety targets by the FEP Key facilities where this strategy may be beneficial are the empty D1208 high-active liquor tanks and potentially the Shaft wastes Potential technical challenges associated with making the case for the higher activity waste Would facilitate release of Zones 1B, A, B, C and H, at IEP Generates approximately 9,700m^3 of waste for offsite disposal to D3100 (LLW) and landfill (non-rad waste), with 9,000m^3 of waste for on-site disposal (volume that could be used for slightly radioactive demolition wastes)