# On-Site, Near Surface Disposal of Graphite Wastes in the UK - 11271

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## ABSTRACT

Reactor graphite makes up about 30% by volume of the UK's inventory of intermediate level waste (ILW). There is estimated to be about 15,000m$^3$ of graphite arisings prior to 2040, mainly comprising operational waste streams (Magnox and AGR fuel sleeves), along with core graphite from the decommissioning of experimental and prototype reactors. A further 65,000m$^3$ of graphite is forecast to arise after 2040, comprising core graphite from the final decommissioning of the Magnox and AGR reactors. Consequently, the management and disposal of graphite wastes is of key strategic importance in the UK.

The current baseline strategy for reactor graphite wastes in the UK is to encapsulate them upon retrieval using a cementitious grout in stainless steel "Nirex" containers in accordance with NDA Radioactive Waste Management Directorate (RWMD) Letter of Compliance (LoC) specifications, and to dispose of them following a period of interim storage to the UK's planned geological disposal facility (GDF), when this becomes available, currently planned for around 2040.

Using Magnox's Hunterston A site as a Pathfinder, Energy*Solutions* and its partner organisations have been engaged with the feasibility assessment, options assessment, engineering concept design and environmental safety case development for a proposed on-site, near surface disposal facility for operational graphite wastes (with a preliminary assessment for core graphite). The proposal is consistent with the emerging Scottish Government policy framework.

This work may in due course, subject to the confirmation of feasibility and agreement from the NDA to pursue implementation, support applications for regulatory and planning approval and subsequent placement of contracts for detailed design and build of a disposal facility at Hunterston A.

## RADIOACTIVE GRAPHITE IN THE UK

Reactor graphite makes up about 30% by volume of the UK's inventory of intermediate level waste (ILW). The principal form of reactor graphite is irradiated core bricks, used as a moderator within the Magnox and Advanced Gas Cooled (AGR) reactors.

Graphite bricks of irregular shape and with a greater impurity content were also used as reflectors around the reactor core. These waste streams are due to be retrieved at the time of final decommissioning and site clearance (FD&SC), which for the Magnox sites owned by the Nuclear Decommissioning Authority (NDA) is about 85 years after shutdown. Graphite was also used as fuel sleeves around fuel elements at various reactors. AGR graphite sleeves are stored at Sellafield or at the site of arising. There are Magnox graphite fuel sleeves in interim storage at waste facilities, principally at Hunterston A and at Berkeley. These operational graphite wastes are due to be retrieved during the Care & Maintenance Preparations phase of the Magnox reactor lifecycle, over the next several years.

There are also volumes of irradiated graphite in storage at various sites, resulting from smaller, experimental reactor operations and decommissioning projects. Examples include irradiated graphite from the decommissioning of experimental reactors which are stored at Dounreay and irradiated core bricks from the Windscale Advanced Gas Cooled Reactor (WAGR) which are in storage at Sellafield.

There is estimated to be about 15,000 $m^3$ graphite arisings prior to 2040, mainly comprising operational waste streams (Magnox and AGR fuel sleeves), along with core graphite from the decommissioning of experimental and prototype reactors. Much of this waste has already been retrieved and is in interim storage pending the availability of the GDF. A further 65,000 $m^3$ graphite is forecast to arise after 2040, principally comprising core graphite from the final decommissioning of the Magnox reactors and AGRs. At Hunterston A, the inventory of operational and core graphite is recorded in The 2007 UK Radioactive Waste Inventory [1] and reproduced in Table 1.

Table I: Operational and Core Graphite Waste Stream Volumes at Hunterston A (from [1])

| WASTE STREAM | VOLUME ($m^3$) |
|---|---|
| Operational Graphite | |
| ILW | 1499 |
| Core Graphite | |
| ILW | 2843 |
| LLW | 578 |

The principal radionuclides of concern from a disposal perspective on irradiated reactor graphite waste streams are the long-lived radionuclides C-14 (a low energy beta emitter with a 5700 year half-life) and Cl-36 (a relatively low energy beta emitter with a 300,000 year half-life). Both radionuclides are mobile and readily taken up in the food-chain. However, Cl-36 in particular is a key radionuclide for disposal safety cases because of its high mobility and uptake into plants.

In addition, the presence of significant concentrations of Co-60 (a high energy gamma-emitter with a 5.7 year half-life) and tritium (a low energy beta emitter with a 12 year half-life) on reactor graphite waste streams must be taken into consideration during waste retrieval and handling. Much lower concentrations of fission products and actinides present on some graphite waste streams are unlikely to materially effect disposal assessments.

## UK GOVERNMENT POLICY ON HIGHER ACTIVITY WASTES

During its deliberations on policy for the long term management of the UK’s higher activity wastes, the Committee on Radioactive Waste Management (CoRWM) considered the option of near surface, on-site disposal of short-lived ILW and reactor graphite arising from reactor decommissioning. Whilst CoRWM recommended geological disposal for much of the UK’s higher activity waste, they made a specific recommendation in relation to the large volumes of ILW that will arise from reactor decommissioning (Recommendation No.8). In their published response to CoRWM [2], UK Government accepted this recommendation, tasking the NDA with determining whether or not a safety case for near surface disposal of such ILW could be made, including consideration of on-site, or near site, disposal options. A Pathfinder project, funded by the NDA, has consequently been initiated by Magnox North, Ltd at the Hunterston A site to test the technical feasibility and public acceptability for the development of a near surface disposal facility for operational graphite wastes at this site.

## SCOTTISH GOVERNMENT POLICY ON HIGHER ACTIVITY WASTES

In June 2007 the Scottish Government announced that its policy for the long-term management of higher activity radioactive wastes arising in Scotland is to:
*"support long-term near surface, near site storage facilities so that the Waste is monitorable and retrievable and the need for transporting it over long distances is minimal."*

This announcement [3] was followed by discussions with representatives of nuclear site operators, waste producers and regulators, the NDA, Scottish Local Authorities and other stakeholders. It became clear from these discussions that all parties needed greater clarity on the implications of the policy to enable them to undertake the work, and duties, for which they are responsible.

These discussions identified a need for a more detailed statement of policy by those involved in the management of the waste. This is particularly relevant to enable the clean-up and decommissioning of nuclear sites. Engagement with stakeholders on the waste arising in Scotland has also identified the option for extending the Policy to include near surface, near site disposal as well as near surface, near site storage.

The Scottish Government has recently consulted on a detailed statement of policy for Scotland's higher activity radioactive waste. This is needed by owners and producers of radioactive waste to enable them to plan for the management of their higher activity radioactive waste now and in the longer term. It is also needed to provide the policy framework to enable regulators to regulate the management of higher activity radioactive waste. In its draft detailed statement of policy [4], Scottish Government states that its policy for higher activity radioactive waste is:

*"to support long-term near surface, near site storage and disposal facilities so that the waste is monitorable and retrievable and the need for transporting it over long distances is minimal."*

The policy allows for the storage or disposal of the waste in facilities constructed on the surface or near to the surface down to depths of several tens of metres, in facilities located on existing nuclear sites or near existing nuclear sites; and the treatment of the waste, in accordance with the waste management hierarchy, including sending it elsewhere for treatment, subject to any requirements by the relevant regulators in the UK and overseas for the return of secondary waste.

In the context of the policy statement, storage is defined as placing the waste in a suitable facility with the intent to retrieve it at a later time. Disposal is defined as the emplacement of the waste in a specialised land-based disposal facility without the intent to retrieve it at a later time. The time of emplacement will be regarded as the time when disposal occurs, even if the facility is eventually closed many years later. Retrieval may be possible but, if intended, the appropriate term is storage.

The definition of near surface, which will apply to both near surface storage and near surface disposal facilities, is:

- Facilities located at the surface of the ground or at depths down to several tens of metres below the surface;
- Near surface facilities may use the geology (rock structure) to provide an environmental safety function, but some may rely solely on engineered barriers. They could include facilities constructed under the seabed but accessed from land; and,
- Near surface facilities may use existing structures if an acceptable environmental safety case is made.

The concept of retrievability for a disposal facility recognises that, at a certain point in time after a facility has been closed, it would not be possible to recover the waste or the waste packages without additional new engineering activity. This does not mean that the waste could not be retrieved, for example, by using mining techniques, rather that the intention is not to retrieve it. The policy definition will recognise that if, at some point in time, the waste needed to be recovered, the decision would require further regulatory agreement. It might also, depending on the disposal facility, require significant engineering activity, in order to do so.

There is already a well established regulatory framework in Scotland for the management of the waste, which includes requirements for monitoring. The policy reflects the requirements of the existing regulatory framework to define the term monitorable. As such, the policy:

- Does not prescribe how monitoring should take place. That is a matter for operators to determine to the satisfaction of regulators; and,
- Requires regulators to be satisfied that the monitoring of treatment, storage or disposal facilities is sufficient to ensure that there is protection of the environment and people in accordance with the definition of 'long-term'.

The policy does not specify the type of packaging which will be required to enable the transportation, long-term storage, or disposal, of the waste. It enables consideration to be given to alternative options. It is for waste producers and owners and facility operators to satisfy the appropriate regulators that the waste is being managed or held in a form which complies with environment, health, safety, security and transport regulations.

## REGULATORY FRAMEWORK AND CONTEXT

With the publication of the Environment Agencies' (for England, Wales Scotland and Northern Ireland respectively) Guidance on Requirements for Authorisation (GRA) of Near Surface Disposal Facilities for Radioactive Waste in 2009 (known as 'the Near Surface GRA') [5], the regulatory framework within England, Wales, Scotland and Northern Ireland to enable the pursuit of proposals for the near surface disposal of shorter-lived ILW or less radiotoxic ILW was clarified.

As a result, the regulatory framework in England, Wales, Scotland and Northern Ireland clearly allows for the near surface disposal of shorter-lived ILW (e.g. certain radioactive metals) and less radiotoxic ILW (e.g. reactor graphite), subject to production of an acceptable environmental safety case.

The guidance explains that:

*"Near-surface disposal facilities are those located at the surface of the ground, or at depths down to several tens of metres below the surface. Near-surface facilities may use the geology (rock structure) to provide an environmental safety function, but some may rely solely on engineered barriers. They could include facilities constructed under the seabed but accessed from land. Near-surface disposal facilities may use existing structures if an acceptable environmental safety case can be made."*

The guidance explains the requirements that the Environment Agencies expect a developer or operator to fulfil when they apply for an Authorisation under the Radioactive Substances Act 1993 (RSA93) to develop or operate such a disposal facility. The guidance sets out the radiological protection requirements and explains the regulatory process that leads to a decision on whether or not to Authorise radioactive waste disposal. It also describes the environmental safety case the relevant Environment Agency would expect from a developer or operator of such a disposal facility.

## NUCLEAR LICENSING SITUATION

Whilst the principle regulator for the disposal of radioactive waste is the relevant Environment Agency, if sited on the nuclear licensed site any such facility would be subject to regulation by the NII under the Nuclear Installations Act 1965 (NIA65) and the relevant license conditions would apply in the same manner as for other facilities for the management of radioactive waste. Any such facility sited on a nuclear licensed site would consequently require a nuclear safety case, including a demonstration that doses are ALARP.

It is unclear at this point whether or not a disposal facility for reactor graphite would necessarily need to be licensed under NIA 65, if the proposed siting location was not on an existing nuclear licensed site. If the siting location was on land adjoining an existing nuclear licensed site, the boundary of the nuclear licensed site could readily be extended to include the footprint of the disposal facility. At an off-site location, it might be necessary for the applicant to seek a new license under NIA 65.

## BASELINE GRAPHITE WASTE MANAGEMENT STRATEGY

The current baseline strategy for reactor graphite wastes is to encapsulate them upon retrieval, using a specially formulated cementitious grout, in stainless steel ‘Nirex’ containers ($3m^3$ ‘Nirex’ boxes for operational wastes, 4 meter ‘Nirex’ Boxes for FD&SC wastes) according to “Radioactive Waste Management Directorate (RWMD) Letter of Compliance (LoC) specifications” and to dispose of them in due course following a period of interim storage.

As note above, in England and Wales, disposal may be to the UK’s planned geological disposal facility (GDF) when this becomes available. Government policy in Scotland is for ‘near site, near surface’ storage or disposal of higher activity radioactive wastes.

## DEVELOPMENT OF AN ALTERNATIVE - FEASIBILITY ASSESSMENT AND CONCEPT IDENTIFICATION

The NDA’s remit is to ensure that the UK’s civil public sector nuclear sites are decommissioned and cleaned up safely, securely, cost-effectively and affordably, in ways that protect the environment for this and future generations. In October 2008, the Department of Energy and Climate Change (DECC) was given a Departmental Strategic Objective (DSO) to manage energy liabilities effectively and responsibly. To help achieve this target, the NDA is required to “establish a safe, affordable, innovative and dynamic market for clean-up and decommissioning” and to ensure progress in tackling the civil nuclear liability in line with agreed end-states for the NDA’s sites.

There is now significant interest in potential alternative treatment and disposal strategies that reflect the risks posed by this legacy. The availability of a lower cost, fit-for-purpose management solution for reactor graphite would significantly reduce the volume of waste that will need to be consigned to the GDF and could effectively de-couple Magnox decommissioning strategy from GDF availability. This would help to support the business case for a demonstration, accelerated final reactor decommissioning project, which remains an aspiration for the NDA.

The NDA has set up an Integrated Project Team on Reactor Decommissioning Wastes (IPT), to assess strategic options for the management of reactor wastes and to undertake underpinning R&D activities to support strategy development in this work area. Whilst the IPT plans to assess options for the management of reactor decommissioning wastes generally, it is currently focusing on potential alternative management strategies for irradiated reactor graphite. This also fulfils a specific Recommendation (No.8) from the CoRWM to investigate on-site, near surface opportunities for disposal of reactor wastes. At the

Hunterston A Decommissioning Site, a Graphite Pathfinder project has been established, funded by the NDA, tasked with establishing the feasibility of an on-site, near surface disposal strategy for an operational graphite waste stream.

The Graphite Pathfinder project, which incorporates both the Engineering Concept Design and Environmental Safety Case work packages, has been ongoing since April 2010. It has recently entered a more detailed construction and concept options development phase, including a thorough technical review of available options and generation of construction cost estimates for the proposed concept design. However, underpinning this current phase of the project, a great deal of feasibility assessment and options assessment work has been undertaken, including a series of technical workshops.

**Feasibility Study**

During 2009/10, an Energy*Solutions* led team undertook a series of feasibility assessments for the management of reactor graphite, designed to support the NDA's strategic development activities in this work area and to support consultation with a wide range of stakeholders. Specifically, the work was designed to help to inform considerations regarding the option of near surface disposal for reactor graphite.

The feasibility work undertaken was based primarily on a review of Energy*Solutions* proprietary concept and design for the near surface disposal of reactor graphite, which has been developed specifically for application across the NDA estate. The feasibility study took into account relevant policy and regulatory considerations, the current status of the UK's reactor graphite inventory, a review of international proposals for near surface disposal of reactor graphite, identification of generic siting considerations, presentation of an outline conceptual design for the disposal facility and a comparison of lifecycle costs relative to the baseline management scheme.

**Disposal Facility Concept and Location**

A technical expert review was conducted in June 2010 in order to consider broad facility concept / form and siting location options for a near surface, on-site facility for the disposal of the un-segregated contents of Solid Active Waste Building (SAWB) Bunkers 2-5 at the Hunterston A Decommissioning Site. This took into account the emerging Scottish policy framework for the management of higher activity radioactive wastes and the requirement from the NDA to test technical feasibility and stakeholder acceptability during the current financial year for the option of near surface, on-site disposal of operational graphite and other associated wastes at Hunterston A.

Following a preparatory, options generation workshop, the main assessment workshop considered seven broad concept designs, and fourteen potential areas for siting a facility, based on information prepared in advance of the workshop and on technical expertise shared between participants during the course of the workshop. The study was conducted as a "semi-quantitative" assessment, reflecting the fact that not all of the options under consideration were fully underpinned against all of the assessment attributes.

Overall, the workshop concluded that one concept design, based on a "*Disposal Cell Type Facility in Bedrock*", presented the best overall performance and value for money. This conclusion was robust to all sensitivity analyses undertaken. It was recommended that this option be taken forward for further investigation and optimisation studies.

Potential siting locations were then evaluated on the basis of hosting such a facility. The workshop concluded that one location, identified as an area of foreshore reclaimed land (the Foreshore Reclaimed Area) to the west of the Hunterston A site, presented the best overall performance. The area is characterised by the presence of a significant glacial till overburden.  An additional area to the south and east of the Hunterston A site was also identified as offering good overall performance and, on some measures, better value for money than the previous foreshore area.

## CONCEPT DESIGN OVERVIEW

Following the concept and location assessment, the Engineering Concept Design project team set about defining and developing a set of options for construction of different aspects of the proposed disposal facility, based upon the concept of a "*Disposal Cell Type Facility in Bedrock*". In developing the concept design, the project team considered six key facility features during a series of concept refining workshops:

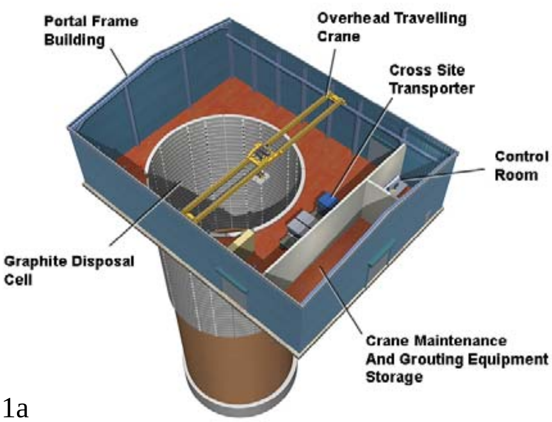
A. Means of dewatering the facility during construction, and potentially during filling;
B. Structure of the facility in the 'soft' ground above rock-head;
C. Structure of the facility below rock-head;
D. Means of closing the facility;
E. Means of preventing releases from the facility; and,
F. Means of monitoring the facility.

The options associated with each facility feature were extensively developed, refined and assessment, resulting in definition of an outline concept design at an early stage, upon which preliminary cost estimates could be generated. Of key importance during the concept design development process was consideration of likely interactions between preferred options.

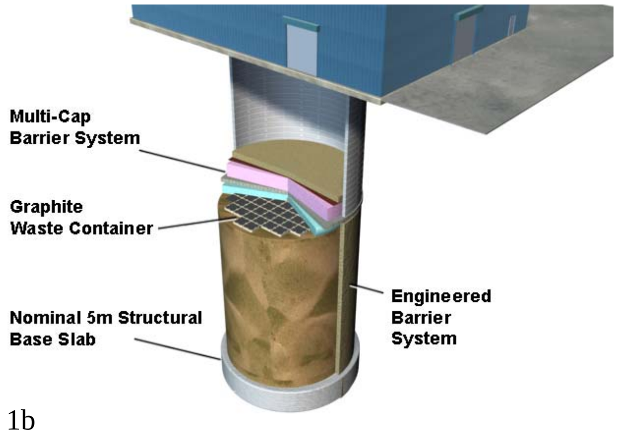
Consequently, the disposal concept under development is for a facility comprising of one or more concrete lined, cylindrical disposal cells, sited within the near surface environment at tens of meters depth below ground level.  The approach is consistent with the emerging Scottish Government policy framework.  The concept is modular and designed to be easily replicated across the NDA estate, should this be required.  The construction of the disposal cell relies on mature engineering and standard technology readily available within the civil engineering field.

The facility will comprise a cylindrical disposal cell located in bedrock, connected to the surface by an access shaft of similar dimensions, constructed through the overlying superficial deposits and made ground (Figs. 1a and 1b). The disposal cell will be constructed at sufficient depth such that inadvertent human intrusion associated with gross disruption of the facility, for example resulting from agriculture or building construction [1], is not credible and waste emplaced in the facility could not be impacted by coastal erosion or sea level rise.  It is being sited in a location where the hydrogeology is well understood and there is confidence that groundwater flow pathways that could impact the disposal facility over the long term would discharge to the marine environment, rather than to the terrestrial environment.  The intention is to construct the facility such that the waste disposal horizon is entirely located within a single geological unit (Old Red Sandstone at Hunterston A), making use of an engineered multi-barrier system within the walls, base and facility cap.  Waste will be emplaced in simple, stackable packages using an overhead travelling crane and a temporary package receipt facility.

[1] However, inadvertent human intrusion, for example stemming from borehole drilling scenarios, should be assessed further.




1a




1b

Figs. 1a and 1b. Schematic representations of a “*Disposal Cell Type Facility in Bedrock*”, showing key features of the design

## ENVIRONMENTAL SAFETY CASE DEVELOPMENT

An Environmental Safety Case work package, run in parallel to the Engineering Concept Design work package, has taken responsibility for developing a robust and fully encompassing environmental safety case for the proposed near surface, on-site disposal facility at the Hunterston A decommissioning site. As such, the following key lines of reasoning [from 6] contribute to the development of an effective environmental safety case:

- The waste material poses a relatively low hazard;
- The radioactive inventory of the waste is dominated by relatively short-lived radionuclides;
- A programme of design work, performance assessment, site investigation and environmental safety analysis is being undertaken to develop the optimal disposal system, consistent with good practice and reasonable expectations;
- The current engineering concept design for the facility is a robust system with several very effective engineered barriers. The environmental safety case will not be compromised even if one or more of those barriers fails;
- The disposal system will isolate the wastes from the external environment for a period during which significant radioactive decay of the radioactive inventory will occur;
- At all times, any release of radioactivity from the disposal system to the environment will occur at a low rate, consistent with very low impacts; and,
- The facility will be constructed at sufficient depth below ground level that the likelihood of unintentional human intrusion will be much reduced. The surrounding geosphere also provides a barrier to human intrusion.

Following these lines of reasoning, the performance of the disposal facility in both the near-term and the long-term (on a range of timescales) can be defined using a combination of qualitative and quantitative justifications, many of them related back to key features of the facility’s design.

## FACILITY PERFORMANCE

The underlying disposal principle is that the facility shall retain the radioactive inventory in such a manner as to ensure that the rate of return of radionuclides to the environment is sufficiently low as to be acceptable for all time. Of key importance is minimising the risk of subaerial exposure during foreseeable credible geological events over the next few 100,000 years (short term sea level changes and erosion). Both the facility's location and depth have been designed so as to minimise this risk.

As a primary objective, the concept design considers the importance of a dry disposal cell during the operational waste emplacement / facility closure period in particular, which is assumed to have a duration of approximately 5 years. Ultimately, the facility is being designed with the purpose of delaying the release of radioactivity to the environment for as long as possible. Containment will not be absolute, and will reduce over time, but will continue to ensure that releases of radionuclides to the environment occur at a sufficiently low rate to provide protection of people and of the environment.

After facility closure, the disposal system will evolve gradually in a fashion that can be predicted and which continues to provide high levels of protection. As a result, the following arguments [from 6] summarise the characteristics of performance which will provide protection of people and the environment over different timescales:

- For some decades (corresponding approximately to the period of authorisation), the disposal system will be designed to optimise waste containment such that the waste disposal cell radioactive inventory will be largely isolated from the accessible environment. This will be characterised by physical isolation and chemical binding via the engineered barriers constituting the 'near field'. During this period, natural radioactive decay will substantially deplete the inventory of many of the shorter-lived radionuclides and will lead to some reduction in the inventory of all radionuclides. The risk of accidental human intrusion will be negligible during the period of authorisation. The depth of the facility means that the disposal system will be insensitive to sea level rise or to the potential effects of coastal erosion;
- Over the period out to some hundreds or thousands of years, the multiple engineered barriers will continue to limit the rate of release of radionuclides into the environment, such that impacts to people and to the environment are maintained at low levels (and within all relevant statutory limits, design targets and regulatory guidelines). This period will largely be characterised by chemical retardation of release from the disposal facility; although some radionuclides will be released to the environment. The rate of release will be low, leading to very low potential impacts on the environment. Further reduction of the waste inventory will occur through radioactive decay; and,
- Over timescales of tens of thousands of years, the natural barriers presented by the geosphere will continue to provide some dilution and dispersion of radionuclides before entry to the accessible environment, such that anticipated impacts to people and to the environment are maintained at low levels. During this period, natural evolution of the local environment (for instance due to climate change) may lead to significantly different conditions with resultant changes to the biosphere. The remaining inventory of many of the radionuclides (including those with long half lives) will have been depleted due to natural radioactive decay and due to gradual release to the environment.

At some time in the future (possibly as early as the next glaciation event or more distantly as the cycle of glacial and inter-glacial periods continues) it is possible that the current bedrock will be removed due to erosion. Owing to the specific topographic setting of the Hunterston Site within a fjordic setting, high vertical rates of erosion of the underlying bedrock are predicted during a single glaciation. This would most likely completely destroy the disposal facility. The disposal facility and eroded material would be subject to a range of physical processes during a glaciation. It is considered that the glacial and glacio-fluvial processes acting on the eroded material would result in significant dispersion, effectively diluting the residual activity concentrations of C-14 and Cl-36 to trivial levels and will only lead to very low impacts to people and to the environment. Further work is recommended to quantify the effect of such processes.

## SUMMARY

A systematic process of regulatory and policy review, feasibility assessment and concept development has been undertaken at the Hunterston A decommissioning site as part of the Graphite Pathfinder project. This has considered the development of an on-site, near surface disposal facility, in the form of a "*Disposal Cell Type Facility in Bedrock*", for the site's operational graphite inventory and other associated waste streams.

Energy*Solutions* and its partner organisations have been closely involved with the Graphite Pathfinder project since it started in April 2010. Though a series of key workstreams, this work has focussed on the development of an engineering concept design for the facility, incorporating an engineered multi-barrier system in the construction, and preparation of environmental safety case documentation in order to demonstrate regulatory compliance. This work may in due course, subject to the confirmation of feasibility and agreement from the NDA to pursue implementation, support applications for regulatory and planning approval and subsequent placement of contracts for detailed design and build of a disposal facility at Hunterston A.

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