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Agree assessment criteria for retrieval and Assess retrieval options against criteria

Author(s): **Lead Author R Jarvis**

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Deliverables T-1.6.1/D-1.6.2/T-1.6.3
Agree assessment criteria for retrieval
and
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Executive summary

The paper describes a set of assessment criteria which can be used to select methods for the retrieval of irradiated graphite. These criteria were developed based on workshops, the annual CARBOWASTE project meeting and other meetings/workshops organised in the UK involving NNL, Doosan-Babcock and AMEC.

Use of the criteria for the selection of retrievals technologies is placed in the context of the CARBOWASTE approach to the selection of strategies for the treatment and disposal of irradiated graphite. Broad retrieval technology options will be considered as part of the CARBOWASTE strategy selection. The strategy will then influence detailed retrievals technology selection.

This report provides feedback into tasks 1.3 and 1.4 to assist with development of the overall multi-criteria decision approach for strategy selection.

History /Revisions

Rev.	Date	Short description	Lead Author	Internal Review	Task Leader	WP Leader
1	28-09-09	Draft	H Eccles	AW Banford	AW Banford	H Eccles
2	12-05-10	Issue for comment	R Jarvis R Jarvis	D Ross David N. Ross	AW Banford AWB	AW Banford AWB

CONTENTS

1. INTRODUCTION

This paper addresses the irradiated graphite retrieval considerations, as required of WP1 by Task 1.6.1 '*Agree assessment criteria for retrieval'* and D1.6.2 '*Assess retrieval options against above criteria*' of the CARBOWASTE submission, Annex 1-'Description of Work', version U (07.02.2008). The contents of this paper are to be used to feed back retrievals technology selection issues into the strategy selection Multi-Criteria Decision Analysis (MCDA) process as required by Task 1.6.3. Some of the information in this paper has already been presented to the CARBOWASTE consortium at the WP1 workshop in Manchester 16-18 Feb 2009[1], the annual CARBOWASTE project meeting in Marcoule 20-22 April 2009[2] and at the WP2 Workshop in Gateshead, 14-16 July 2009[3] . Aspects of the work have influenced presentations on the progress within WP1[4,5,6].

The evolution of the report has been accomplished by several meetings in the UK involving representatives from the NNL, Doosan-Babcock and AMEC NNC. This work led to the issue of the first issue of this report[7] presenting a set of criteria for assessing retrievals. Since this time the process for the selection of strategies for irradiated graphite processing has been refined and published in a series of papers culminating in the dissemination report[8]. This has allowed the interaction between strategy selection and retrievals technology selection to be better defined. Consequently, this paper extends and updates the earlier work taking more recent developments into account.

2. GRAPHITE RETRIEVAL AS PART OF AN INTEGRATED WASTE MANAGEMENT STRATEGY

The irradiated graphite retrieval criteria are synergistic with and have largely evolved from the route map[9] considerations. It is crucial that retrieval, treatment and disposal are integrated into an overall strategy selection process. A Multi-Criteria Decision Analysis (MCDA) approach to strategy selection has been developed within the CARBOWASTE project[8]. Figure 1 illustrates how this approach is expected to interact with more detailed selection of retrievals technology.

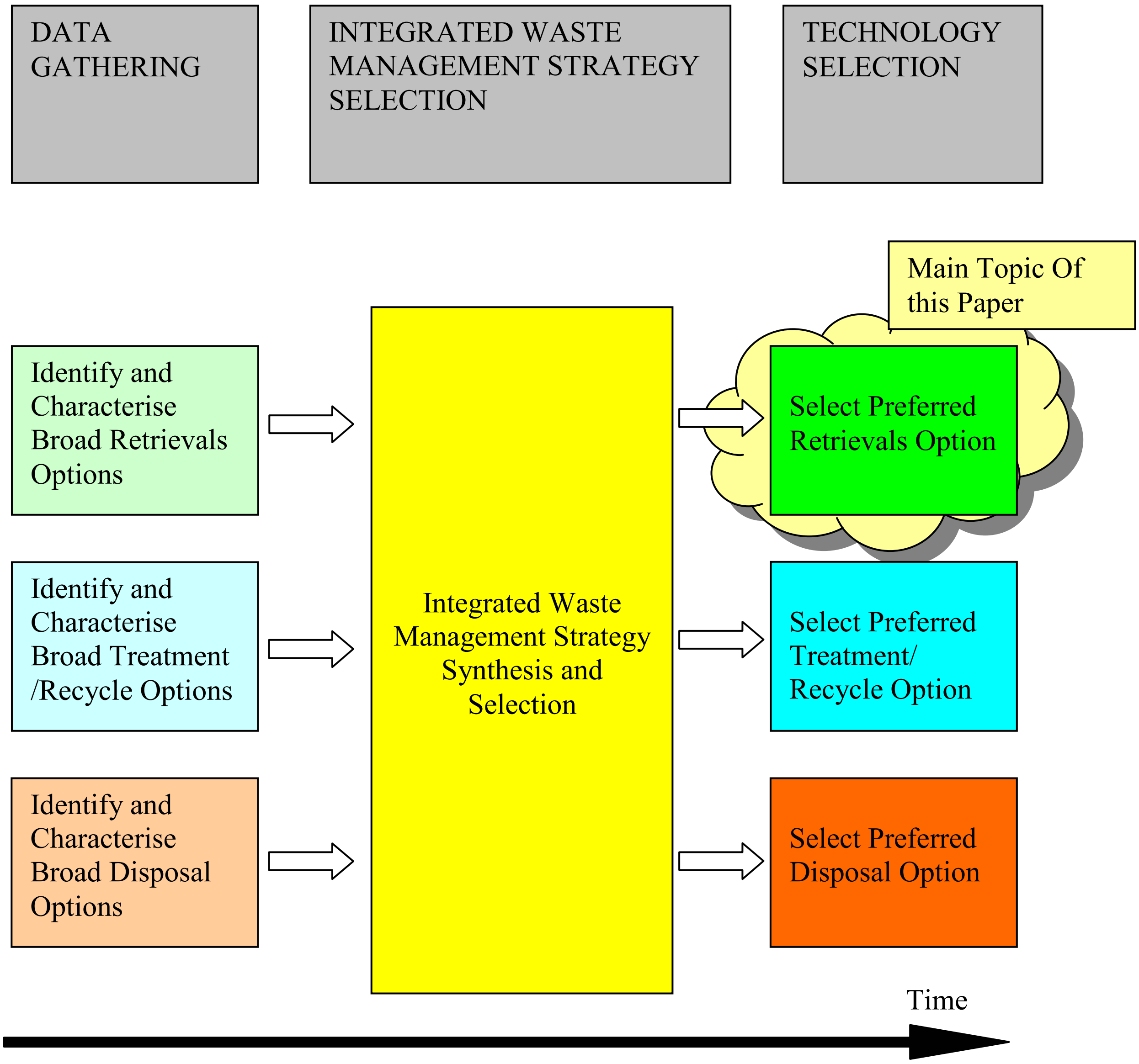

Figure 1: Selecting Strategy and Retrievals Technology

Initially, a set of broad options for irradiated graphite retrievals, treatment (including recycle) and disposal must be identified. A range of potential strategies can then be synthesized using combinations of the broad options. The strategies are then assessed against the strategy selection criteria to select a preferred strategy.

It is expected that the strategy selection will define a number of key decisions that will influence technology selection. In particular it is expected that the strategy will define:

- the decay period prior to beginning retrievals;
- the form in which the graphite is required following retrievals;
- the medium in which retrieval is to be performed (e.g. air or water);
- what segregation is required (e.g. between moderator and reflector graphite, or between graphite and other solid waste); and
- the required end date and so retrievals rate and acceptable duration for development of the retrievals technology.

Finally, detailed technology selection can be performed to deliver the requirements of the preferred strategy option. In addition to strategy issues, technology selection will be influenced by such parameters as reactor and core design/configuration, quantity of irradiated graphite and contamination/impurity values. It is this final step, applied to retrievals technology selection, that forms the main subject of this paper.

3. KEY CRITERIA FOR GRAPHITE RETRIEVAL

A broad range of potential criteria were developed over a number of meetings. Initial concepts were discussed at the workshop in Manchester[1,2]. Further inputs were made at the Gateshead workshop[3]. This resulted in a broad range of criteria; this list was subsequently grouped into a smaller number of retrievals technology selection criteria to minimise the amount of duplication in assessing the various candidate technologies. More recently the integrated waste strategy selection criteria have been developed [6] and these have been reviewed to see whether they suggest additional criteria relevant for selection of retrievals technology. Consideration was also given to deciding whether the various criteria could be viewed solely as constraints, that is whether they acted as “go”/ “no go” decisions rather than requiring options to be compared based on their strengths and weaknesses. Figure 2 has been adapted from the strategy selection process report[6] for use in the selection of retrievals technology.

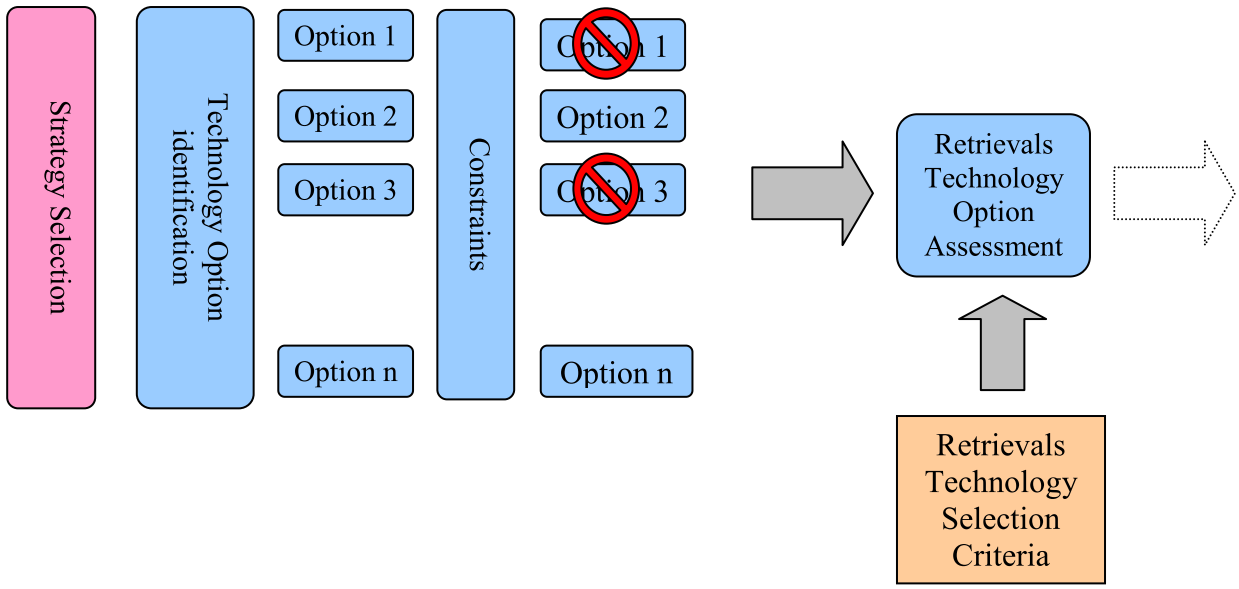

Figure 2: Process for selection of retrievals technology

Following strategy selection, the figure shows that a range of retrievals technology options is available. The options are then screened using a set of constraints. Such constraints may be imposed by the strategy that has previously been selected, or may be imposed by the structure containing the graphite. Constraints may include the need to extract largely intact blocks, deployment issues (such as equipment size and weight), timescale issues (such as the need for high retrieval rates or immediate deployment), shielding constraints (the need to provide adequate shielding) and any other constraint that can eliminate an option from consideration. The result of applying the constraints is a set of feasible options which proceed to assessment using the retrievals technology selection criteria.

Table 1 considers the strategy selection sub-criteria[6] and considers whether these are appropriate for use as retrievals technology selection criteria. The lists of retrievals criteria developed in the workshops [1,2,3] and in an earlier version of this report[5] were reviewed against this table to identify the selection criteria shown in **bold face**. Rows with a relevant criterion are shaded. The retrievals technology selection criteria developed through the process above are summarised in Table 2.

Table 1: Derivation of Retrievals Technology Selection Criteria from Generic Subcriteria

Generic Sub-criterion	Applicability to Retrievals Technology Selection
Radiological impact - man	Selection of technology is not expected to have a great impact on this objective. The strategy defines the required end point (e.g. powder or blocks), decay period prior to retrievals and retrieval medium (e.g. under water, in air, in inert gas) and so will largely dictate this impact. Given these strategic decisions, differences between technologies for producing a similar product are expected to be small.
Radiological impact - environment	A similar argument applies to that for "Radiological impact – man" above.
Resource Usage	**Resource usage**: requirement for the treatment of secondary wastes may result in significant resource use. Resource use can be minimised if equipment can be reused.
Non Radiological discharges	A similar argument applies to that for "Radiological impact – man" above.
Local Intrusion	It is not expected that retrievals technology selection would have a significant impact on local intrusion – noise and light will be inside the reactor bioshield and the technologies are unlikely to result in dramatic visual impact. Size of the technologies is not sufficiently different that vastly different amounts of equipment transport to site would be required.
Hazard Potential	Hazard potential is affected by radiological inventory, form of materials stored and time to realise a potential risk. None of these items is directly affected by retrievals technology selection, though some are affected by the strategy.
Worker Safety - radiological	**Worker safety - radiological** is directly affected by technology selection – particularly by dose incurred during deployment or maintenance of equipment.
Worker Safety – non-radiological	**Worker Safety – conventional** is directly affected by technology selection – particularly the decision of hands on vs remote techniques.
Security - misappropriation	Retrievals technology selection is not expected to impact on the vulnerability of materials to misappropriation. Strategy will have an impact on security by defining end products.
Cost + Spin Off	**Cost** of retrievals technology is an important objective. Cost must be a lifecycle cost, including not only equipment purchase but disposal of PPE and other secondary waste. Spin off from retrievals technology both for use on other decommissioning projects and outside the nuclear industry are possible and must be assessed as a monetary value.

Generic Sub-criterion	Applicability to Retrievals Technology Selection
Concept Predictability	This is a key objective for technology selection and warrants subdivision into a number of contributing parts: • **Simplicity** – gives confidence that the equipment will perform as expected. • **Maturity** – also contributes to confidence that the equipment will perform as expected.
Operational Predictability	This is a key criterion for equipment selection and so has already been considered elsewhere[8]. The technology subcriteria listed there are: • **Versatility** – ability to accommodate a range of process feeds • **Flexibility** – ability to accommodate changes in operating conditions • **Simplicity** – simplicity contributes to operational predictability as well as concept predictability • **Robustness** - inherently reliable equipment will be available when required and will not impose long outages • **Efficiency** - processes require minimal rework and wastage • **Predictability** – able to predict the outcome of decommissioning • **Compactness** – able to deploy equipment in a confined space • **Quality** of product and equipment – ability to test equipment and guarantee consistent product quality
Stability of Employment	Some options require availability of skilled workers and might suggest use of an alternate option if these were in short supply. **Employment** is therefore a relevant retrievals technology selection objective.
Burden on Future Generations	It is not expected that retrievals technology selection would have a significant effect on burden on future generations. Once again this is dictated by strategy.

Table 2: Summary of retrievals technology selection criteria

Retrievals Technology Selection Criterion	Discussion
Resource Usage	Must include the equipment itself, PPE required to operate and maintain the equipment, clean up aerial and liquid effluents and resources used for disposal of the equipment/PPE at the end of its life.
Worker Safety - radiological	Considers dose incurred by operators in operating and maintaining equipment.
Worker Safety – non-radiological	Some technology choices will expose operators to greater hazards such as working at height.
Cost + Spin Off	Cost of retrievals equipment will be a lifecycle cost, including not only equipment purchase but disposal of PPE and other secondary waste. Spin off from retrievals technology both for use on other decommissioning projects and outside the nuclear industry are possible and will be assessed as a monetary value.
Simplicity	Gives confidence that the equipment will perform as expected.
Maturity	Contributes to confidence that the equipment will perform as expected.
Versatility	The ability to accommodate a range of process feeds
Flexibility	The ability to handle variations in the nature of the feed materials and operating conditions is important since perfect characterisation is unlikely to be possible.
Robustness	Inherently reliable equipment will be available when required and will not impose long outages
Efficiency	Processes require minimal rework and wastage
Predictability	Able to predict the outcome of decommissioning operations
Compactness	Able to deploy equipment in a confined space
Quality of product and equipment	The equipment must be able to be tested and deliver the required product consistently
Employment	Access to appropriately skilled operators is required and an option that requires fewer highly skilled workers is more likely to be able to be operable taking into account available skills, sickness and so forth.

4. RETRIEVALS TECHNOLOGY ASSESSMENT

A wide range of retrievals technologies are available[10]. For the assessment performed in this paper, these have been grouped into five broad categories:

1. Robots, tele-manipulator or servo manipulators.
2. Airborne, ground and submerged Remotely Operated Vehicles (ROVs), crawlers.
3. Cranage (existing, purpose built or mobile) (overhead gantry, jib, polar, etc), gantry systems (x,y, z type), telescopic tube principle.
4. Master-Slave Manipulator (MSM) type manipulators (single piece, simple gimbal mounted tongs, 3 piece MSMs), simple hinged arms (mechanical or driven), tool poles, long reach tools (e.g. CeeVee reachers).
5. Manual entry and hands on access (with or without shielding/breathing air systems) within the legal requirements of health and safety (H+S) legislation.

The retrievals technology categories are assessed against the criteria in Table 3. These are necessarily generic assessments which cannot take into account constraints imposed either by strategy or the physical situation of a particular waste stream. When a specific technology is being considered for use on a specific waste stream a strategy will already have been selected for handling that waste stream and a more specific assessment can then be performed.

Table 3: Assessment of Retrievals Technology Categories against Criteria

Criterion	Robots and tele-manipulators	ROVs	Crane or gantry mounted devices	Master-Slave Manipulator type manipulators	Manual deployment within constraints of H+S Legislation
Resource Usage	Can often be redeployed avoiding the need to dispose of the equipment after use.	Can often be redeployed avoiding the need to dispose of the equipment after use.	Cannot typically be reused and so must be disposed of after use. Large amount of equipment to dispose of waste on completion of project. Decontamination may be possible.	Can often be reused. Equipment is smaller than some other options.	Small equipment, but may produce significant amounts of PPE/worn out equipment for disposal.

Criterion	Robots and tele-manipulators	ROVs	Crane or gantry mounted devices	Master-Slave Manipulator type manipulators	Manual deployment within constraints of H+S Legislation
Worker safety – radiological	Remote operations will minimise operator dose uptake, but sophisticated devices will require maintenance/ replacement and hence decontamination/ maintenance facilities will be required and these need to address dose uptake issues. Equipment must be designed to minimise contamination pick up, and have Emergency Recovery features.	Will also reduce operator dose uptake but will still require maintenance/ replacement and hence airlock/ decontamination/ maintenance facilities will also be required. Equipment must also be designed to minimise contamination pick up, and have Emergency Recovery features.	Remote capability will reduce operator dose uptake, but cranes will require inspection/ decontamination/ maintenance facilities and have Emergency Recovery features.	Localised shielding and/or containment facilities may be required to enable operation of these devices. Although using simpler equipment, maintenance/ replacement facilities will still be required.	This option will be the most dose intensive for operations, but will not require any sophisticated maintenance facilities for manual equipment. Will require appropriate PPE e.g. PVC suits, and possibly localised shielding and containment facilities, with extensive radiation/ contamination monitoring equipment.

Criterion	Robots and tele-manipulators	ROVs	Crane or gantry mounted devices	Master-Slave Manipulator type manipulators	Manual deployment within constraints of H+S Legislation
Worker safety – non-radiological	Minimal risk to workers during operations, but robots will require safety mechanisms/ guarding/ interlocking/ to ensure no man/machine conflict during testing/maintenance.	Minimal risk to workers during operations, but ROVs will also require safety mechanisms/ guarding/ interlocking/ to ensure no man/machine conflict during testing/maintenance.	Minimal risk to workers during operations when crane is used remotely.	Workers must be protected from risks such as over straining when manually operating/handling the equipment, possibly working from height etc.	This option presents significant risks which would have to be controlled e.g. from manual handling, slip/trip hazards, poor lighting, gas/fume/dust, confined space, working from height, moving machinery, heat stress, lifting operations/ suspended loads , emergency recovery of personnel etc.

Criterion	Robots and tele-manipulators	ROVs	Crane or gantry mounted devices	Master-Slave Manipulator type manipulators	Manual deployment within constraints of H+S Legislation
Cost+Spin Off	Potentially expensive development and equipment purchase, but reuse of the robot may be possible and may save some expense. Reasonable potential for spin-off applications.	Potentially expensive development and equipment purchase, but reuse of the robot may be possible and may save some expense. Reasonable potential for spin-off applications.	Large, but relatively simple items. Deployment through the bioshield at a reactor may result in additional expense. Unlikely the equipment can be reused so disposal costs must be included. Unlikely to generate spin-off applications.	Simpler equipment that will be cheaper to acquire.	Cheap equipment, but with increased costs of labour and of disposal of used PPE. Unlikely to generate spin-off applications.
Simplicity	This is usually the least simple of the options, although the class spans a wide range of simplicity/ complexity levels.	These devices are not inherently simple, but there is a wide range of simplicity/ complexity levels available between different ROV types.	Cranes are relatively straight forward and simple devices, but nuclearising them tends to compromise this simplicity e.g. by adding in back up redundancy, modularity and emergency recovery mechanisms. The devices may have an impact on structural integrity of reactor that may add complexity.	Some of these devices can be extremely cheap and simple e.g. tool poles, whilst some can be mechanically very complex e.g. through wall MSMs.	Simplest of all, but complex procedures require trained and skilled people to perform them safely and efficiently, and time to prove and perform.

Criterion	Robots and tele-manipulators	ROVs	Crane or gantry mounted devices	Master-Slave Manipulator type manipulators	Manual deployment within constraints of H+S Legislation
Maturity	Extensively used and well proven in outside industries, but their application in the nuclear environment is not as developed or mature. This can cause real problems if the system is poorly designed e.g. due to poor reliability or difficulty in maintenance.	Extensively used and well proven in outside industries, with some limited application in the nuclear environment. Problems can easily arise if the system is not well designed e.g. due to unsuitability to the particular environment such as difficulty in surmounting unexpected obstacles.	Extensively used and well proven in outside industries, and also with many successful applications and proven record in the nuclear field.	These technologies are very mature, well proven and extensively used within the nuclear industry.	Manual access techniques and procedures are well developed and extensively used within the nuclear industry.
Versatility	Potentially very versatile, although this may require reprogramming in some circumstances.	Access may make deployment of ROVs difficult for other work streams.	Fixed location makes using the equipment for multiple streams difficult.	Flexible equipment providing visibility to the target stream is adequate and access can be provided.	Maximum versatility providing man access is available for all work streams.

Criterion	Robots and tele-manipulators	ROVs	Crane or gantry mounted devices	Master-Slave Manipulator type manipulators	Manual deployment within constraints of H+S Legislation
Flexibility	Usually have high dexterity and manoeuvrability to access unexpected areas. Can have high payload capacity, but sometimes their reach is limited and requires other means to access the whole environment. Most machines are designed for operation in air, but a smaller range of underwater devices are available.	Usually have high level of mobility to access a significant part of the work area, but this can be limited by the physical constraints of the environment. Can obtain machines with high payload capacity. Devices for air and underwater use are available.	Good design can provide sufficient work area coverage, and usually have very high payloads. Devices for air and underwater use have been used in the past.	Usually restricted to certain operating envelopes and restricted payloads, but can be moved relatively easily to different locations. Devices for air and underwater use are available.	Hands on access and vision provides great flexibility to cope with the unexpected, but payloads are limited. Not suitable for underwater recovery.
Robustness	Most complex option, hence least likely to be robust. Relies on efficient design to build in high levels of reliability/ maintainability. May need extensive inactive testing to prove acceptable levels of robustness.	Can still be complex equipment and hence can still encounter significant problems with robustness in certain environments. Relies on efficient design to build in high levels of reliability/ maintainability. May need extensive inactive testing to prove acceptable levels of robustness.	Relatively robust equipment but still relies on efficient design to build in high levels of reliability/ maintainability, e.g. modularity to assist maintenance and redundancy to increase reliability.	Simpler equipment hence usually more reliable and maintainable. Usually more easily replaced/ repaired/ disposed of upon failure.	Lowest levels of robustness required for this option but a certain level is still required for workheads otherwise throughput can be compromised and additional man entries are required to recover.

Criterion	Robots and tele-manipulators	ROVs	Crane or gantry mounted devices	Master-Slave Manipulator type manipulators	Manual deployment within constraints of H+S Legislation
Efficiency	Efficiency may improve over time if it is possible to program simple repetitive tasks.	Efficiency will depend on both the tooling and visibility to the workface as well as the skill of the operator.	Efficiency will depend on both the tooling and visibility to the workface as well as the skill of the operator.	Efficiency will depend on both the tooling and visibility to the workface as well as the skill of the operator.	Efficiency depends on ability and training of the workforce. This is often the most efficient option for complex operations.
Predictability	Potentially the most predictable for repetitive tasks, but can be expected to struggle with one-off tasks.	Predictability depends on details of the design.	Movements are predictable, but the performance of the end-effectors needs consideration.	Predictability depends on details of the design and the need to switch between alternate end-effectors.	Predictability can vary between operators depending on level of training and experience.
Compactness	Equipment size depends on the design and required duty.	Equipment size depends on the design and required duty.	The least compact of the options.	Can be compact, but light equipment may be able to handle only light loads.	Equipment is very compact, but access is required for men and possibly additional lighting and air lines.

Criterion	Robots and tele-manipulators	ROVs	Crane or gantry mounted devices	Master-Slave Manipulator type manipulators	Manual deployment within constraints of H+S Legislation
Quality of product and equipment	Automation and repeatability should be possible due to the use of robotics, but still heavily reliant on the material behaviour and environment. Due to complexity of equipment, requires a very high level of quality of equipment, and needs to be fully tested/ proven before deployment.	Similar to robots/tele-manipulators, but perhaps slightly more variable due to the mobility of the ROV. Not quite as demanding as for robots/tele-manipulators.	Robust equipment with large coverage area should assist in ensuring product quality. Lifting equipment inherently has to have a high level of quality and to be tested/inspected at regular intervals.	Will be more reliant on the skill of manual operators than other techniques. Due to the simpler equipment, this option requires a lower level of quality and reliability.	Hands on access is a potentially good means of ensuring consistent product quality, but this is reliant on operators' competence and diligence. Lowest levels of quality required for this option but a certain level is still required for workheads otherwise throughput can be compromised and additional man entries are required to recover.

Criterion	Robots and tele-manipulators	ROVs	Crane or gantry mounted devices	Master-Slave Manipulator type manipulators	Manual deployment within constraints of H+S Legislation
Employment	Usually requires team of skilled operators/ technicians to maintain/ operate. Often reliant on specialist companies to supply/ support/ maintain. Automation has the ability to reduce the demand for a large labour force.	Similar to robots and tele-manipulators, but not quite as demanding.	Probably the least demanding option.	May require skilled operators with experience of handling these tools.	Dependent on the actual dose levels, this option may require a large team of operatives. Usually non specialist / unskilled workers but still require training in nuclear practices.

5. CONCLUSIONS

1. A set of criteria for the selection of irradiated graphite retrieval equipment has been presented.
2. A process for the interaction between overall waste management strategy selection and retrievals equipment selection has been proposed. Selection of an integrated waste management strategy must precede retrievals equipment selection.
3. An assessment of retrievals equipment categories against the criteria has been completed. This will inform detailed assessments required for each waste stream.
4. The retrievals equipment selection criteria may be modified as more information becomes available and the criteria are tested.

6. RECOMMENDATIONS

1. The criteria reported in this paper should be used for further assessment of irradiated graphite retrieval equipment.

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