CARBOWASTE

Treatment and Disposal of Irradiated Graphite and Other Carbonaceous Waste

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MCDA Assessments

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MCDA Assessments

Executive summary

This report summarises the twenty-four options for management of irradiated graphite considered by the CARBOWASTE project, the criteria for their assessment and introduces Multi-Criteria Decision Analysis (MCDA) methods for their comparison.

The report presents the quantitative assessment of a power reactor case study using each of the criteria. This represents the first stage of the MCDA analysis and is achieved by:

- Considering each criterion in turn and examining the impact of each option on that criterion; and
- Considering each option in turn and comparing its impact across all criteria (a pairwise comparison normalised against Option 1: encapsulation and deep repository).

The results presented in this report allow a detailed examination of the impact of each option on each of the criteria. Since the criteria consider a range of unequal measures, with different units, the direct comparison of performance between options is not possible. A future report (Identification of Preferred Options D-1.5.4) will present the remainder of the MCDA process, particularly the assigning of scores and weights to the outcomes of the option flowsheets. This allows the allocation of an overall weighted score for each option, enabling direct comparison and the selection of preferred options. This future report will also consider case studies two (generic test reactor) and three (generic vault) and a sensitivity analysis of the MCDA process.

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List of Acronyms

AGR	Advanced Gas-cooled Reactor
ALARP	As Low as Reasonably Practicable
ANDRA	Agence Nationale pour la Gestion des Déchets Radioactifs
AVR	Arbeitsgemeinschaft Versuchsreaktor (test pebble bed reactor)
BAT	Best Available Technique
CCS	Carbon Capture and Storage
CIEMAT	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
EA	Environmental Agency
EDF	Électricité de France
ENRESA	Empresa Nacional de Residuos Radiactivos
FZJ	Forschungszentrum Jülich
GDF	Geological Disposal Facility
GLEEP	Graphite Low Energy Experimental Pile
HSE	Health and Safety Executive
IAEA	International Atomic Energy Agency
ILW	Intermediate Level Waste
MAUT	Multi Attribute Utility Theory
MCDA	Multi-Criteria Decision Analysis
MTR	Materials Test Reactor
NDA	Nuclear Decommissioning Authority
NECSA	South African Nuclear Energy Corporation
NNL	National Nuclear Laboratory
PGA	Pile Grade A (a grade of graphite)
PSA	Pressure Swing Absorption
R&D	Research & Development
RWMD	(NDA) Radioactive Waste Management Directorate
TRL	Technology Readiness Level
SHS	Self-propagating High temperature Synthesis
SMART	Simple Multi Attribute Rating Technique
UNGG	Uranium Naturel Graphite Gaz Reactor
WAGR	Windscale Advanced Gas Reactor

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1 Introduction

1.1 Flowsheet Options

Work Package 1 of the CARBOWASTE project has developed a set of twenty-four flowsheets for waste management of irradiated graphite (Mierzewska, 2011), which are provided in Appendix 1. These flowsheets have been applied to a case study representing the treatment of graphite contained within a power reactor. This case study has then been assessed using criteria (provided in Appendix 2) developed in year three of the project (Ross and Jarvis, 2009). All the required data, including decontamination performance, costs and discharges to the environment have been gathered from CARBOWASTE partners, the open literature and in some cases, especially regarding costs, estimated based on engineering judgement and a set of reference projects. Every criterion has been quantified for each of the twenty-four flowsheets making up the range of available retrieval, treatment, reuse and disposal options for irradiated graphite.

Each of the twenty-four flowsheet options was expanded into a quantified flow diagram tracking the flow of radionuclides through the various flowsheet steps. The flow diagram was then extended to additionally calculate measures of each of the criteria for option assessment. The result is a set of metrics which assess all aspects of the performance of the flowsheets relevant for waste management option selection. The summarised output from these flowsheets is provided in Appendix 3 – Flowsheet Outputs.

The assumptions that the flowsheets are based on, as well as how numerical values for each of the sub-criteria are calculated are presented in Appendix 4 – Flowsheet Basis Document.

The flowsheet options consider:
- In-situ storage in the reactor;
- Retrieval technique;
- Treatment and conditioning of the primary and secondary wastes;
- Effluent treatment (liquid and aerial);
- Interim storage;
- Transport of wastes and raw materials; and
- Nature of the waste repository.

Three case studies have been identified, requiring graphite disposal from:
- Case Study 1 - A generic power reactor (based on data for a Magnox, UNGG or AGR reactor). This will have a significant inventory of graphite, with high activation and will have additional material (such as thermocouples) associated with the graphite.
- Case Study 2 - A generic test reactor (based on data for Dido or other MTRs). This may have relatively low inventory and activation, and will have minimal additional material.
- Case Study 3 - A generic vault (based on data for a vault such as those at Vandellos or Hunterston). This has an intermediate inventory of graphite, but potentially a wide range of additional wastes mixed with the graphite.

A full Multi-Criteria Decision Analysis (MCDA) process has been performed for the first case study (power reactor). Case studies two and three are considered qualitatively and via sensitivity studies in the future report (Identification of Preferred Options D-1.5.4).

1.2 Assessment Criteria

The concept of achieving a sustainable solution to the challenge of i-graphite waste management is fundamental to the CARBOWASTE project.

The World Commission on Environment and Development (the Brundtland Commission) produced a report in 1987 for the United Nations called 'Our Common Future' (World Commission on Environment and Development, 1987). The 'Brundtland' definition of sustainable development - "development which meets the needs of the present without compromising the ability of future generations to meet their own needs" is commonly referred to as the 'original' or 'classic' formulation of the term. It is from this definition that most interpretations of sustainable development emanate.

The three objectives or 'pillars' of sustainable development are commonly referred to as:

- Safety and Environmental;
- Economy; and
- Society.

These three objectives are adopted for the CARBOWASTE project. These objectives are, however, too broad to be easily assessed, and are therefore supported by seven criteria as follows:

Objective 1: Safety and Environmental	Criterion 1: Environment and Public Safety
	Criterion 2: Worker Safety
	Criterion 3: Security
Objective 2: Economic	Criterion 4: Economic Cost and Benefit
	Criterion 5: Technology Predictability
Objective 3: Social	Criterion 6: Stability of Employment
	Criterion 7: Burden on Future Generations

Each criterion is supported by a number of sub-criteria (detailed in Section 1.4 below and illustrated in Appendix 2). CARBOWASTE provides the data that enables evaluation of options against these sub-criteria. Member states are able to input country and/or region specific factors, including socio-political.

1.3 Criteria

Earlier work for CARBOWASTE (Ross and Jarvis, 2009) has identified that objectives and criteria for MCDA processes must be:

- Discriminatory between options;
- Comprehensive;
- Relevant;
- Manageable in number; and
- Not duplicated.

In this section criteria are discussed with reference to these considerations and are developed in more detail to explain the rationale for inclusion.

1.3.1 Environment and Public Safety

This criterion considers the potential for an option to have impacts on the environment. Since members of the public form part of this environment, impacts on members of the public are also included here. Workers employed on the project to deliver the option are subject to additional hazards and so are considered separately in Criterion 1.3.2 (Worker Safety).

Both regulated discharges to the environment and accidental releases are considered as part of this criterion. Releases may be radiological or non-radiological (e.g. toxic materials), or a mixture of both. Use of natural resources and impacts of operations on ecosystems are also considered here.

1.3.2 Worker Safety

Criterion 1.3.1 (Environment and Public Safety) considered public safety; however the workforce will be exposed to risks over and above those borne by the public since they are working on a decommissioning site. It is therefore important that worker safety is considered to select the preferred strategy option. Both radiological (dose) and non-radiological (e.g. falls, asphyxiation) impacts are considered.

1.3.3 Security

This criterion considers the protection afforded against deliberate, malicious actions. Two aspects are identified: protection against misappropriation of materials and vulnerability of materials and buildings to malicious, purposeful attacks. The criterion also considers any safeguards necessary to support nuclear non-proliferation.

1.3.4 Economic Costs and Benefits

Economic factors include, at their simplest, the cost of delivering the project. This cost will be assessed over all project phases and will include the costs of research and development, design, construction, operation and decommissioning of any facility. Costs include the processing and treatment of wastes and secondary wastes formed as part of operating an option. Economics can also consider the benefits of potential spin-off work. Since timescales can be very long for the complete project (from in-situ to disposed), an appropriate discount rate must be selected and applied.

1.3.5 Technology Predictability

Technology selection will have impacts in several criteria. Emissions and effluents will influence Criterion 1.3.1 (Environment and Public Safety), the nature of the technology (e.g. hands-on vs. remote handling) will affect Criterion 1.3.2 (Worker Safety), capital and operating costs will influence Criterion 1.3.4 (Economic Costs and Benefits). Thus, most performance measures are reflected elsewhere. However, there is uncertainty associated with the feed materials and potentially equipment performance, when it is deployed, and this uncertainty results in the need for this criterion.

This criterion considers both the design uncertainty associated with untested equipment, and the flexibility and robustness of the equipment to variations in the feed and operating conditions.

1.3.6 Stability of Employment

Nuclear power stations tend to be located in remote regions, and are frequently a major local employer. Dramatic swings in employment can therefore have significant local impacts. Closing facilities can result in high unemployment, while construction projects can stretch the local infrastructure, making life unpleasant for local residents. Managed change in employment levels allows the community time to adjust to change.

1.3.7 Burden on Future Generations

A problem with the criteria above is that continual delay appears to be a good option: activity decays, costs are depreciated and arisings of activity are deferred and potentially reduced. However, staff experienced in the operation of the plant retire and knowledge about the nature of the wastes is lost, buildings decay and there are moral concerns in leaving work for future generations when the benefits of the reactor operation have been experienced by the current generation. These aspects are grouped together and assessed as part of this criterion.

1.4 Generic Sub-Criteria

Each of the criteria above has been subdivided into a number of sub-criteria as shown in Appendix 2.

The sub-criteria described below have been developed to deliver the fundamental aim of the CARBOWASTE project of providing a sustainable solution to the challenge of i-graphite waste management. The concept of sustainability for CARBOWASTE has previously been defined. A comprehensive set of sub-criteria which cover all aspects of safety and environmental, economic and social considerations is essential in achieving this aim.

1.4.1 Radiological Impact – Man

This sub-criterion considers the impact of regulated discharges on man. The potential effect of accidents is considered in the separate category “Hazard Potential”. The world collective dose arising from discharges from all facilities associated with an option (storage, retrieval, treatment and disposal) is calculated over a long period (500,000 years has been chosen as an appropriate time horizon, though CARBOWASTE participants can select time horizons appropriate to their waste streams).

The International Commission on Radiological Protection (ICRP) (1996) notes that, although not intended as a tool for epidemiological studies and risk projections, collective dose is nonetheless an instrument for optimisation and for comparing radiological technologies/protection measures. Since the world collective dose is known to be dominated by a large number of very low risks, it is felt that European collective dose is the most appropriate measure and is used as the performance measure for this sub-criterion.

1.4.2 Radiological Impact – Environment

There is no guarantee that a measure of collective dose to man will adequately reflect harm to other parts of the environment. Recently the Environmental Risk from Ionising Contaminants: Assessment and Management (ERICA) (Garnier-Laplace and Gilbin, 2006) programme has established a three-tier approach to assessing the impact of radiation on the environment. The first screening tier defined by ERICA provides a measure of the impact of radiation on the environment. This measure compares the concentration of radioisotopes in the environment to a value which results in a broadly acceptable dose to the most vulnerable organism. When the resulting quantity is summed over all radioisotopes a measure of the impact of the radiation on the environment is obtained.

A tier 1 ERICA assessment therefore produces a measure comparable to collective dose, but applied to the most exposed organisms in the environment rather than to man. The tier 1 ERICA assessment is therefore recommended as the performance measure for this category. The first step of the assessment is the dispersion modelling of discharged activity into the environment, so that concentrations of contaminants can be obtained. In the absence of dispersion modelling, it will be necessary to take the pessimistic view that end-of-pipe concentrations will be used in the assessment. It is possible that the impact on man is proportional to the impact on the environment i.e. that the sub-criterion 'radiological impact – man' acts as a proxy for this criterion. This can only be established after testing and, if it is found to be the case, member states could choose to assess only one of the two sub-criteria.

1.4.3 Resource Usage

Some options may use more resources than others. Resources may include water, power, steel and concrete. 'Resources' can be combined into a single measure by considering the energy used to produce them. For example, the energy used for mining ore, extracting iron and producing steel would all be considered in the impact of using steel. Similarly, the energy used during the extraction and processing of minerals used in the manufacture of concrete can be considered.

This approach assumes that the detriment arising from the use of energy (e.g. global warming as a result of CO_2 discharges) will dominate other detriments such as the depletion of natural resources. This would cease to be true if world stocks of a resource were significantly depleted by the completion of a particular option; this is not expected to be the case for common materials likely to be used for the retrieval, packaging and disposal of i-graphite.

The performance measure for resource usage is therefore the energy used in the lifecycle of each of the resources used for retrieval, treatment and disposal of i-graphite.

1.4.4 Non-Radiological Discharges

In addition to the impact of radiological discharges, the impact of non-radiological discharges will be considered. Similarly to radiological discharges, the impact will be assessed over all stages of the project for a significant period of time. Different discharges can be combined by the use of Environmental Quality Standards to provide reference discharge levels.

1.4.5 Local Intrusion

The other sub-criteria consider national and international impacts of each strategy option. This sub-criterion assesses the local impact of noise, traffic during construction and operations, artificial light, ground vibration and land use on man and the environment.

1.4.6 Hazard Potential

Previous sub-criteria have considered the impact of regulated discharges on man and the environment. However, these sub-criteria have not considered the potential impact of accidents. In principle, such incidents could be incorporated into the sub-criteria above by considering the probability and consequence of each accident. In practice, this results in high consequence and low probabilities being combined. The result is very sensitive to the probability, which is difficult to establish without considerable work and is consequently rather difficult to explain to stakeholders and time-consuming to generate for a wide range of strategies. For this reason, the hazard potential is considered as the performance measure. The emphasis of the sub-criterion is to encourage the selection of passively safe techniques with minimum hazardous inventory, in accordance with radioactive waste management best practice.

1.4.7 Radiological Worker Safety

Sub-criteria above consider public safety; however the workforce will be exposed to risks over and above those borne by the public since they are working on a nuclear licensed site which is undergoing decommissioning. It is assumed that good working practices will protect individuals from receiving an unacceptable dose; however, cumulative dose to the entire workforce is an appropriate measure of radiological safety for workers.

1.4.8 Non-Radiological Worker Safety

The fatality rate for the relevant industry sector(s) provides a suitable indication of the level of risk from non-radiological hazards (e.g. falls, asphyxiation). The rate is derived from the number of employees for each option together with an assessment of the risk to which they are exposed. Risk will be assessed in categories such as “mining”, “construction” and “industrial activity” with established risk profiles.

1.4.9 Security - Misappropriation

The Hazard Potential sub-criterion discussed above encourages passive storage of material to achieve hazard reduction, in accordance with established radioactive waste management standards and guidance. This assists in the mitigation of both accidents and security issues arising from malicious damage. However the protection afforded against deliberate, malicious misappropriation of materials has not been considered. Protection against misappropriation requires storage of materials at secure sites, in secure buildings and in difficult to move packages. Materials must also be protected during transport. The assessment is conducted at the point where waste is most vulnerable, since misappropriation is a deliberate action that can be targeted.

1.4.10 Cost

Cost of project delivery must consider all aspects of the project including research and development, design, capital expenditure and operating costs, with appropriate discounting over the duration of the assessment.

1.4.11 Spin-Off

Investment will lead to spin-off opportunities not directly related to the delivery of the project. For example, metal fabrication skills used in manufacture of waste packages might allow fabrication for other customers, with associated economic benefit. No spin off was identified for any option, therefore all options had values of zero for this category, which was excluded from the assessment of MCDA results.

1.4.12 Concept Predictability

This criterion considers the uncertainty, or ‘readiness’, associated with the technology chosen for a particular option. Mature technology is associated with a lower risk than completely new concepts.

1.4.13 Operational Predictability

This criterion considers the uncertainty associated with the operational phase of a particular option. Uncertainty may be the result of feed variability, unreliability or equipment complexity, or lack of experience with the technology.

1.4.14 Stability of Employment

Delivery of some options will temporarily result in greater levels of employment than others. This sub-criterion considers wider economic concerns such as targeting areas of high unemployment, acquiring transferable skills and stability (rather than absolute levels) of employment.

1.4.15 Burden on Future Generations

A problem with the criteria above is that continual delay appears to be a good option: activity decays, costs are depreciated and arisings of activity are deferred and potentially reduced. However, staff experienced in the operation of the plant retire and knowledge about the nature of the wastes is lost, buildings decay and there are moral concerns in leaving work for future generations when the benefits of the reactor operation have been experienced by the current generation. These aspects are grouped together here under this sub-criterion.

1.5 MCDA Approach

Previously, the various MCDA approaches and tools that are available have been reviewed (Ross, 2009 A and Ross, 2009 B) in relation to the high level objectives of the project. Importantly, the CARBOWASTE project is not intended to identify a single European Union (EU) disposal option but to produce a unified approach that will allow each i-graphite management route to meet its own criteria and authorisation requirements.

Prior to performing MCDA, options must be screened based on the users' constraints. These constraints are expressed as conditions which must be passed for the option to proceed further in the analysis, as shown in Figure 1. One example of a constraint is that options must meet all appropriate national and international legislation. Identification of constraints is also a matter for member states.

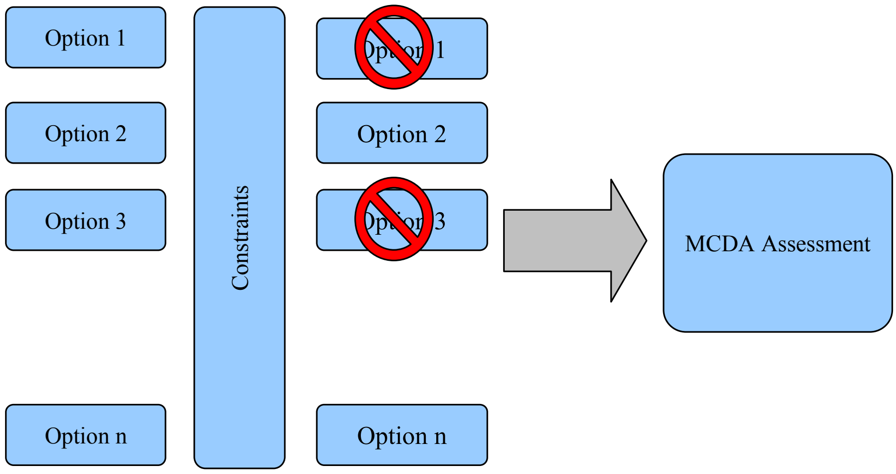

Figure 1 Screening of options based on constraints prior to MCDA

There are many factors that affect and influence the selection of the best route for each waste stream and a rational method of selecting between multiple options, each with different strengths and weaknesses, is required. A review of potential techniques for supporting decision making in the CARBOWASTE project using MCDA tools has been undertaken (Ross, D.N., 2009 A). The aim of using MCDA techniques is to aid decision making, not to take the actual decision itself.

The report draws upon a number previous reviews of decision-making tools and techniques. Several of these have been carried out at national and European levels. The report then describes the MCDA tools and techniques that are prominent in use and in the literature, starting with the most basic 'elementary' techniques and progressing to the more sophisticated and flexible methods.

Prominent MCDA methods include:

- Non-Compensatory 'Elementary' Techniques
- Linear Additive Methods
- Multi Attribute Utility Theory (MAUT) / Simple Multi Attribute Rating Technique (SMART)
- Analytic Hierarchy Process (AHP)
- Outranking
- Ideal Point Methods
- 'Fuzzy' Data Sets

A further report selecting the most suitable MCDA methodologies for the CARBOWASTE project (Ross, D.N., 2009 B) presented the following conclusions:

- No single MCDA technique out-performs the others;
- Three of the leading MCDA methods (MAUT (including SMART and Linear Additive), AHP and Outranking) are suitable for deployment in the MCDA tool box and will be carried forward into the next phase of support software evaluation;
- Several previous (and current) EU projects have studied MCDA in depth, providing 'benchmarks' for the CARBOWASTE project;
- A top level set of criteria suitable for use in the CARBOWASTE project has been proposed; and
- Software systems are available to support the methods; some of the simpler methods require minimal programming.

The remainder of this report details the first stage of the MCDA analysis:

- Considering each criterion in turn and examining the impact of each option on that criterion; and
- Considering each option in turn and comparing its impact across all criteria (a pairwise comparison normalised against Option 1: encapsulation and deep repository).

The results presented in this report allow a detailed examination of the impact of each option on each of the criteria. Since the criteria consider a range of unequal measures, with different units, the direct comparison of performance between options is not possible. A future report (Identification of Preferred Options D-1.5.4) will present the remainder of the MCDA process, particularly the assigning of scores and weights to the outcomes of the option flowsheets. This allows the allocation of an overall weighted score for each option, enabling direct comparison and the selection of preferred options. This future report will also consider case studies two and three and a sensitivity analysis of the MCDA process.

A WP1 MCDA workshop (Abrahamsen, 2013) took place over three days, 9th to 11th January 2013. The workshop reviewed a selection of the results presented in this report and some key points and conclusions made during this workshop are referred to in the discussion of this report.

The workshop also demonstrated the MCDA tool developed by NNL for the selection of preferred options for i-graphite. The workshop explored the different user options for scoring and weighting against previously agreed criteria and considered country-specific constraints and methods of incorporating them into the MCDA process. Further details of the scoring and weighting methods employed will be provided in the future Identification of Preferred Options report.

2 Results

The results presented here are the measures for each criterion against the twenty-four options for management of irradiated graphite considered by the CARBOWASTE project. Large values represent poor performance in that criterion, but this is not necessarily illegal or intolerable. It is expected that illegal, or otherwise unacceptable, options will be removed from the assessment prior to assessment. In order to present a full range of results no options have been removed from the assessment.

2.1 Assessment of Options: Effect on Each Criterion

2.1.1 Environmental and Public Safety

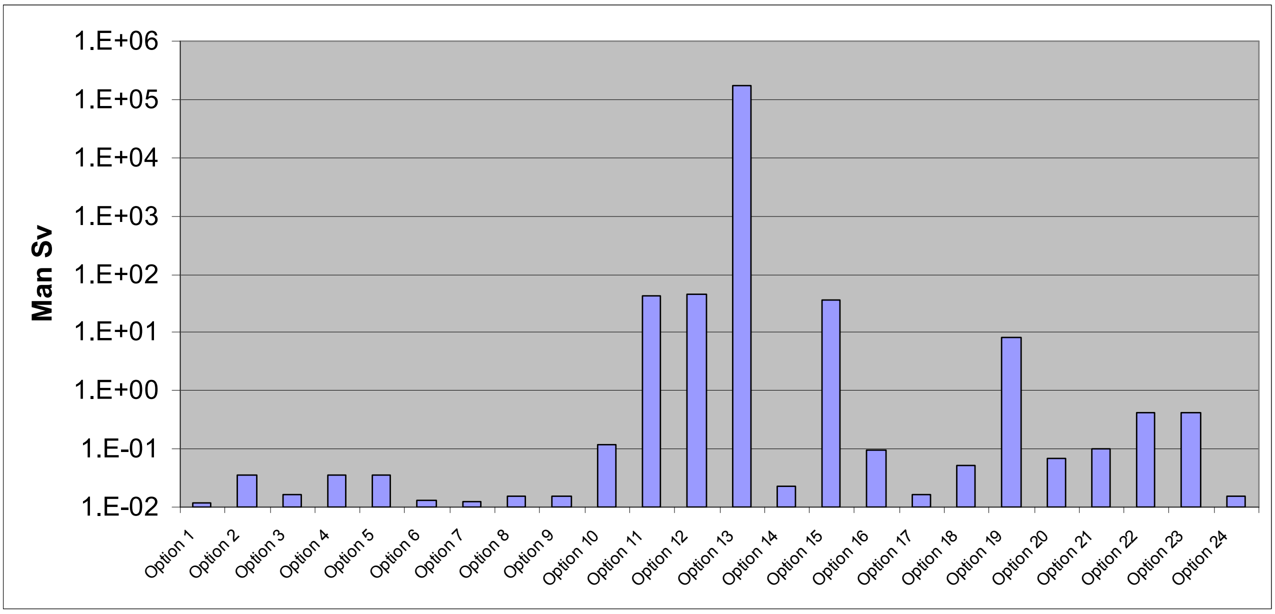

Figure 2 Public Safety: Routine Discharges measured across all options

- Option 13 (Gasification and isotopic dilution with conventional fossil fuel CO_2) is by far the worst performing option for this criterion as this leads to the highest discharges because the entire ^{14}C inventory of the reactor is discharged to air.
- Options 11 (In situ treatment and near-surface repository) and 12 (Ex situ treatment and near surface repository) perform worse than others due to the relatively higher risk associated with a near-surface repository and the use of heat treatments that increase aerial discharges.
- Option 15 (Gasification and isotopic dilution by dispersal as carbonate in the sea) performs badly due to release of the entire ^{14}C inventory to sea.
- Option 19 (In-situ entombment) performs badly due to releases following entombment (no benefits of a repository).
- Options 1, 3, 6 and 7 perform well due to the use of a deep geological repository.

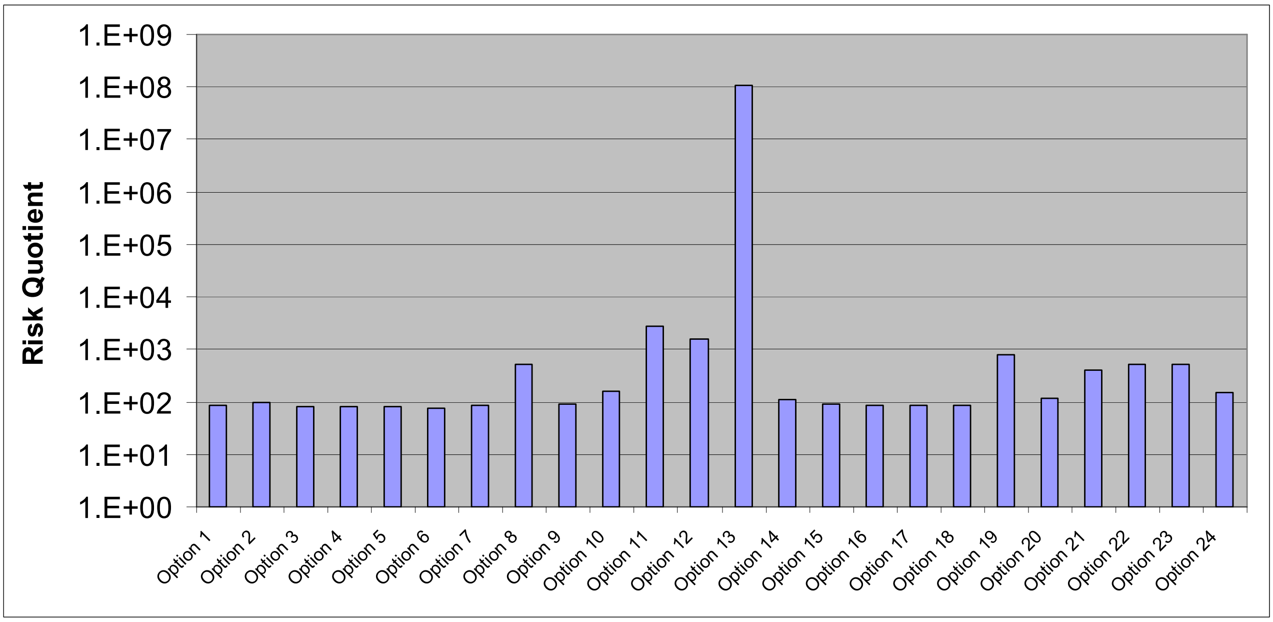

Figure 3 Environmental Safety: Routine Discharges measured across all options

- Again, Option 13 (Gasification and isotopic dilution with conventional fossil fuel CO_2) is by far the worst performing option for this criterion as this leads to the highest discharges.
- Options 11 (In situ treatment and near-surface repository) and 12 (Ex situ treatment and near surface repository) perform worse than others due to the relatively higher risk associated with a near-surface repository and the use of heat treatments that increase aerial discharges.
- Option 19 (In-situ entombment) performs badly due to releases following entombment (no benefits of a repository).
- Option 15 performs relatively well in comparison to its performance for public safety: routine discharges. This is a result of the environmental measure being concentration based, while the public safety measure is total activity based. Early discussion suggested these might be combined into a single measure, but the difference in relative performance suggests this is not appropriate and so the two measures have been retained.

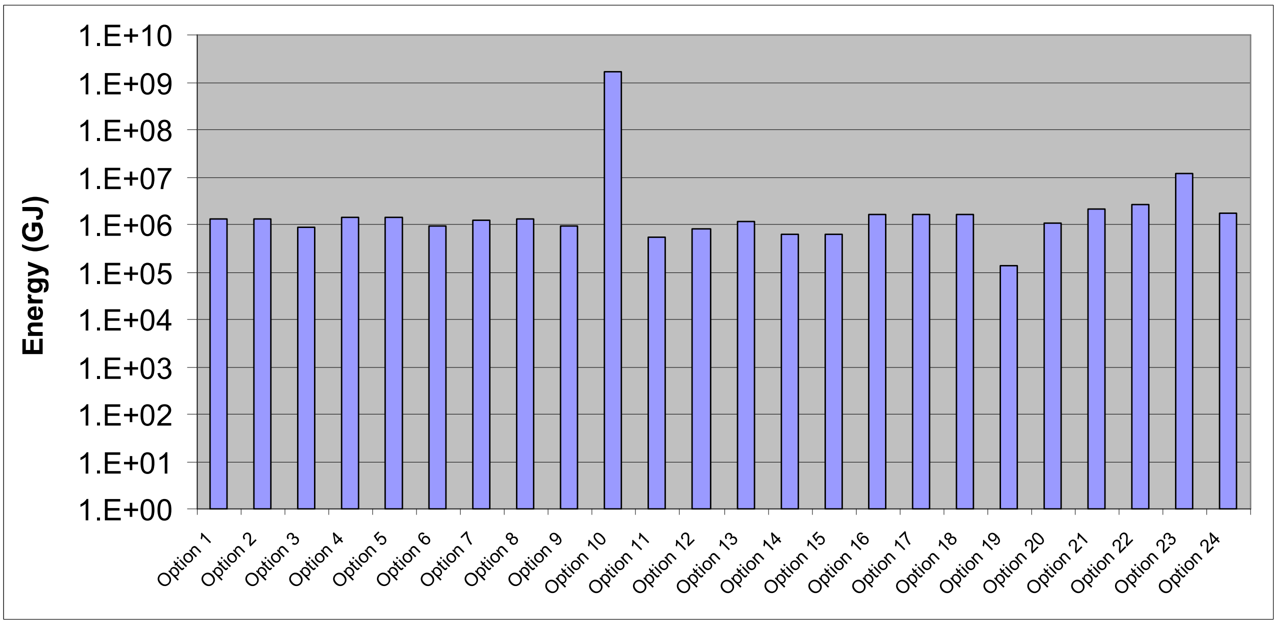

Figure 4 Environment and Public Safety: Resource Usage measured across all options

- Option 10 (Alternative retrieval, encapsulation and intermediate storage) is by far the worst performing option for this criterion, due to the higher resource usage associated with continually replacing surface storage facilities (calculated for 500,000 years of storage).
- Option 23 (Chemically bind ^{14}C) performs badly in terms of resource usage due to the chemical process considered.
- Option 19 (In-situ entombment) has a low resource usage due to it not including a repository.

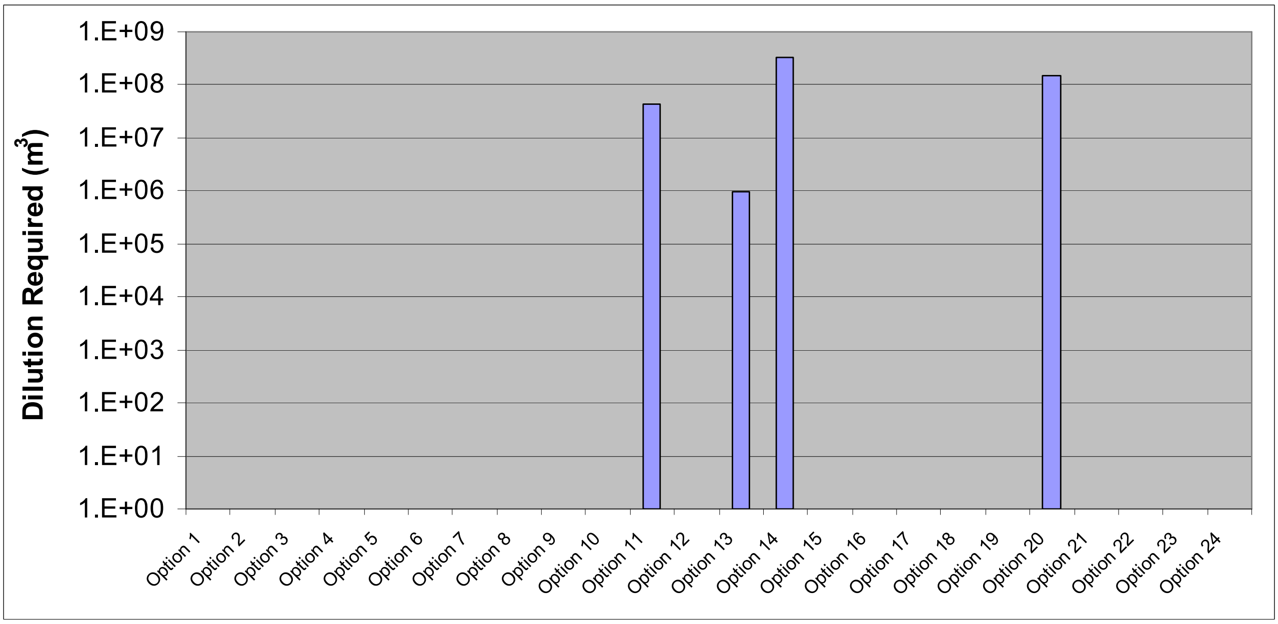

Figure 5 Public Safety: Non-Radioactive Discharge measured across all options

- Very few options had associated non-radioactive discharges. Option 11 generates CO_2 via the in-situ heat treatment process. Option 13 generates inactive CO_2 discharges as a result of incineration of the graphite. This is one case where CO_2 is produced directly, and so was considered as a discharge. All options have indirect CO_2 production, but this is not captured here because it would double count the resource use and truck journeys criteria.

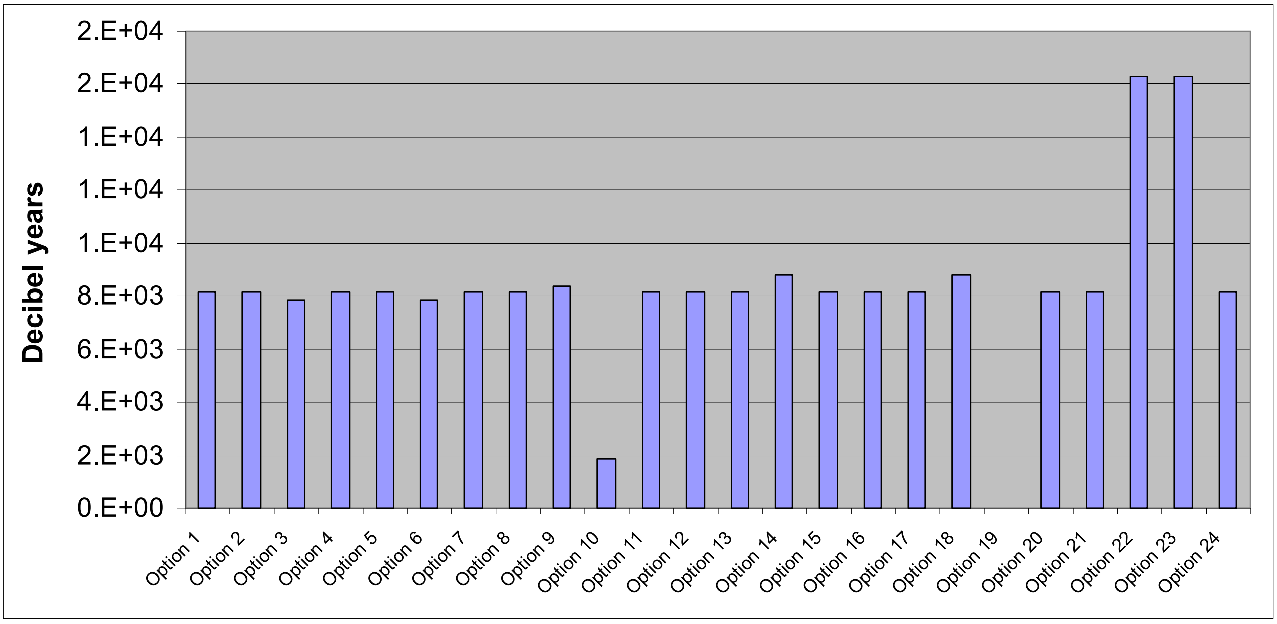

Figure 6 Environment and Public Safety: Local Intrusion: Noise measured across all options

- Option 19 (in-situ entombment) has no impact on noise due to there being no treatment, storage, transport or repository stages. The construction of the sarcophagus takes place on site.
- Option 10 (Alternative retrieval, encapsulation and intermediate storage) has a low impact on noise, since no off-site facilities (e.g. a repository) are built. Continually replacing the stores has no associated impact on noise.
- Options 22 and 23 (Immobilise in medium impermeable to ^{14}C; and Chemically bind ^{14}C) have much larger associated noise due to the construction of both near-surface and deep geological repositories.

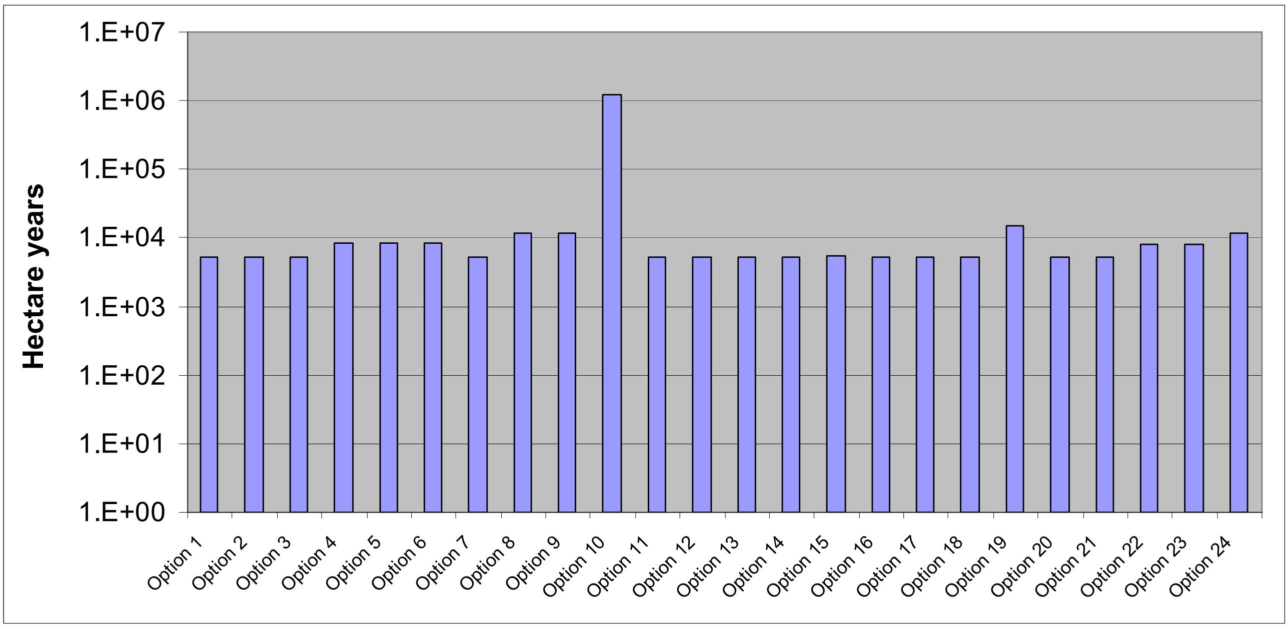

Figure 7 Environment and Public Safety: Local Intrusion: Land measured across all options

- Option 10 (Alternative retrieval, encapsulation and intermediate storage) performs the worst for this criterion, due to the presence of surface storage facilities for a prolonged period.
- Option 19 (in-situ entombment) performs second worst, due to the presence of the entombed reactor for a prolonged period.

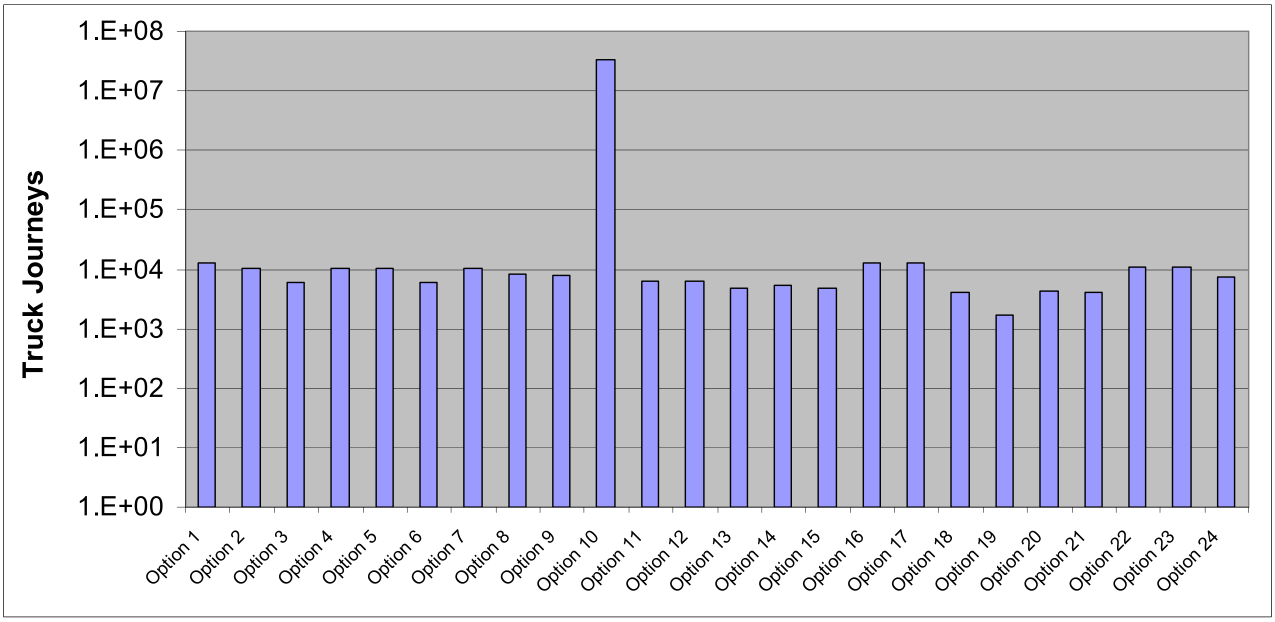

Figure 8 Environment and Public Safety: Local Intrusion: Transport measured across all options

- Option 10 (Alternative retrieval, encapsulation and intermediate storage) performs the worst for this criterion, due to the large number of truck journeys required to bring materials for the continual replacement of surface stores.
- Option 19 (in-situ entombment) has the lowest number of truck journeys, since the only transport required is the movement of materials for entombment to the reactor site.
- Options 18 (Graphite re-use for nuclear application only), 20 (Waste volume reduction and emission to atmosphere) and 21 (Immobilise in medium impermeable to ^{14}C) have a lower number of truck journeys since the processes consider a fraction of the ^{14}C being diverted elsewhere, with less i-graphite requiring consignment to a repository.

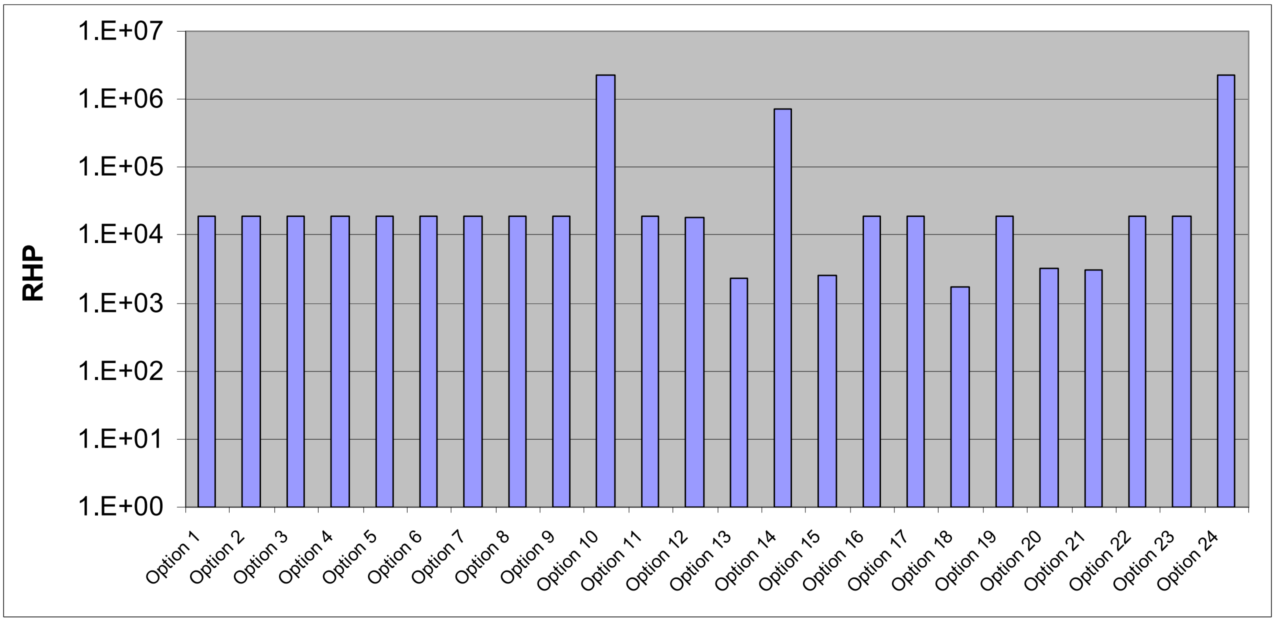

Figure 9 Environment and Public Safety: Hazard Potential measured across all options

- Option 10 (Alternative retrieval, encapsulation and intermediate storage) performs the worst for this criterion, due to the 100 year interim storage period of i-graphite in particulate form before encapsulation.
- Option 24 (Interim storage of raw waste and repository) has a high hazard potential due to the 100 year interim storage period of i-graphite in block form before encapsulation.
- Option 14 (Gasification and isotopic dilution with conventional fossil fuel CO_2 as a result of sequestration) has a high hazard potential due to the long-term storage of sequestered CO_2 in a deep geological store.

2.1.2 Worker Safety

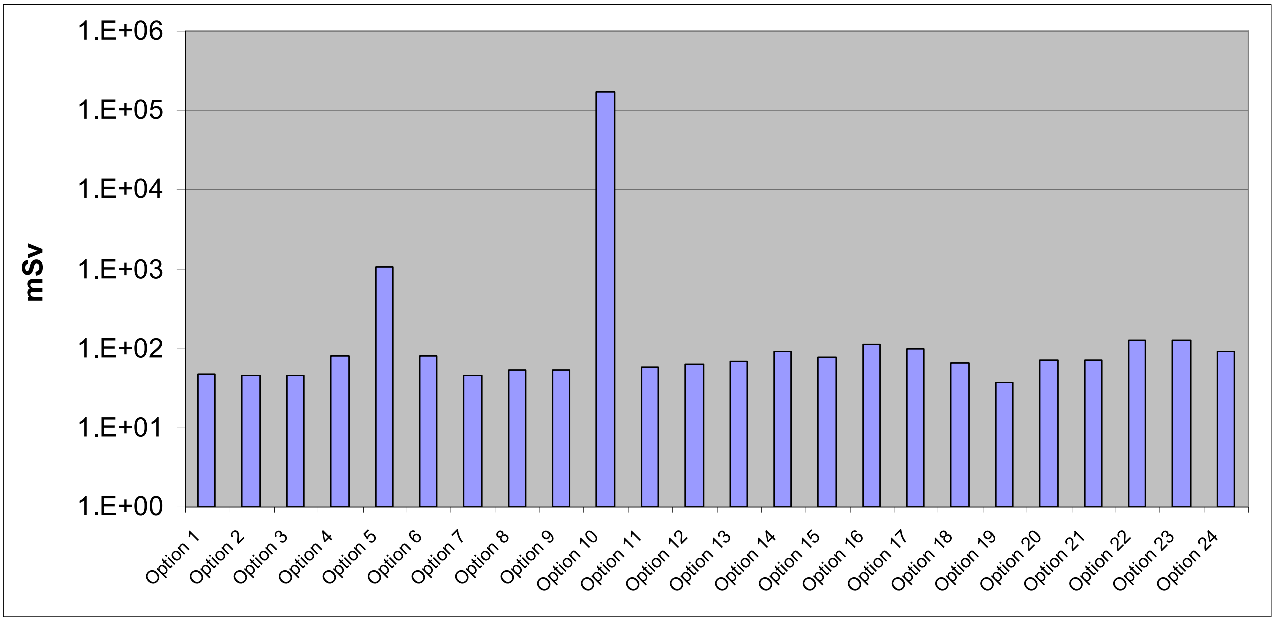

Figure 10 Worker Safety: Radiological Safety measured across all options

- Option 10 (Alternative retrieval, encapsulation and intermediate storage) performs the worst for this criterion, due to the doses arising from monitoring and maintenance of storage facilities for a prolonged period.
- Option 5 (Deferred start with manual retrieval) performs badly compared to other options due to its manual retrieval step, despite a 75 year delay before retrieval.

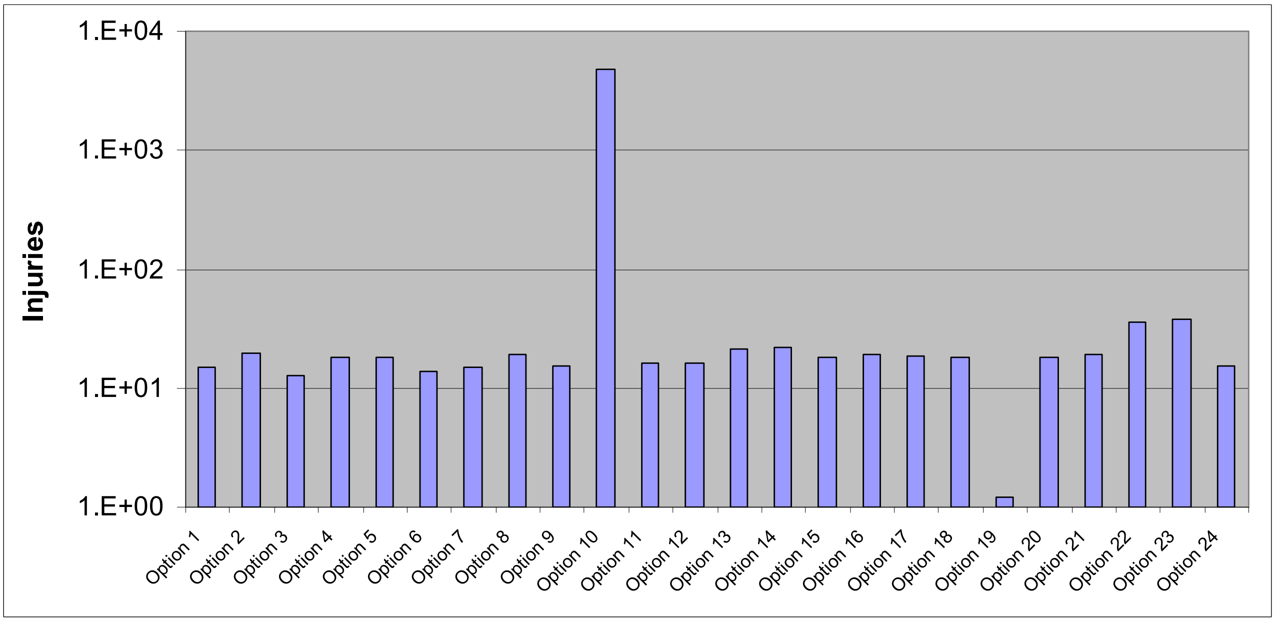

Figure 11 Worker Safety: Conventional Safety measured across all options

- Option 10 (Alternative retrieval, encapsulation and intermediate storage) performs the worst for this criterion, due to injuries associated with the continual replacement of surface stores.
- Option 19 (in-situ entombment) has a low number of injuries due to the low number of workers required in the process.

2.1.3 Security

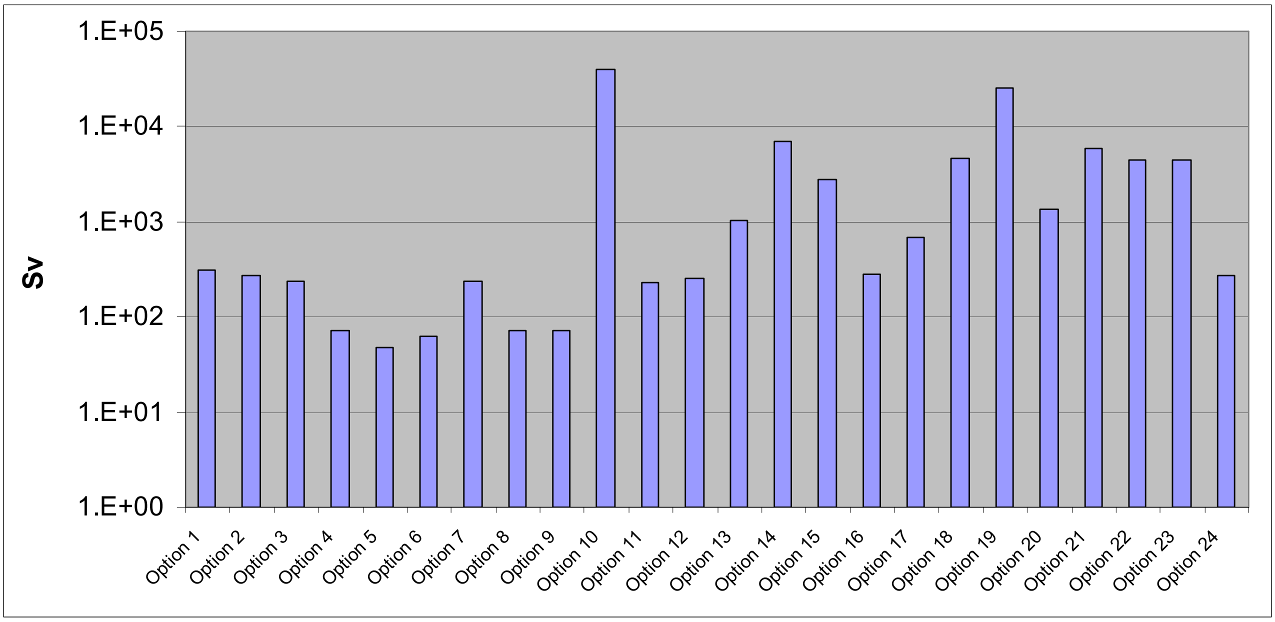

Figure 12 Security Misappropriation measured across all options

- Option 10 (Alternative retrieval, encapsulation and intermediate storage) performs the worst for this criterion, due to the prolonged period that i-graphite remains in surface stores, which are more vulnerable to misappropriation than a repository.
- Option 19 (in-situ entombment) performs badly due to the vulnerability of an entombed reactor compared to a repository.

2.1.4 Economic Costs and Benefits

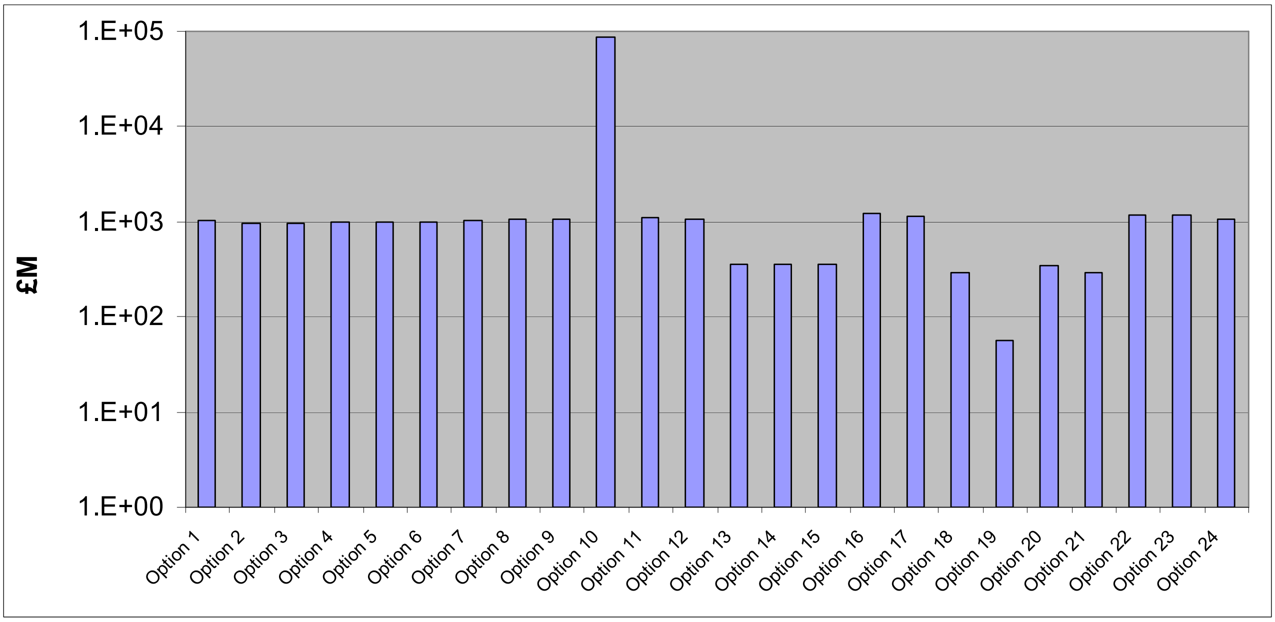

Figure 13 Economic Costs measured across all options

- Option 10 (Alternative retrieval, encapsulation and intermediate storage) has the highest associated costs due to the continual replacement of surface stores.
- Option 19 (in-situ entombment) has the lowest costs due to the lack of any construction stages other than the entombment itself.
- Options 13 (Gasification and isotopic dilution with conventional fossil fuel CO_2), 14 (Gasification and isotopic dilution with conventional fossil fuel CO_2 as a result of sequestration), 15 (Gasification and isotopic dilution by dispersal as CO_3 in the sea), 18 (Graphite re-use for nuclear application only), 20 (Waste volume reduction and emission to atmosphere) and 21 (Make use of graphite as inert filler, removing the need for some encapsulation) have a lower cost due to a fraction of the ^{14}C being diverted elsewhere (with less i-graphite requiring consignment to a repository) or to a near-surface repository.

2.1.5 Technology Predictability

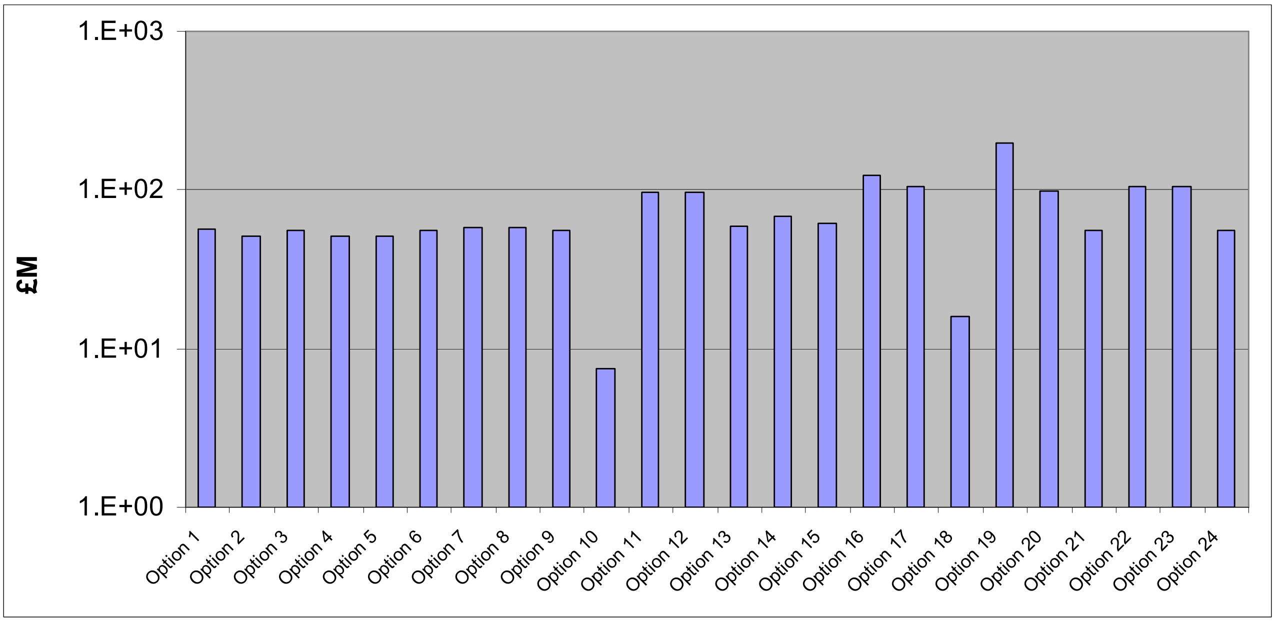

Figure 14 Technology Predictability: Concept: Cost to Fully Develop across all options

- Option 10 (Alternative retrieval, encapsulation and intermediate storage) has the lowest associated costs to develop the concept since storage facilities are a well developed, mature technology.
- Option 18 (Graphite re-use for nuclear application only) is considered to utilise well-developed technologies (noting that economic viability is not considered in this sub-criterion).
- Option 19 (in-situ entombment) would face difficulties in demonstrating entombment as a safe, long-term option for i-graphite.

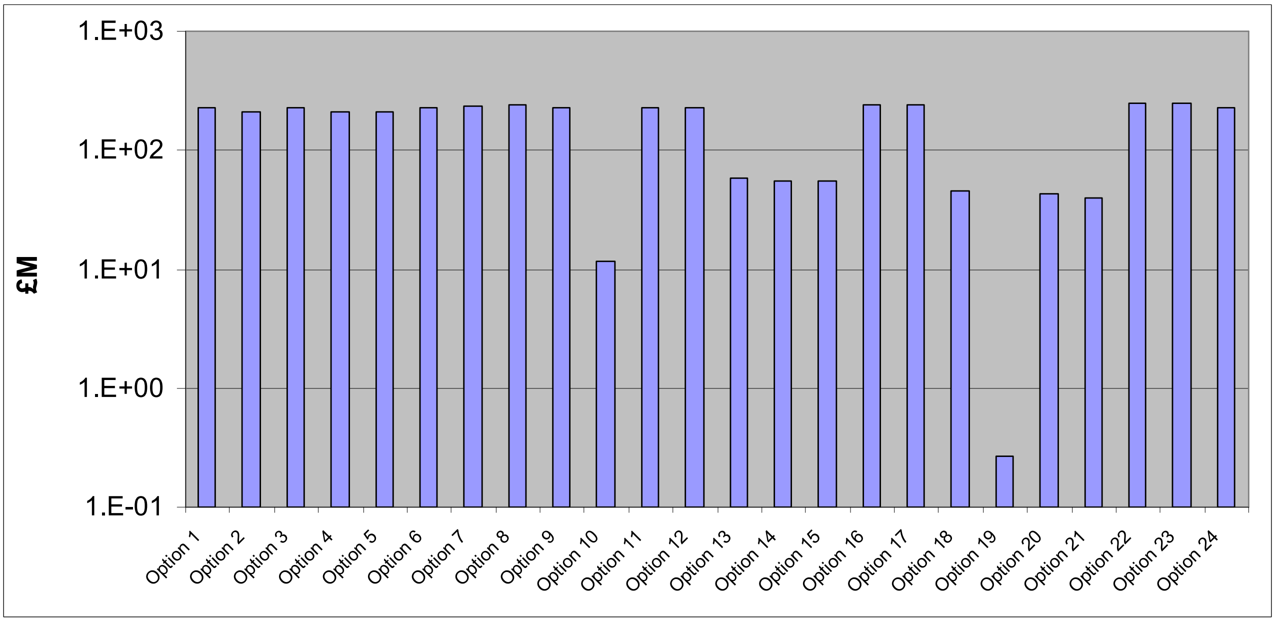

Figure 15 Technology Predictability: Operational: Cost as a Result of Risk measured across all options

- Option 19 (in-situ entombment) has the lowest associated costs as a result of risk since, once proven, the entombment process is expected to have low technical risk.
- Option 10 (Alternative retrieval, encapsulation and intermediate storage) has the second lowest associated costs as a result of risk, since the construction of stores has a low risk of failure.

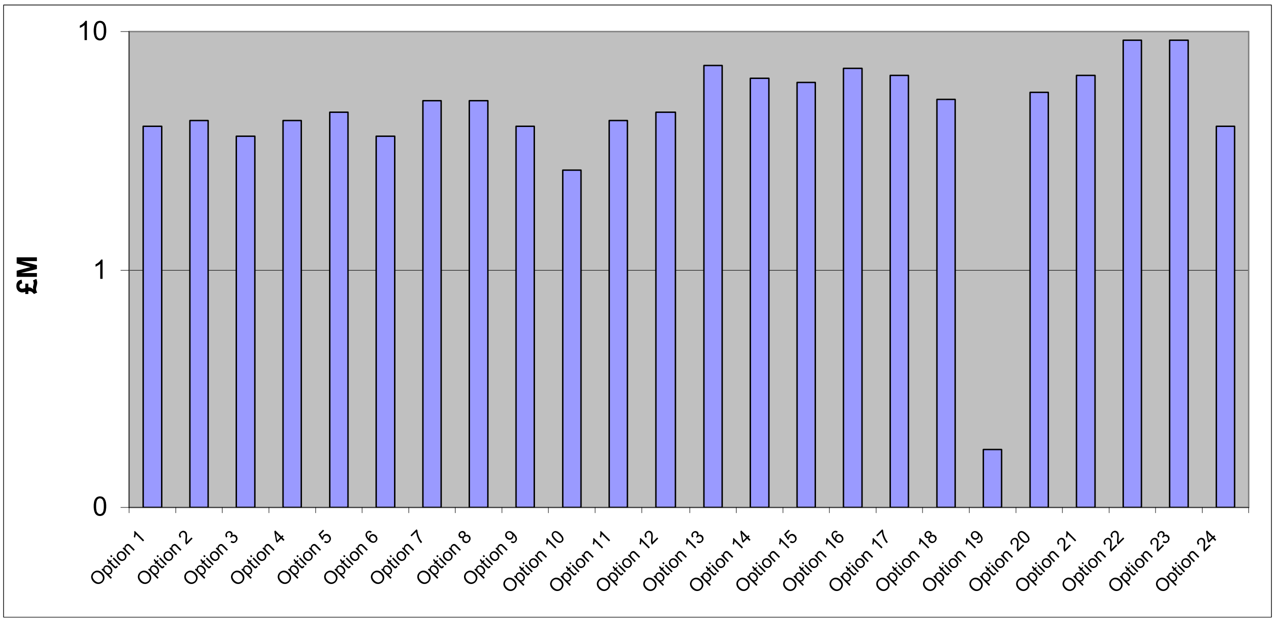

Figure 16 Technology Predictability: Operational: Cost of Delay as a Result of Risk measured across all options

- Option 19 (in-situ entombment) has the lowest delay as a result of risk since, once proven, the entombment process is expected to have low technical risk.
- Otherwise, this criterion does not provide a great deal of differentiation between the options.

2.1.6 Stability of Employment

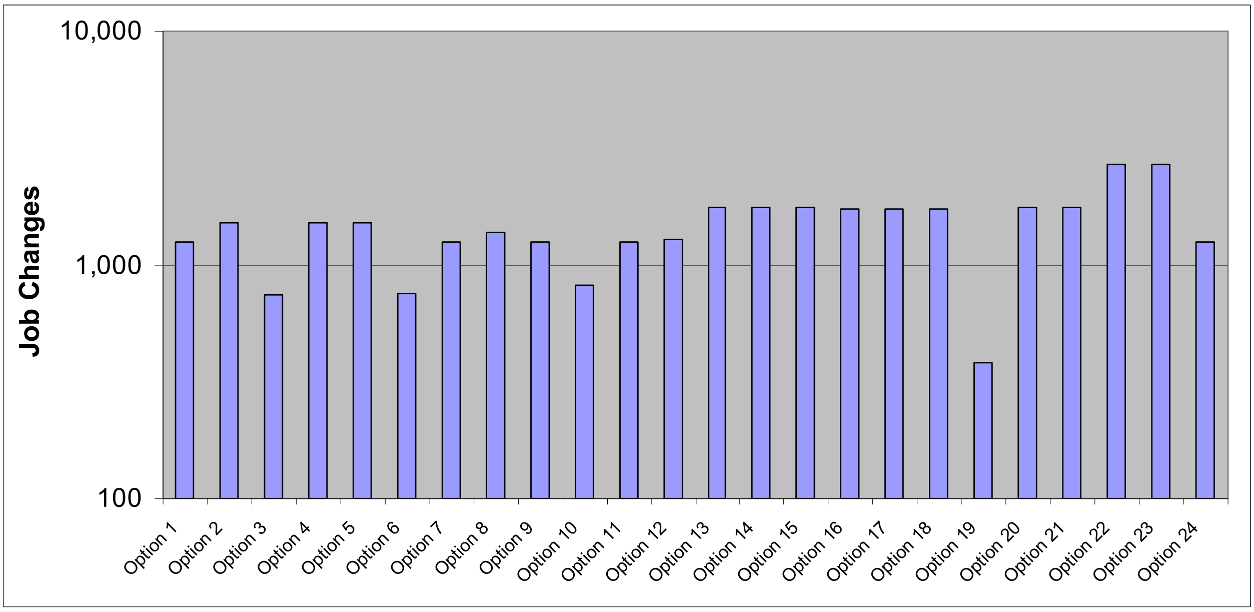

Figure 17 Stability of Employment measured across all options

- Option 19 (in-situ entombment) has the lowest associated number of job changes, since no further facilities are constructed.
- Otherwise, this criterion does not provide a great deal of differentiation between the options.

2.1.7 Burden on Future Generations

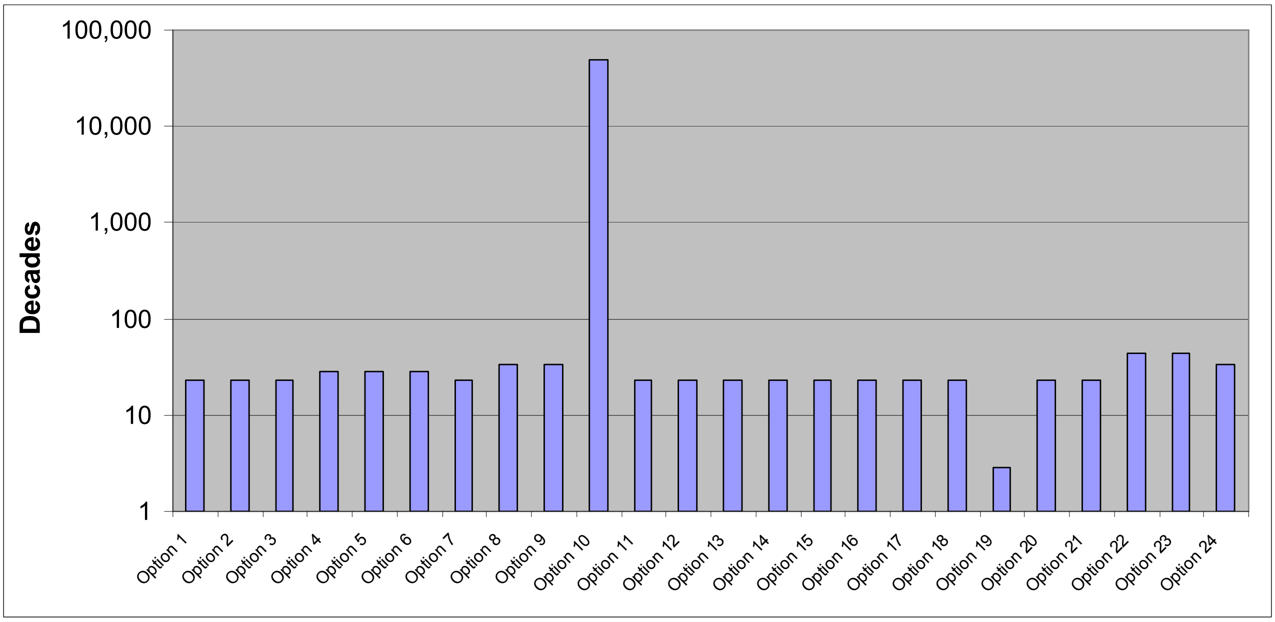

Figure 18 Burden on Future Generations measured across all options

- Option 10 (Alternative retrieval, encapsulation and intermediate storage) has the largest burden on future generations due to the continual replacement of stores that is required.
- Option 19 (in-situ entombment) has the lowest burden, since the entombed reactor is assumed to require no further intervention or monitoring.

2.2 Assessment of Options: Pair-wise Comparison of Options

An alternative method for comparing options prior to scoring and weighting is pair-wise comparison. This technique compares directly the measures for each of the criteria between two options. No weighting is used, and so it is not possible to produce an overall score for each option. Each of the sub-criteria must be considered individually when making the comparison, rather than judging overall performance.

The comparison is made by considering the relative difference between the measures of each option, e.g. when comparing option x to option y, the value of radiological worker safety in option x is divided by the equivalent value in option y and then expressed as a percentage. Since one value is being divided by another, the comparison is dimensionless. A value of 100 indicates a measure in that criterion that is equivalent to option 1 (Encapsulation and deep repository). A value greater than 100 indicates a higher measure in that criterion (poorer performance) and a value less than 100 indicates a lower measure in that criterion (improved performance).

Of course, pair-wise comparison of any options is possible. The following figures show the pair-wise comparison of Options 2 to 24 with Option 1. Values for the non-radioactive discharges criterion were not generated for the large majority of options as it was recognised that non-radiological impacts such as CO_2 output are already accounted for in other criteria (e.g. power usage). For this reason, this criterion is set to zero for the pair-wise comparisons. No spin-off technologies were identified during the optioneering process and therefore the spin-off criterion has been removed from the assessment.

The pair-wise comparisons are presented in Figure 19 to Figure 41 together with key points for consideration.

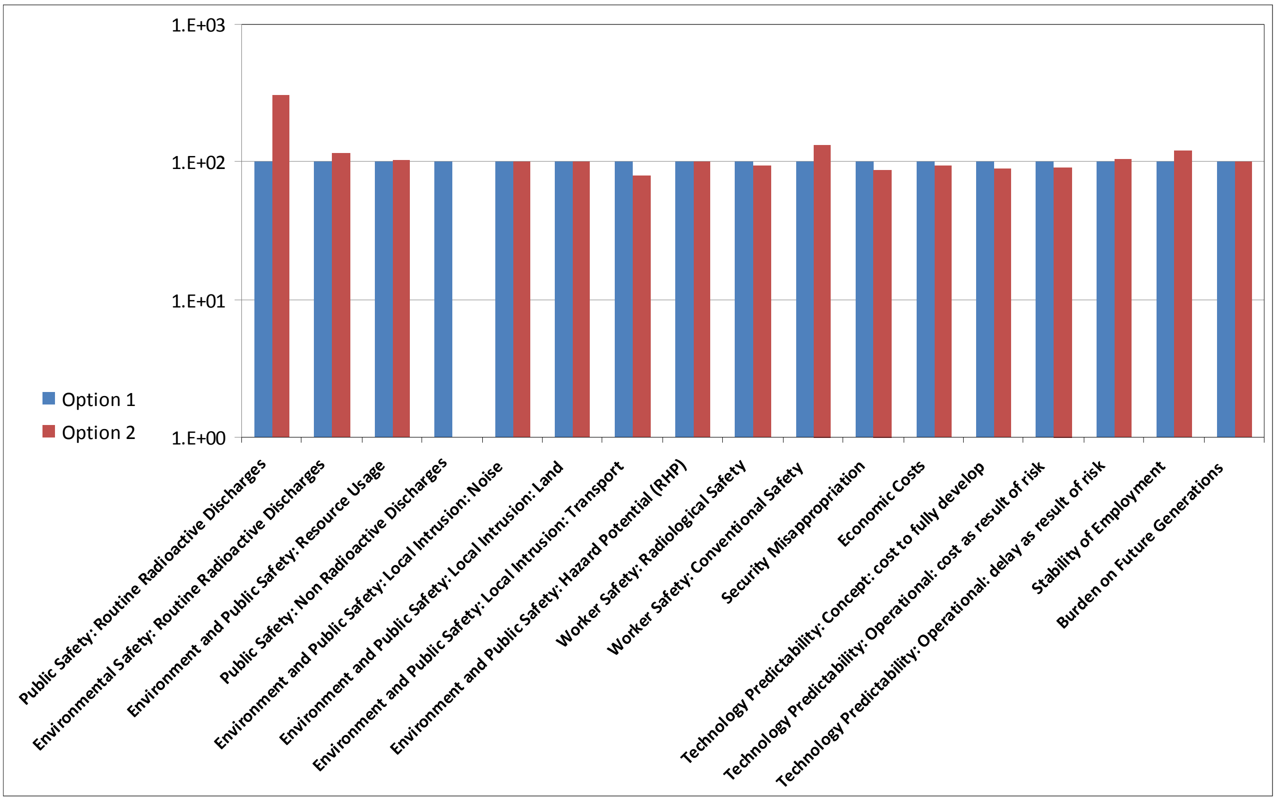

Figure 19 Option 2 sub-criteria measures normalised against Option 1

- Option 2 (Size reduce graphite for minimised waste package volume; local immobilisation) has a higher measure of radioactive discharges, due to the additional size reduction processing step. Otherwise, the differences between these two options are relatively small.
- The stability of employment is slightly worse due to the extra size reduction step. During the MCDA workshop it was noted that in the USA existing staff are often retrained to perform new roles, which was considered unlikely to be feasible in this case as a result of the 25 year delay prior to decommissioning the reactor.

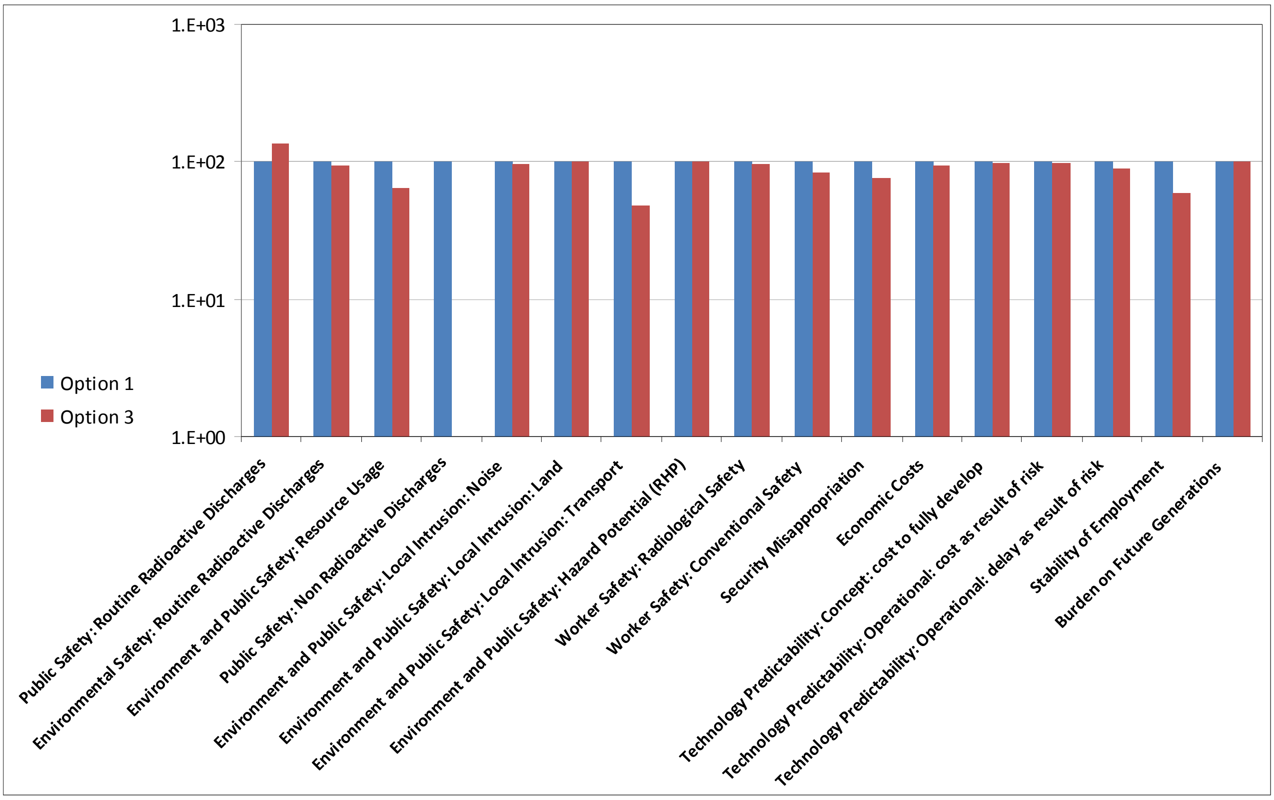

Figure 20 Option 3 sub-criteria measures normalised against Option 1

- Notable differences between Option 3 (Minimum processing) and Option 1 include a lower resource usage, lower number of truck journeys and fewer job changes, all due to the fewer processing steps in this option.
- The impact on public safety via radioactive discharges is greater in Option 3 since the waste is not encapsulated in grout, resulting in greater discharges.
- During the MCDA workshop it was noted that the packaging of raw i-graphite waste (without the use of an immobilising matrix, such as grout) is likely to be unacceptable in many partner countries due to the voids that would be present.

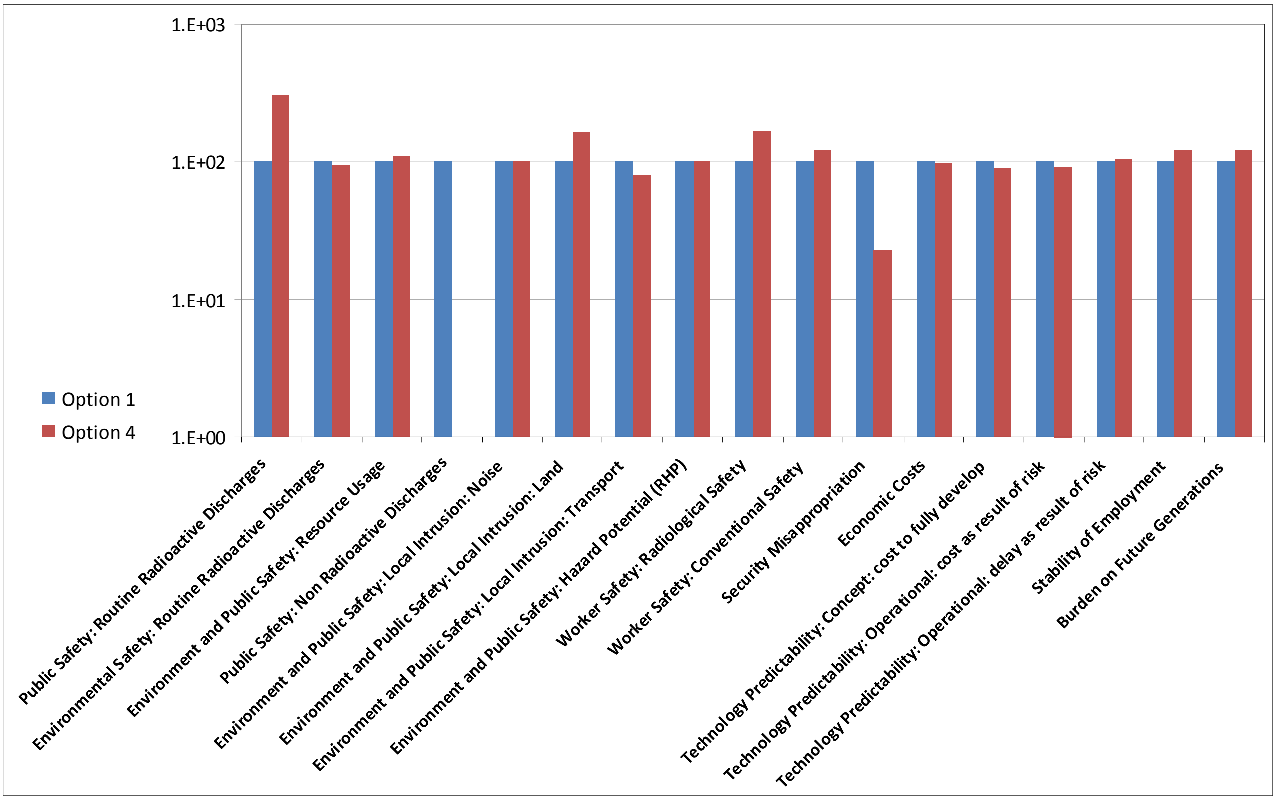

Figure 21 Option 4 sub-criteria measures normalised against Option 1

- Notable differences between Option 4 (Deferred start with remote retrieval) and Option 1 include greater radioactive discharges to the public, due to the prolonged in-situ storage period.
- Security misappropriation is calculated to be improved compared to Option 1, since a greater fraction of activity has decayed before retrieval from the reactor (with its greater number of security barriers).
- There is a greater local intrusion due to land use and greater doses to workers due to the extended in-reactor storage period. This is a result of the required monitoring during storage.
- During the MCDA workshop it was noted that significant technical knowledge would be lost over a 75 year in-reactor storage period, which is not accounted for. Additionally, repeated safety cases would likely be required. It is thought that this option would be unacceptable in some partner countries due to the difficulty in guaranteeing the structural integrity of the reactor for this period, although the cost of minimal monitoring of the structure has been included.

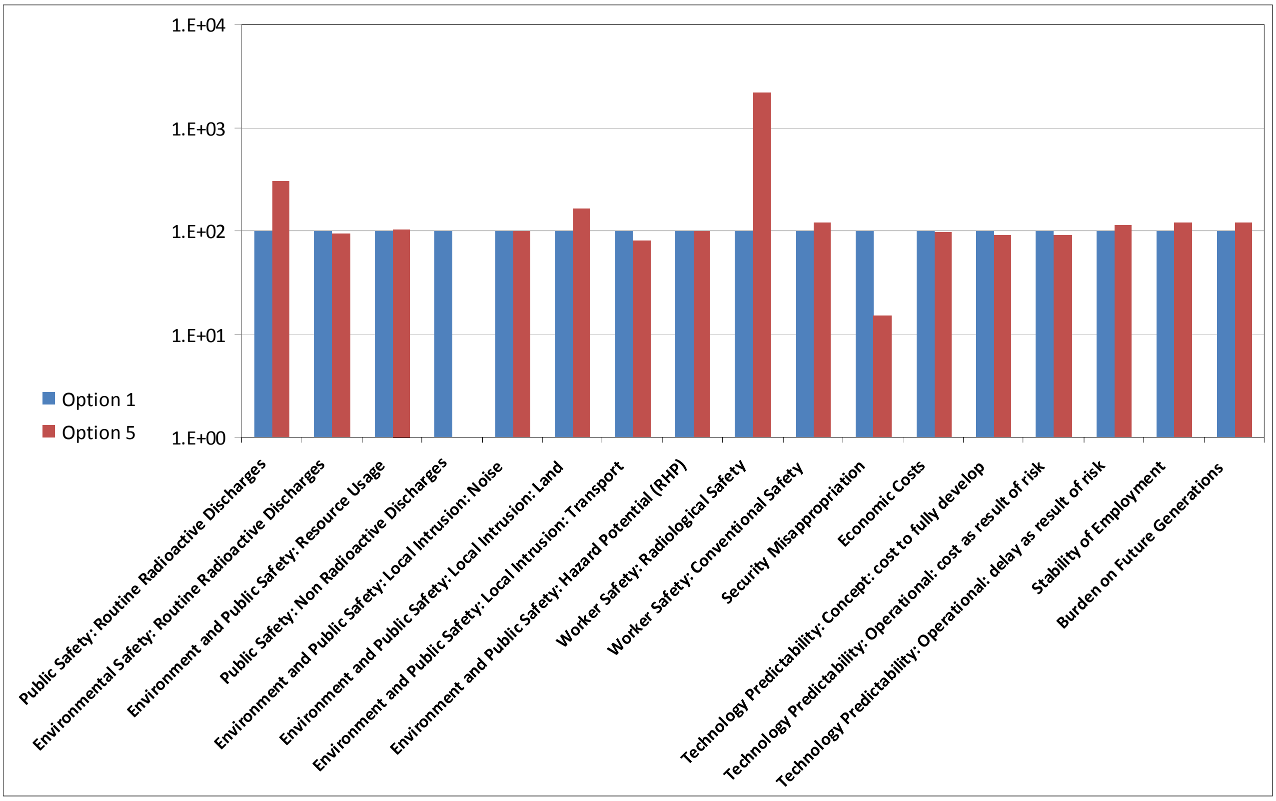

Figure 22 Option 5 sub-criteria measures normalised against Option 1

- Option 5 (Deferred start with manual retrieval) has much greater doses to workers due to manual retrieval. This result does not indicate that manual retrieval is intolerable, since no comparison with any dose limits is made, but it indicates that the worker doses are very high compared to remote retrieval.
- Discharges to the public are larger due to the additional size reduction step.
- Security misappropriation is improved due to radioactive decay during the longer in-reactor storage period.

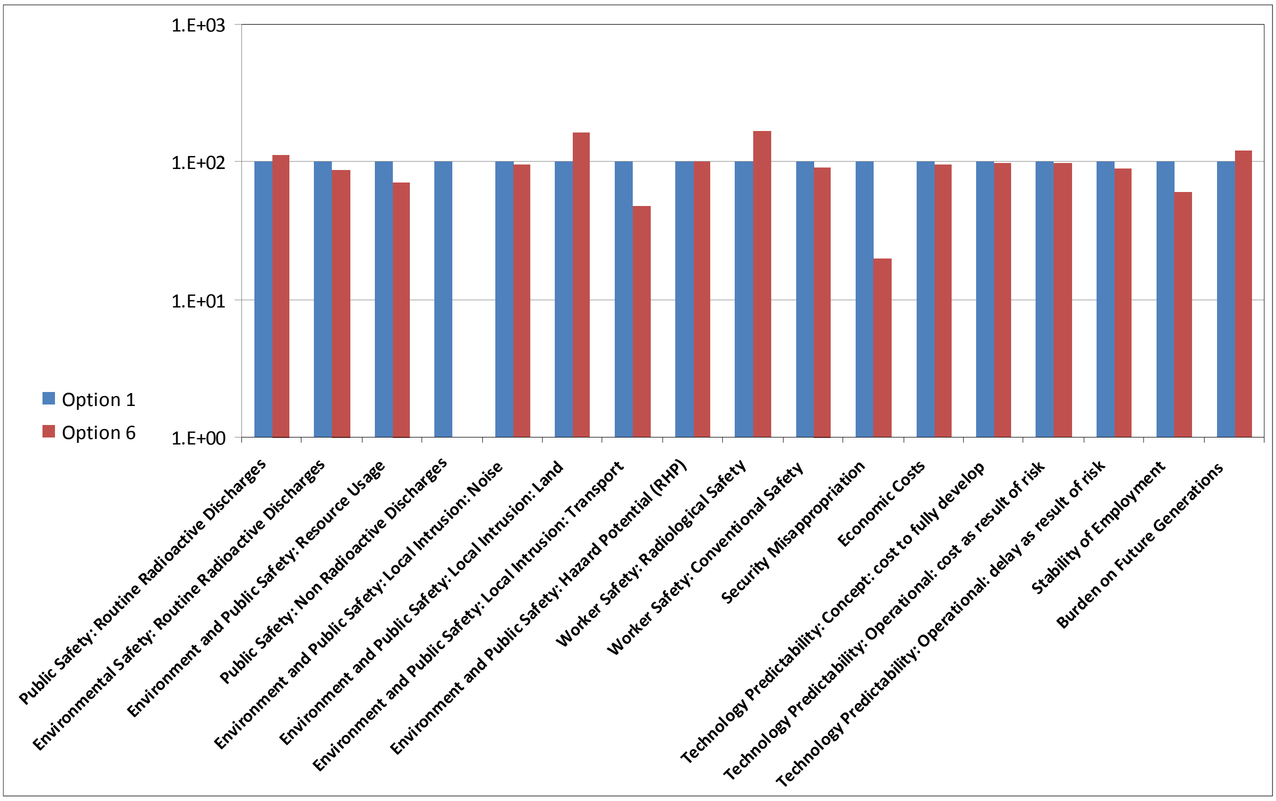

Figure 23 Option 6 sub-criteria measures normalised against Option 1

- Option 6 (Minimum processing with deferred start) has a lower resource use due to minimal processing, a lower number of associated transport journeys, lower impact on employment and an improved security measure, due to the deferred start.
- Local intrusion due to land use and doses to workers are greater due to the longer in-reactor storage period.

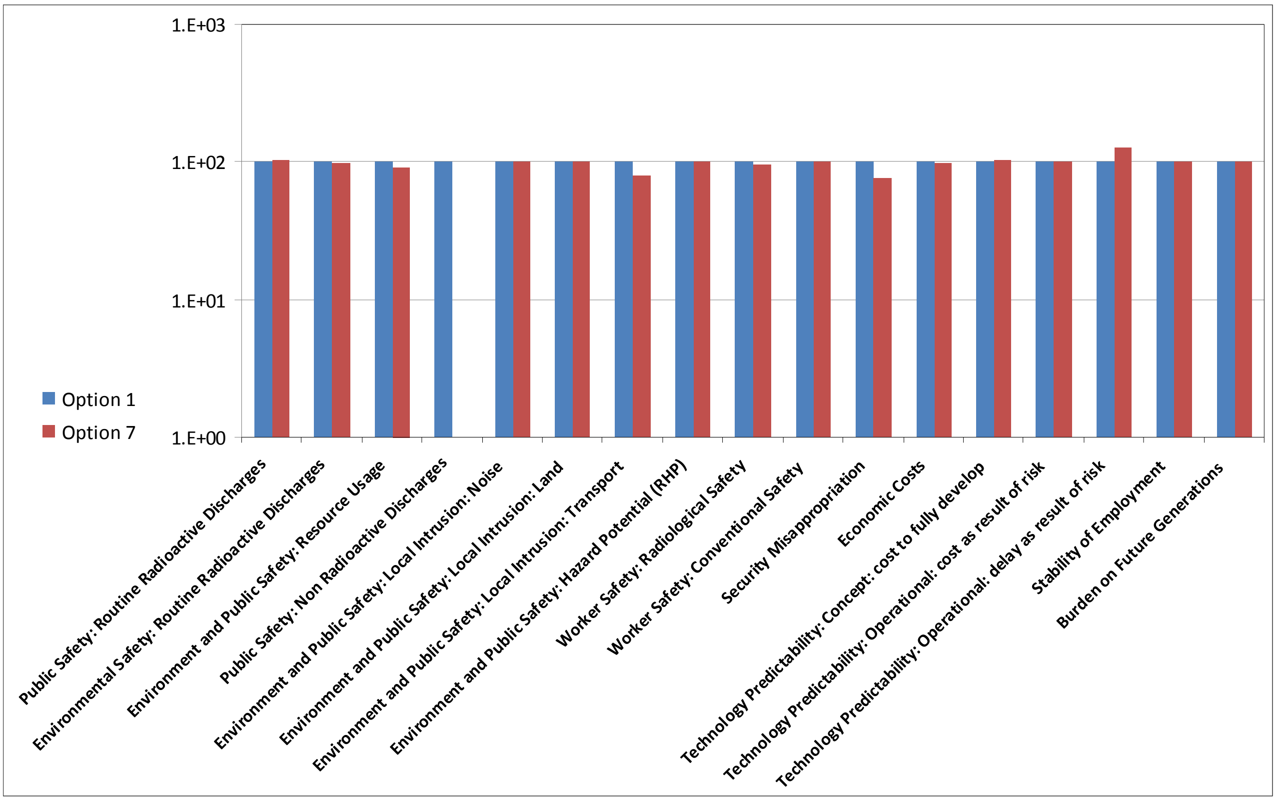

Figure 24 Option 7 sub-criteria measures normalised against Option 1

- There are few noticeable differences between Option 7 (Alternative retrieval (particulate) and graphite form in package) and Option 1. There are slightly fewer transport journeys and security is improved.
- Operational delay as a result of risk is slightly higher, due to the alternative nibble and vac retrieval method of the graphite in particulate form.

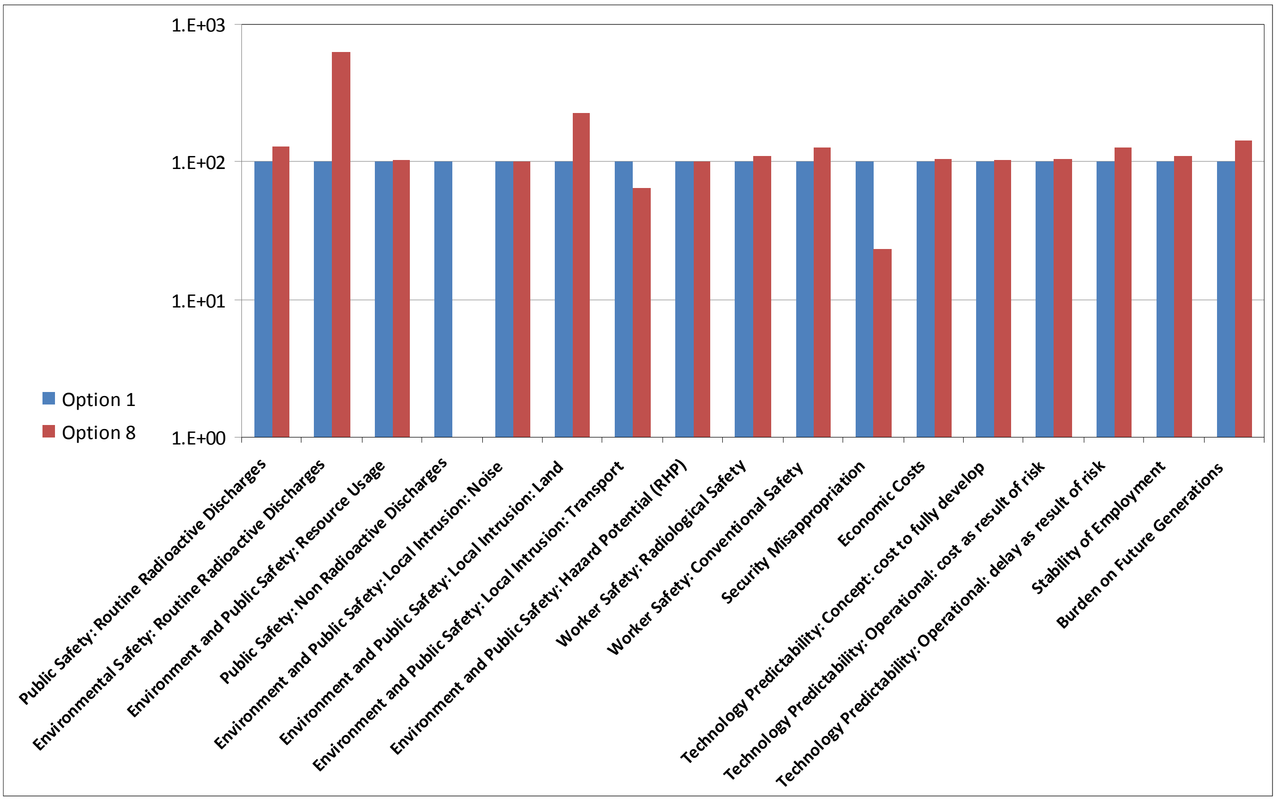

Figure 25 Option 8 sub-criteria measures normalised against Option 1

- Option 8 (Alternative retrieval (underwater) and repository) has larger discharges to the public due to the quantities of ^{14}C assumed to be released during underwater retrieval. This is complex, since discharges could be further reduced by treating the water but, worker doses could be higher due to handling filters, etc. Land use is higher due to the additional interim storage period following encapsulation.
- Security is improved due to the lower radioactive inventory (due to decay) following the additional interim storage period before transport.

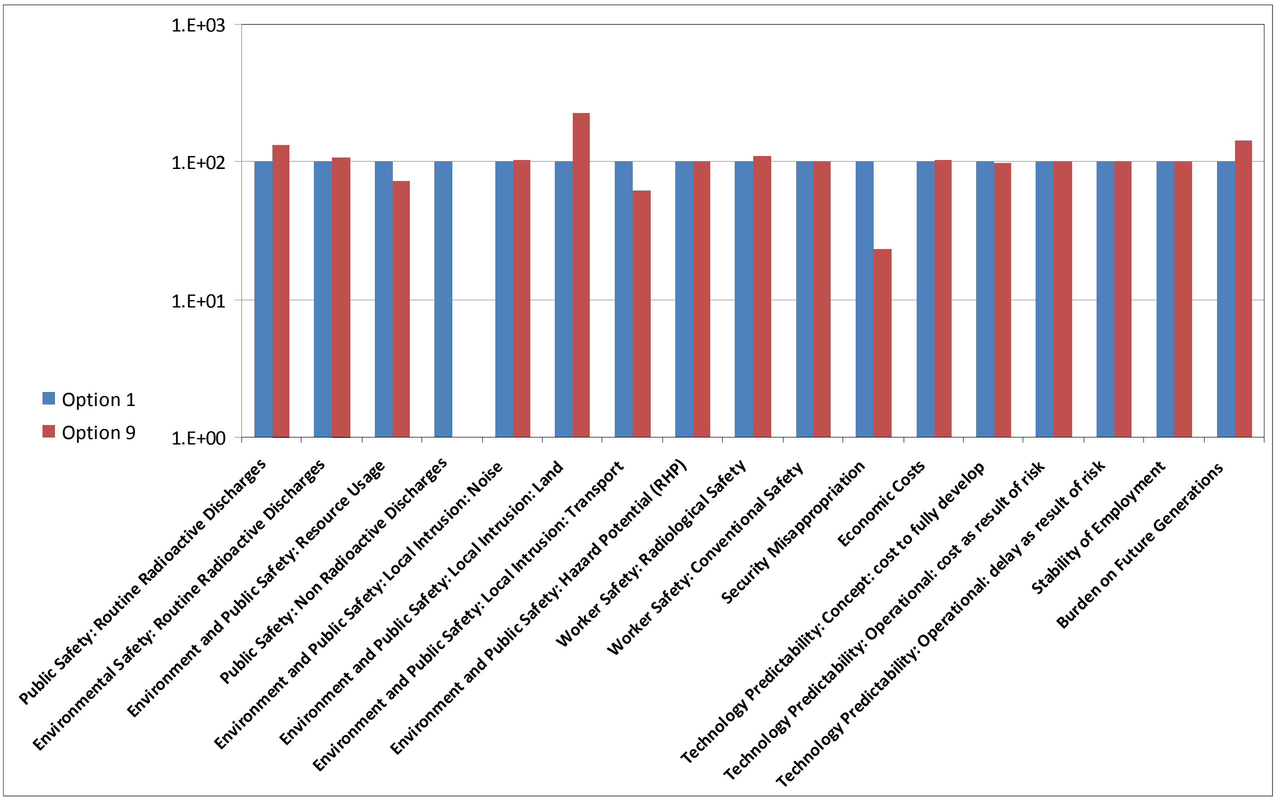

Figure 26 Option 9 sub-criteria measures normalised against Option 1

- Option 9 (Interim storage and repository) has a greater land use due to the additional interim storage period following encapsulation.
- Transport journeys are lower, associated with the construction of the interim depth, as opposed to deep repository.
- Security is improved due to the lower radioactive inventory (due to decay) following the additional interim storage period before transport.

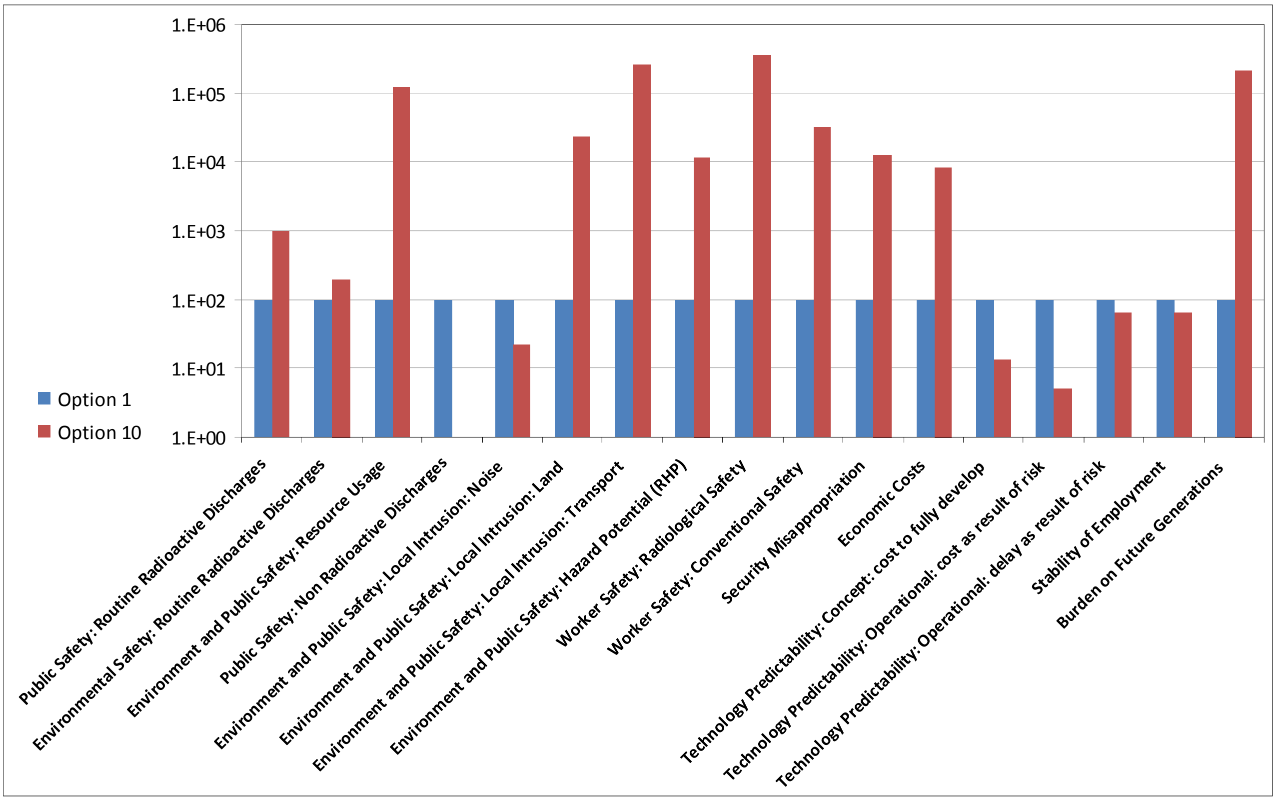

Figure 27 Option 10 sub-criteria measures normalised against Option 1

- Option 10 (Alternative retrieval (particulate), encapsulation and intermediate storage) considers indefinite storage, calculated based on continually replacing surface stores for 500,000 years.
- The option performs significantly worse in all criteria apart from local intrusion due to noise, cost to develop concept, cost as a result of risk, delay as a result of risk and stability of employment. This is because the storage concept is well developed. Stability of employment is slightly improved due to a repository not being constructed and the construction efforts required to build stores spread over a long period.
- The four criteria in which this option performs most poorly are resource usage, number of transport journeys, worker radiological safety and burden on future generations, all associated with the continual replacement of surface stores for a prolonged period.

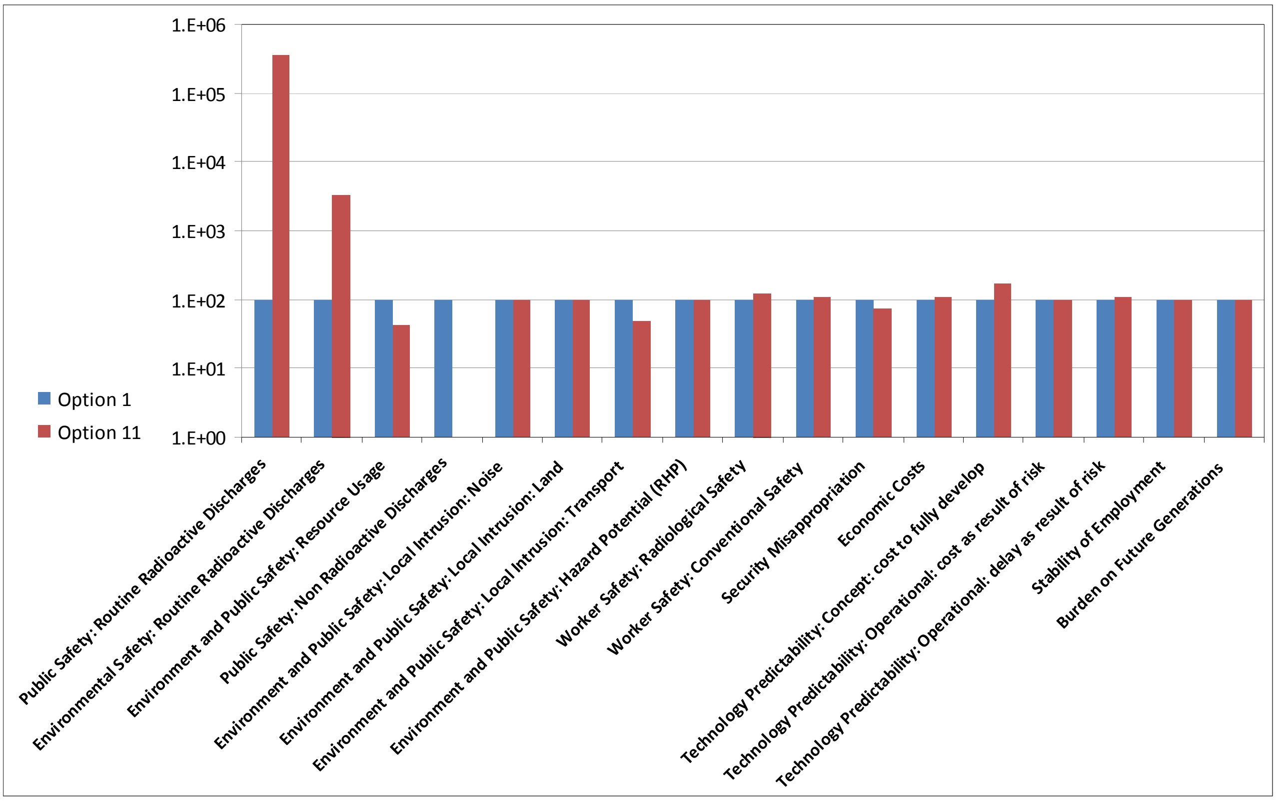

Figure 28 Option 11 sub-criteria measures normalised against Option 1

- Option 11 (In situ treatment and near-surface repository) has much greater radioactive discharges and doses to the public due to the poorer performance of the near-surface repository and, to a lesser extent, due to the in-situ heat treatment process.
- Resource usage and transport journeys are lower due to the near-surface repository.
- It was noted at the MCDA workshop that heat treatment of a power reactor by a controlled temperature excursion outside its operating rules would require revision of safety cases and would receive detailed scrutiny by regulators. It is not credible that this option could be applied in this case.

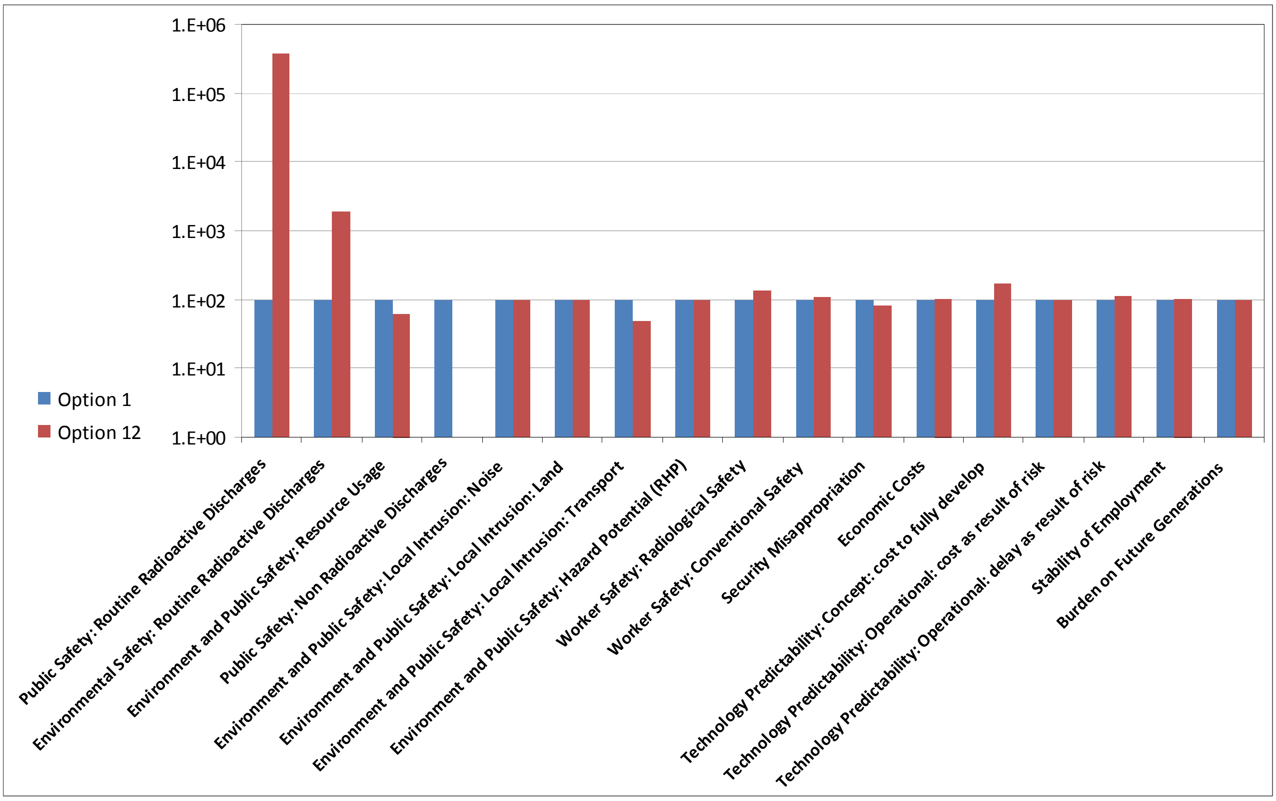

Figure 29 Option 12 sub-criteria measures normalised against Option 1

- As for Option 11, Option 12 (Ex situ treatment and near surface repository) has much greater radioactive discharges to the public due to the poorer performance of the near-surface repository and, to a lesser extent, during the ex-situ heat treatment process. This option performs very similarly to Option 11 in all criteria.
- It was noted during the MCDA workshop that the decontamination factors assumed for the treatment processes are vital in assessing this option's performance. Additionally, there is evidence that as well as reducing the activity in the waste, such heat treatments could remove weakly bound activity, leaving a product with more strongly bound activity which would therefore perform better at resisting leaching in a repository. It was concluded that there is currently a lack of data to properly account for this.

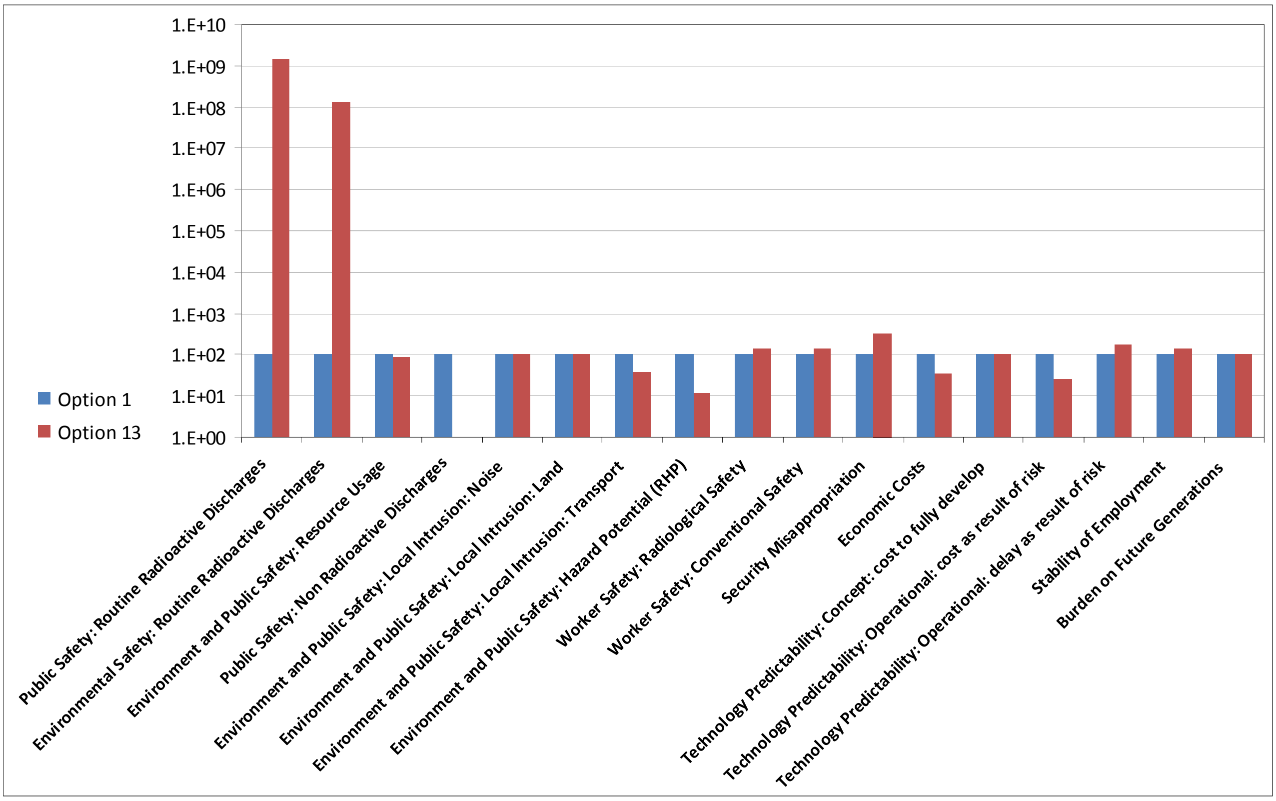

Figure 30 Option 13 sub-criteria measures normalised against Option 1

- Option 13 (Gasification and isotopic dilution with conventional fossil fuel CO_2) has much greater radioactive discharges to the public and environment due to the gasification of i-graphite and isotopic dilution in the atmosphere.
- Hazard potential is considerably lower since a lower inventory is sent to, and considered over the timescales of the repository.

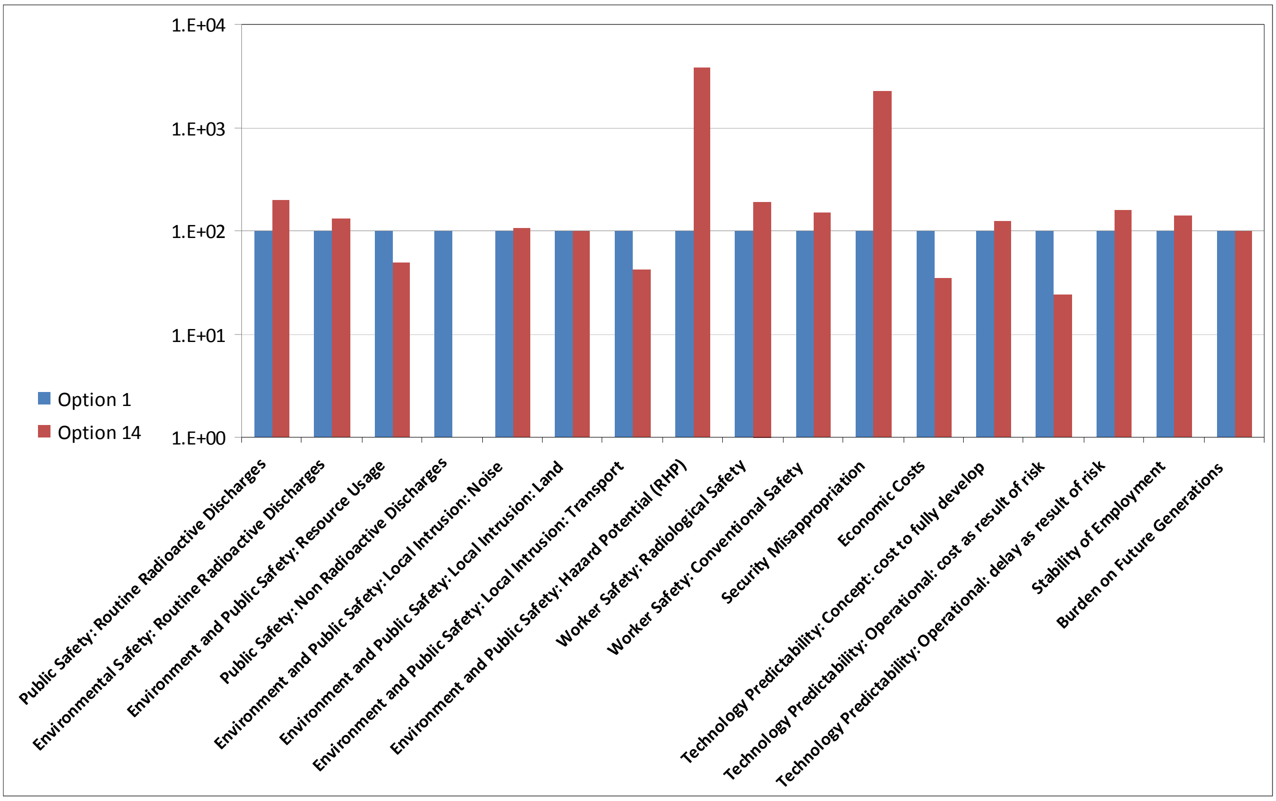

Figure 31 Option 14 sub-criteria measures normalised against Option 1

- Option 14 (Gasification and isotopic dilution with conventional fossil fuel CO_2 as a result of sequestration) has a significantly higher hazard potential and risk of security misappropriation due to the transport by truck of a large amount of activity in liquid form. This could be mitigated by limiting the quantity of material transported in each journey, although this would increase both the cost and local intrusion metrics.
- Economic costs are lower due to the much reduced volume sent to the repository.

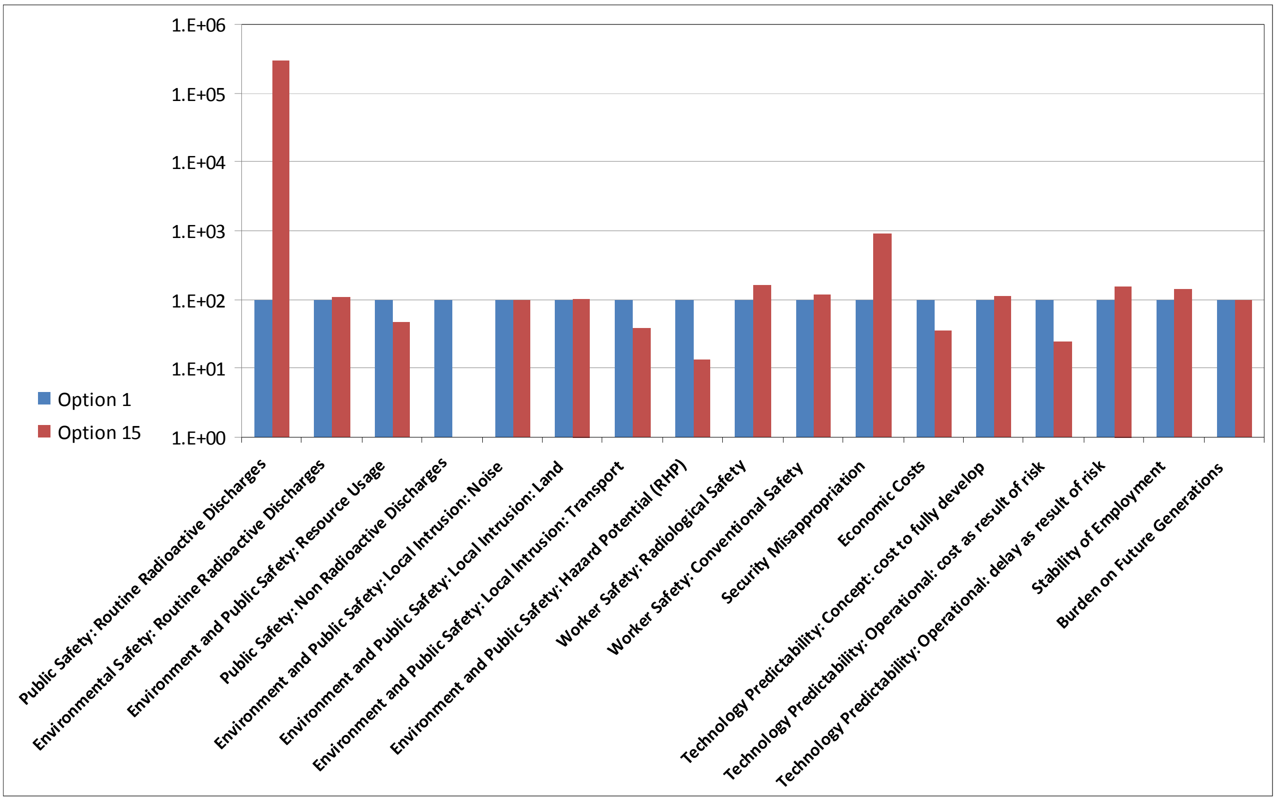

Figure 32 Option 15 sub-criteria measures normalised against Option 1

- Option 15 (Gasification and isotopic dilution by dispersal as CO_3 in the sea) has much greater discharges to the public due to dispersal of ^{14}C in the sea.
- Whilst doses to the public are calculated based on the total activity released, environmental impacts are based on the activity concentration of discharges. It is assumed that ^{14}C discharged to sea is diluted to such an extent that the impact on the environmental safety criterion is negligible.
- The impact on security misappropriation is greater since this option involves transport of ash and gangue material with concentrated activity.
- The hazard potential is lower since a lower inventory is sent to, and considered over the timescales of the repository.

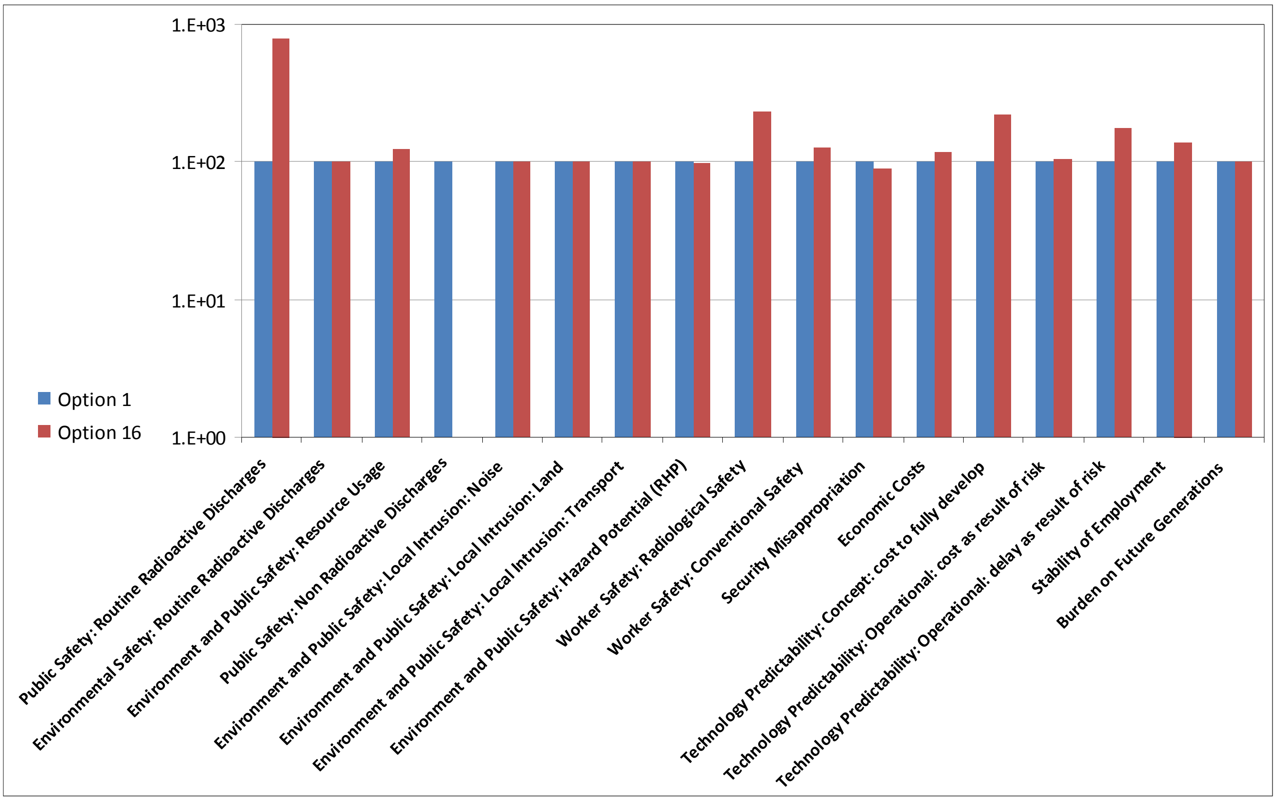

Figure 33 Option 16 sub-criteria measures normalised against Option 1

- Option 16 (^{14}C re-use) has a greater dose to public due to ^{14}C discharged in the ^{12}C-rich stream released during the isotope separation stage.
- Radiological safety is worse due to the doses to workers during the extra processing steps such as isotope separation.
- This option is no longer considered technologically viable by CARBOWASTE partners; particularly the isotope separation stage is not considered economically feasible following investigations into such technologies within the CARBOWASTE project (Bradbury, 2013). Whilst there is demand for ^{14}C in, e.g. the medical industry, it would probably be cheaper to build a dedicated reactor than separate from i-graphite, it could only account for a small fraction of the total i-graphite inventory. The economic costs are only slightly higher than for Option 1, which the attendees at the MCDA workshop considered unlikely because no market to reuse a significant fraction of the graphite had been identified and unless nearly all the graphite could be reused a significant investment in the repository would still be required.

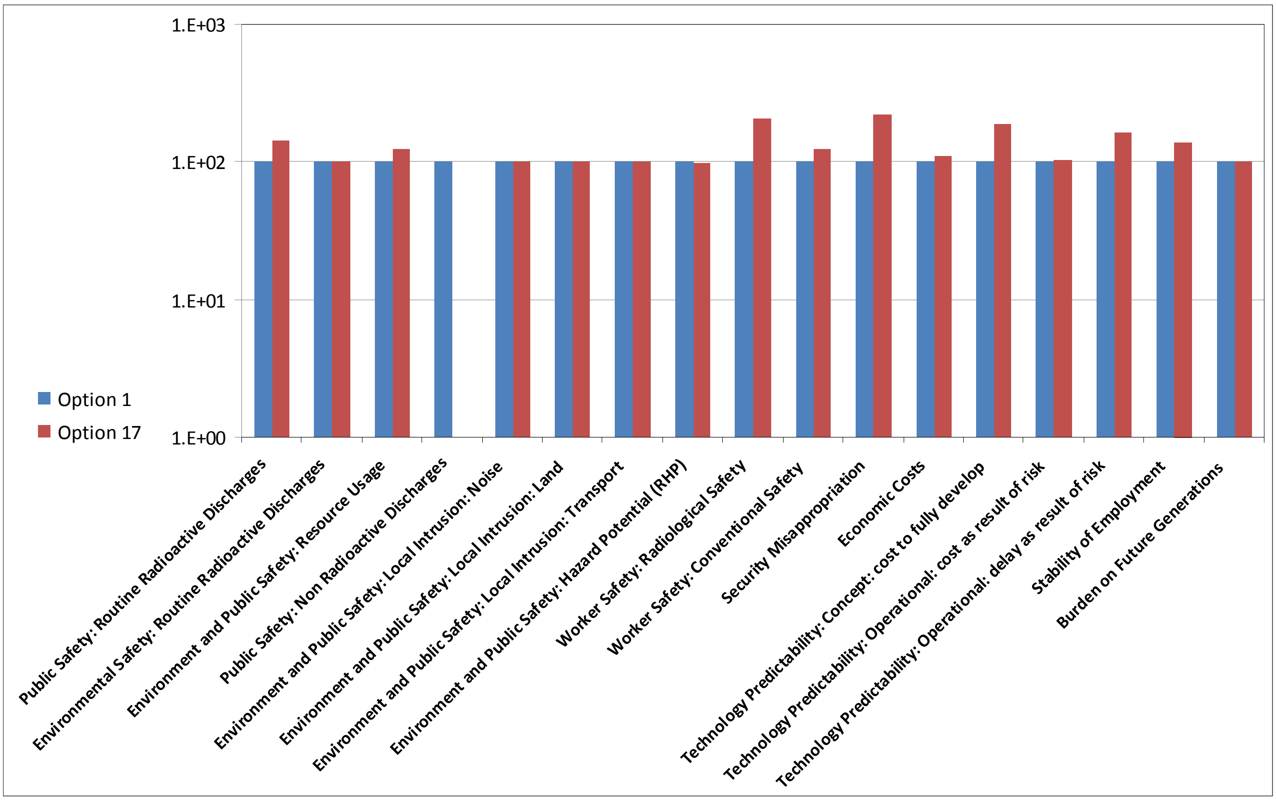

Figure 34 Option 17 sub-criteria measures normalised against Option 1

- Option 17 (^{14}C re-use with no isotope separation) has a similar dose to public because of the lack of the isotope separation stage. Otherwise, the impacts on criteria are similar to those in Option 16.
- It is notable that there are no benefits for reuse in this assessment – both the resources used to reuse graphite exceed those to dispose of it and the costs to reuse exceed the costs to dispose. However, the sensitivity study will indicate whether these differences are significant or not.

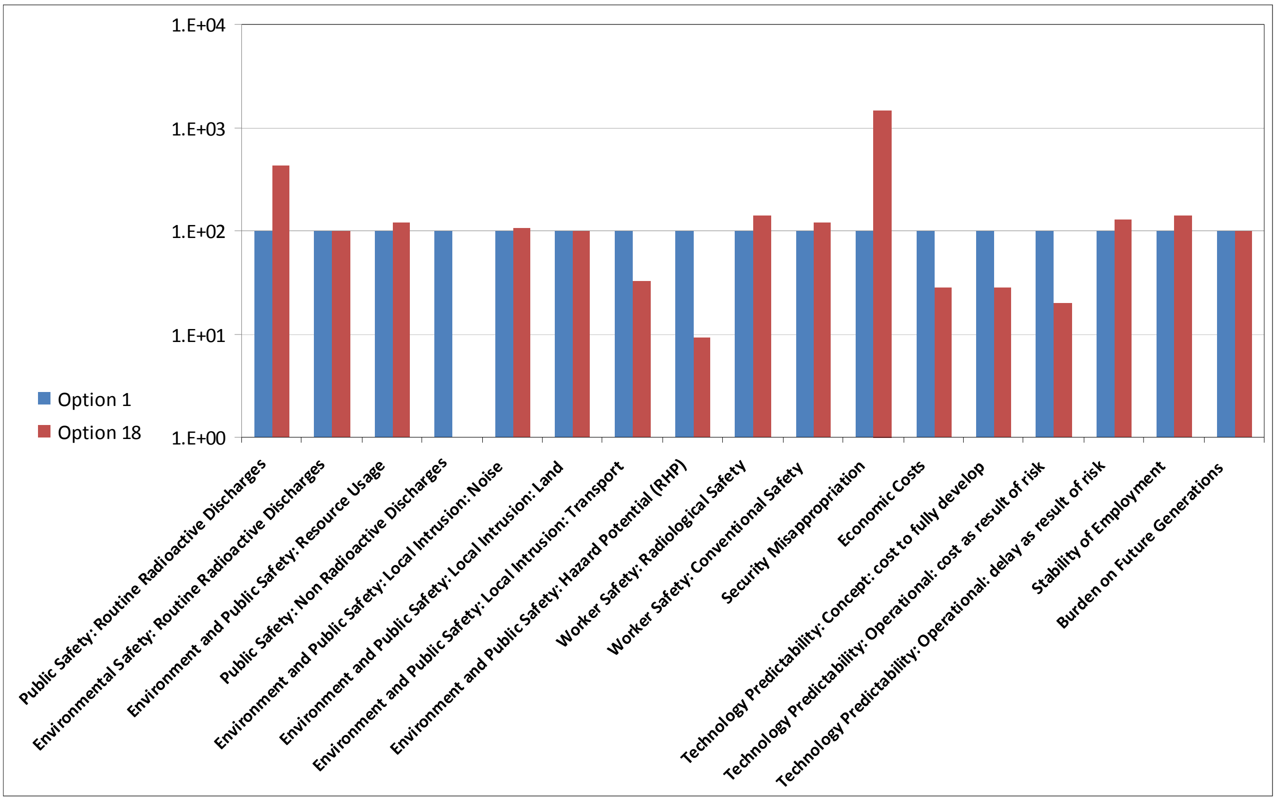

Figure 35 Option 18 sub-criteria measures normalised against Option 1

- Option 18 (Graphite re-use for nuclear application only) has a greater impact on security misappropriation since this option involves transport of material to the repository with concentrated activity. As such, the number of transport journeys is lower.
- The hazard potential is lower since a lower inventory is sent to, and considered over the timescales of the repository.
- Economic costs are lower due to the much reduced volume sent to the repository.
- During the MCDA workshop, this option was considered to be potentially feasible for small quantities of graphite, but not bulk treatment.

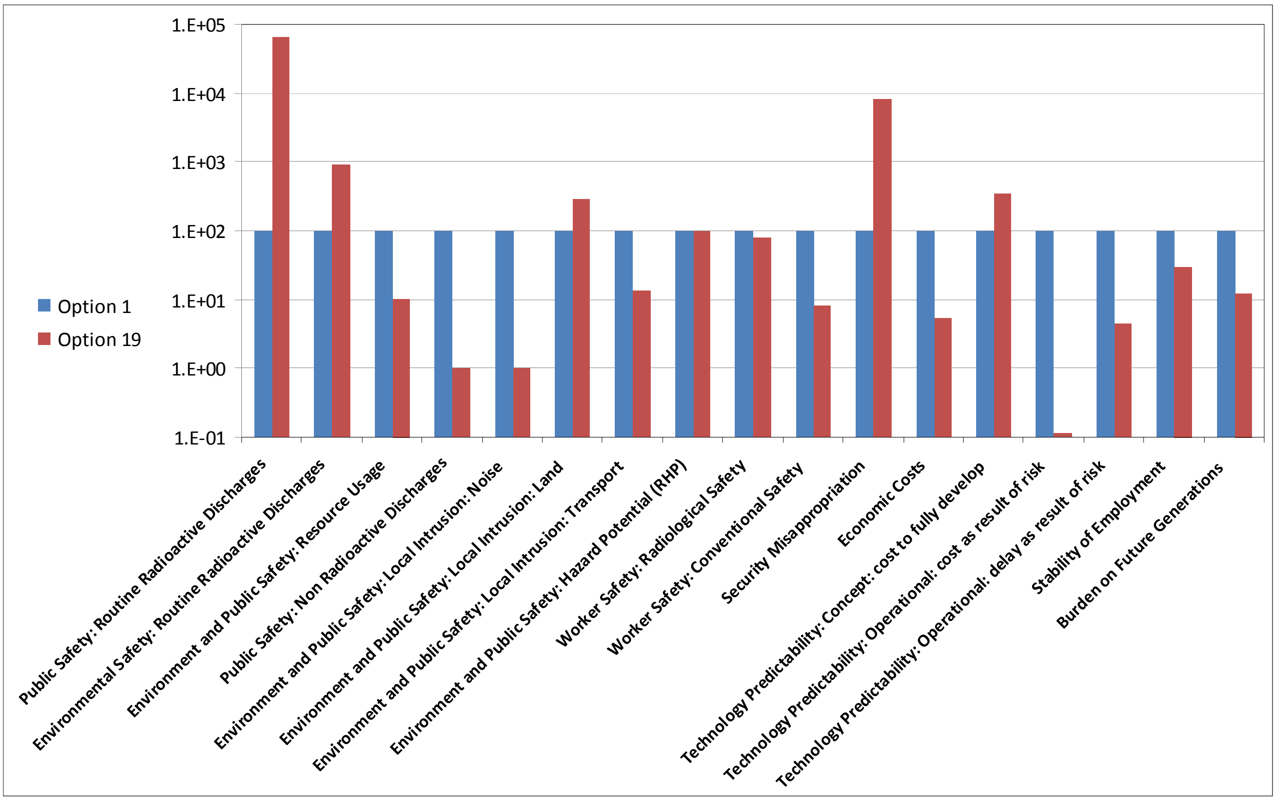

Figure 36 Option 19 sub-criteria measures normalised against Option 1

- Option 19 (In-situ entombment) has a far greater dose to public due to radioactive releases from the entombed structure, which is assumed to be far less effective at containment than a repository.
- The impact on security misappropriation is much greater, since the i-graphite is in a much more accessible form in an entombed reactor compared to a repository.
- Operational cost as a result of risk is much lower than in Option 1, since the entombment process itself is considered to be low cost, predictable and subject to low risk of delays.
- Economic costs, resource usage, conventional safety and local intrusion from noise are lower.
- During the MCDA workshop, attendees commented that entombment may not be achievable. In some cases continued care and maintenance would be required, which would make this option similar to Option 10. Some attendees believed that an entombed reactor would require continued, indefinite institutional control even if care and maintenance were not required, which is not currently considered, but would again mean the option took on some of the characteristics of Option 10.

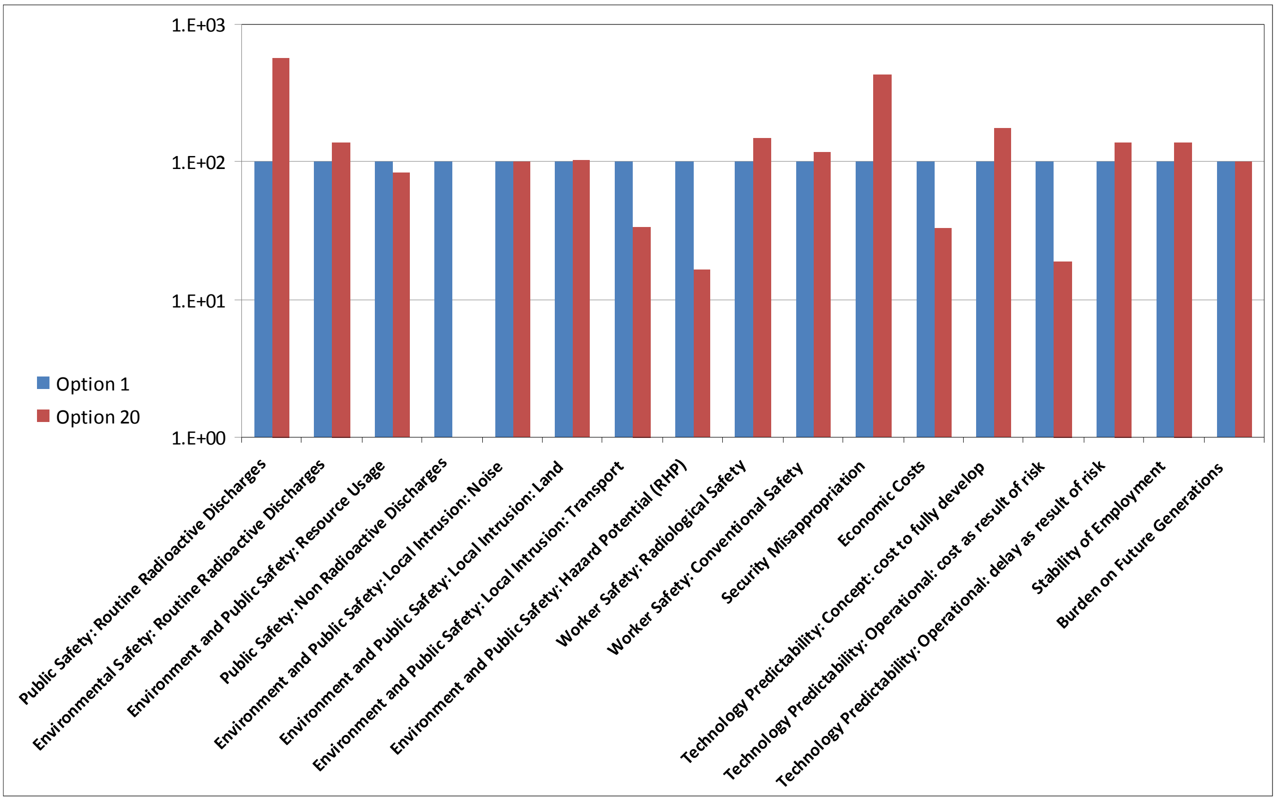

Figure 37 Option 20 sub-criteria measures normalised against Option 1

- Option 20 (Waste volume reduction and emission to atmosphere) has a larger dose to public from the ^{14}C present in the ^{12}C-rich stream that enters the atmosphere for dilution following the gasification stage.
- Impact on security misappropriation is higher due to the gasification stage and because there is transport of material with more concentrated activity.
- The hazard potential is lower since a lower inventory is sent to, and considered over the timescales of the repository.
- The smaller quantities of material being sent to a repository also reduces the number of transport journeys, the economic costs and the operational cost as a result of risk.

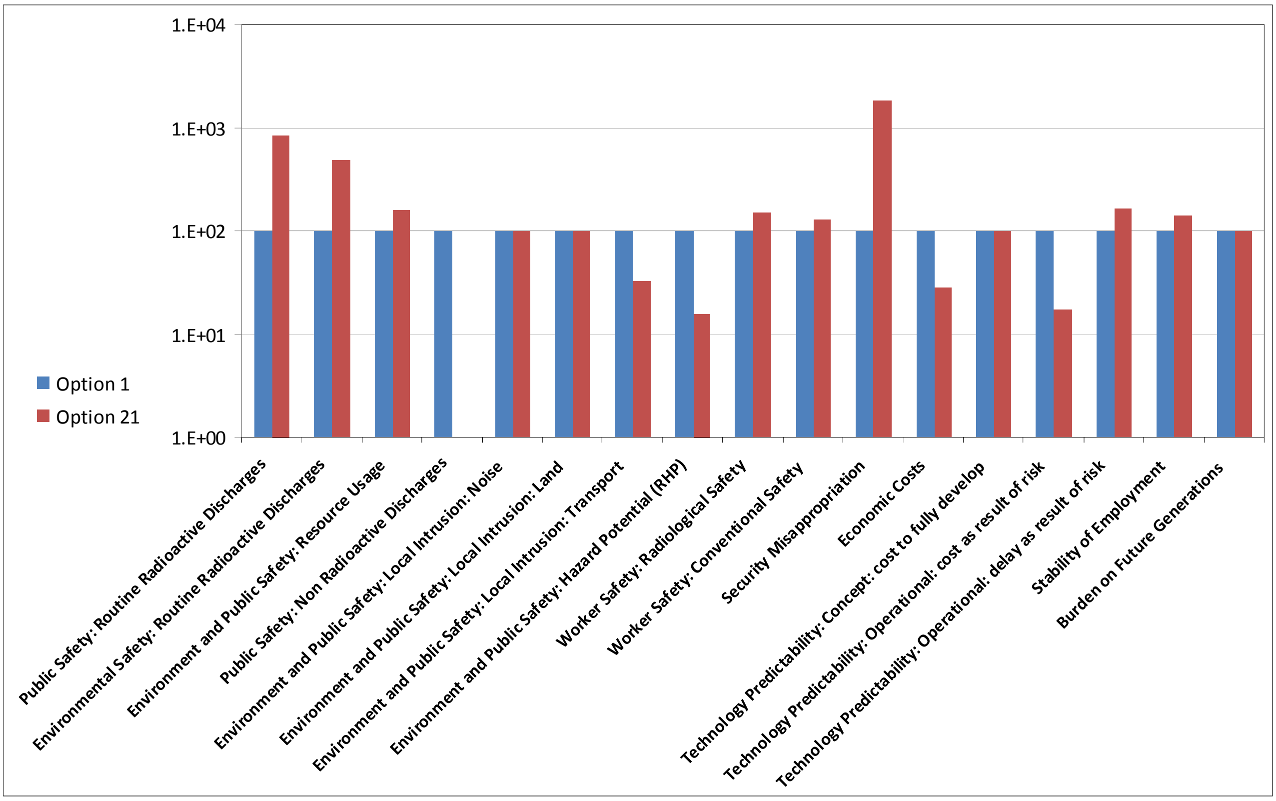

Figure 38 Option 21 sub-criteria measures normalised against Option 1

- Option 21 (Make use of graphite as inert filler, removing the need for some encapsulation) has a larger dose to public (and environmental impact) due to the discharges during the separation and size reduction steps.
- Impact on security misappropriation is higher because there is transport of material with more concentrated activity.
- The hazard potential is lower since a lower inventory is sent to, and considered over the timescales of, the repository.
- The smaller quantities of material being sent to a repository also reduces the number of transport journeys, the economic costs and the operational cost as a result of risk.
- During the MCDA workshop it was noted that certain types of graphite, e.g. reflector material, might be suitable for a technique such as this, but that it is unlikely it could be used to treat the majority of power reactor graphite.

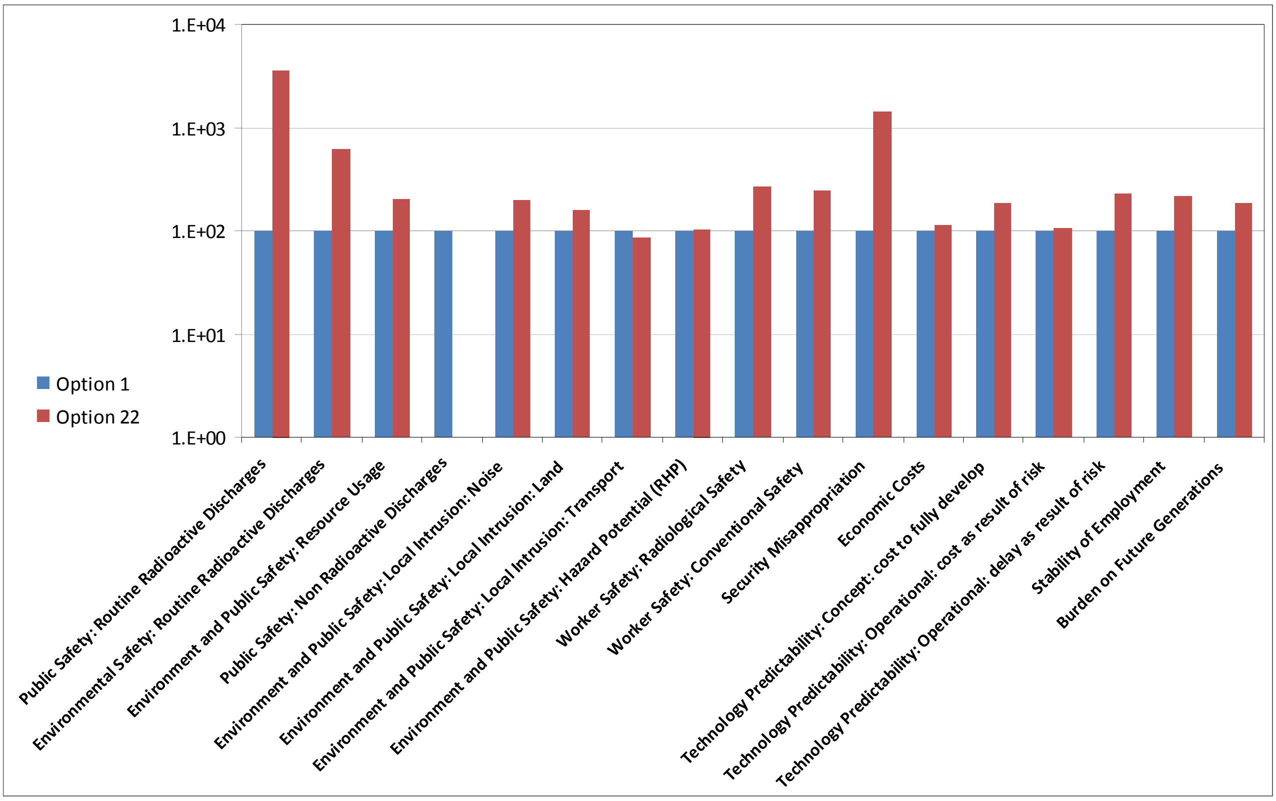

Figure 39 Option 22 sub-criteria measures normalised against Option 1

- Option 22 (Immobilise in medium impermeable to ^{14}C) has greater doses to the public due to the fraction of ^{14}C that is consigned to a near-surface repository. However, this depends on the performance of the medium that is used, and it would be possible for this to be reversed if the medium was particularly effective.
- Impact on security misappropriation is higher because there is transport of material with more concentrated activity.
- This option performs worse than Option 1 in all criteria, except the impact due to transport journeys, which is reduced.

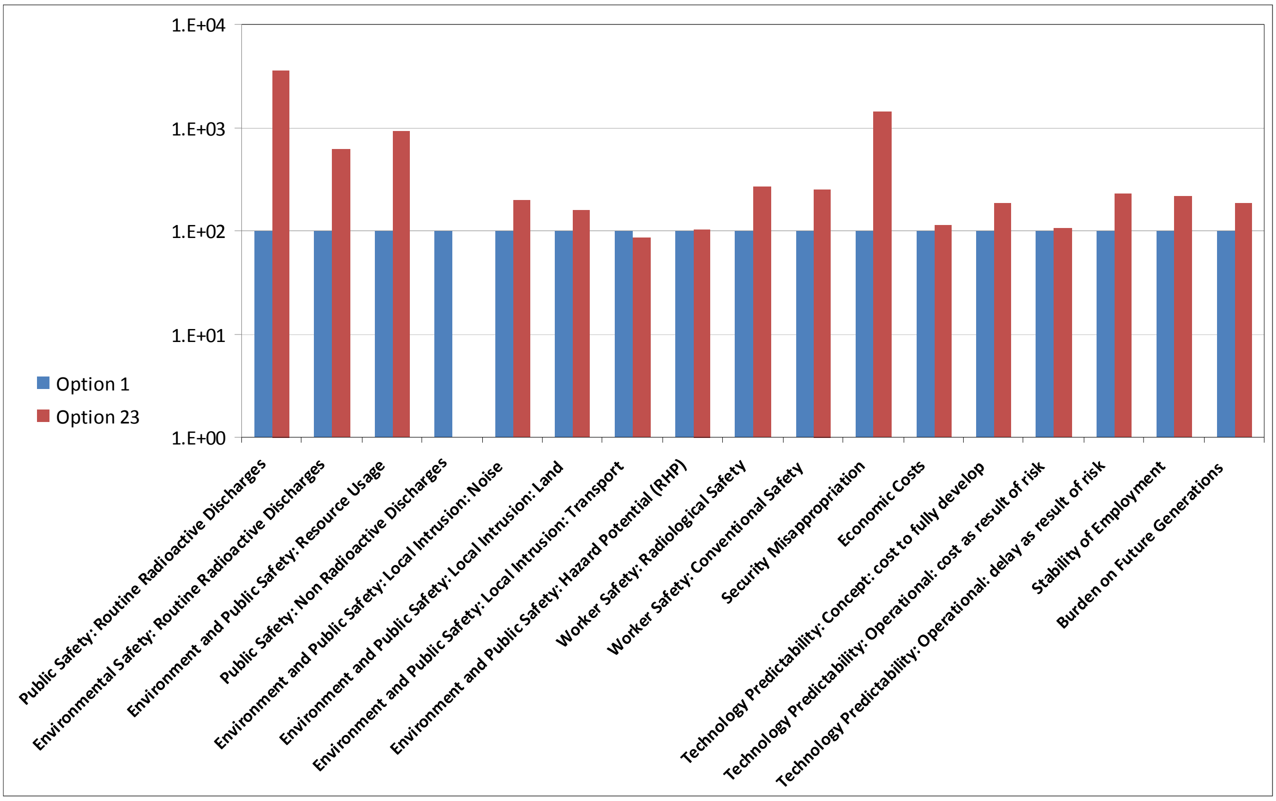

Figure 40 Option 23 sub-criteria measures normalised against Option 1

- Option 23 (Chemically bind ^{14}C) has greater doses to the public due to the fraction of ^{14}C that is consigned to a near-surface repository.
- Resource use is considerably greater, due primarily to the chemical binding (similar to the Russian Self-propagating High-temperature Synthesis (SHS) process).
- Impact on security misappropriation is higher because there is transport of material with more concentrated activity.
- This option performs similarly to Option 22, the biggest difference being the additional resource usage.

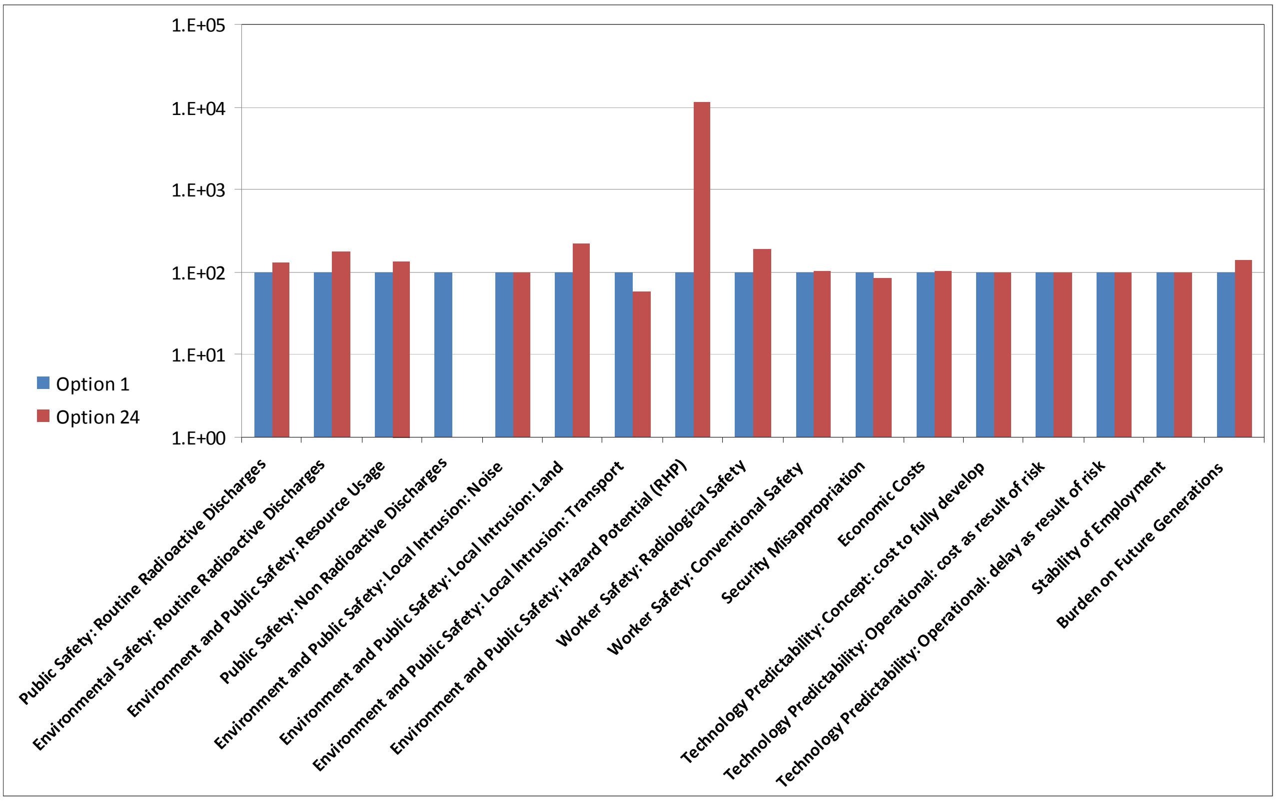

Figure 41 Option 24 sub-criteria measures normalised against Option 1

- Option 24 (Interim storage of raw waste and repository) performs similarly to Option 1 in most criteria, the greatest difference being a much greater hazard potential due to the interim storage of raw, non-encapsulated i-graphite.

3 Conclusions

This report details an assessment of CARBOWASTE options against a set of criteria via (a) how all options impact on individual criteria and (b) pair-wise comparison of options (the impact of an individual option on all criteria, compared to Option 1). This approach allows a detailed assessment of the performance of each option for each criterion.

From the results presented here, it is clear that certain options have particular strengths and weaknesses which may make them suitable for certain i-graphite and associated materials but not for others:

- Geological disposal is a good option for much of the waste, with the key issue being the requirement to demonstrate containment for very long periods.
- Reuse is attractive for selected graphite, however careful assessment is required in each case. Using the estimates of this report it is possible that resource usage in decontaminating graphite may outweigh the savings of graphite reuse.
- Options which have significant discharges (e.g. Options 13 and 15) perform poorly on environmental criteria, but these options reduce hazards, resource use and transport required, and may be cheaper than other options. These options may be appropriate in certain circumstances.
- Continued above ground storage is not a favourable option in most criteria. In particular, it is expensive, uses extensive land, resources and transport, imposes the largest burden on future generations, is expected to result in significant numbers of injuries during construction and has the poorest security. Reduced operation risk is the key advantage due to the wide international track record of constructing above ground stores.
- Options which retrieve material for interim storage score poorly on security and hazard, with no significant benefits. Such projects are likely to be motivated by criteria outside the scope of the criteria developed, such as the need to free a site for reuse, the need to empty an unacceptable structure or the desire to demonstrate a particular technology to reduce risk to future projects.
- Under certain circumstances, entombment could be an attractive option, if it could be shown to be viable for a given material. It has low resource usage, low transport requirements and low cost. However, its key disadvantages are poor security and high radioactive discharges. The future Identification of Preferred Options report will discuss further the implications and viability of the entombment concept for i-graphite.

The results presented in this report allow a detailed examination of the impact of each option on each of the criteria. Since the criteria consider a range of unequal measures, with different units, the direct comparison of performance between options is not possible. A future report (Identification of Preferred Options D-1.5.4) will present the remainder of the MCDA process, particularly the assigning of scores and weights to the outcomes of the option flowsheets. This allows the allocation of an overall weighted score for each option, enabling direct comparison and the selection of preferred options. This future report will also consider case studies two and three and a sensitivity analysis of the MCDA process.

4 References

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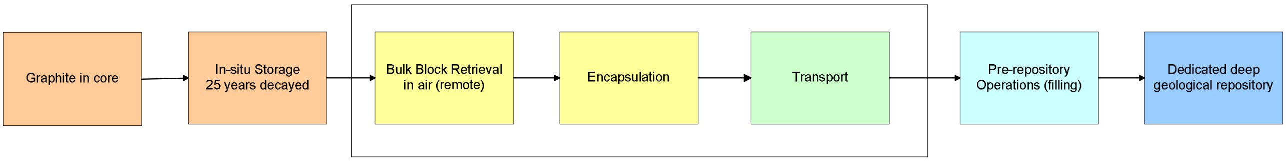
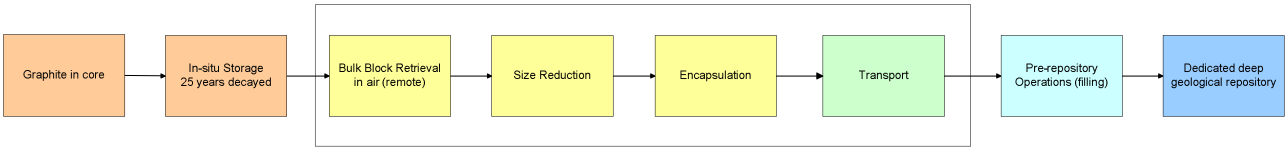
Appendix 1 – Option Flowsheets

Option 1: Encapsulation and deep repository



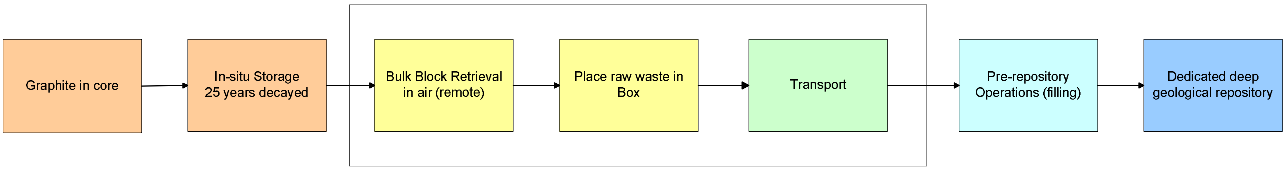
Option 1 allows graphite to decay in the reactor core for 25 years then uses remote retrieval to recover blocks of graphite for on-site encapsulation. The resulting packages are transported to a vault dedicated to graphite within a deep geological repository.

Option 2: Size reduce graphite for minimised waste package volume; local immobilisation



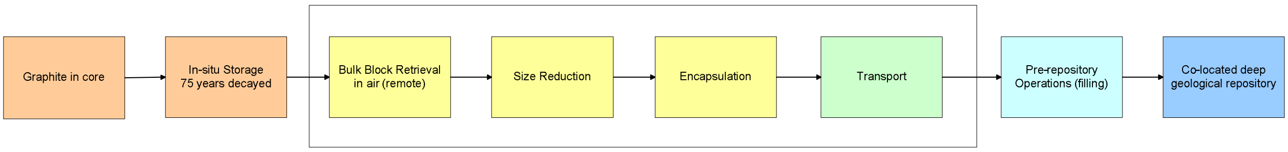
Option 2 differs from Option 1 in that it performs size reduction prior to encapsulation to increase the packing of graphite into boxes.

Option 3: Minimum processing



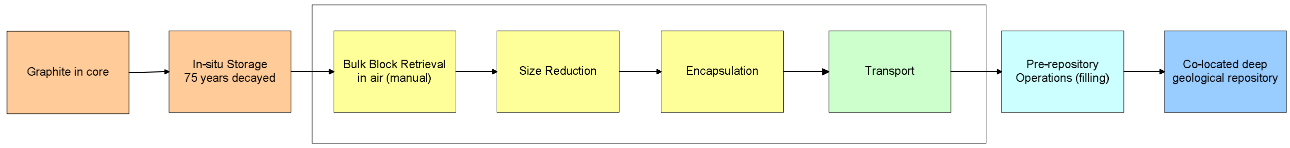
Option 3 differs from Option 1 in that it does not perform encapsulation of the waste, but only boxes the waste.

Option 4: Deferred start with remote retrieval



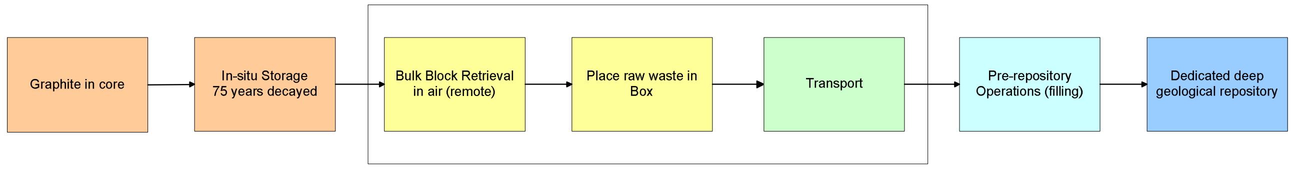
Option 4 differs from Option 1 in that it allows an additional 50 years for cooling in the reactor and then (in common with Option 2) performs size reduction to increase packing of graphite within boxes. This option also uses a deep geological repository where graphite wastes share a vault with other wastes.

Option 5: Deferred start with manual retrieval



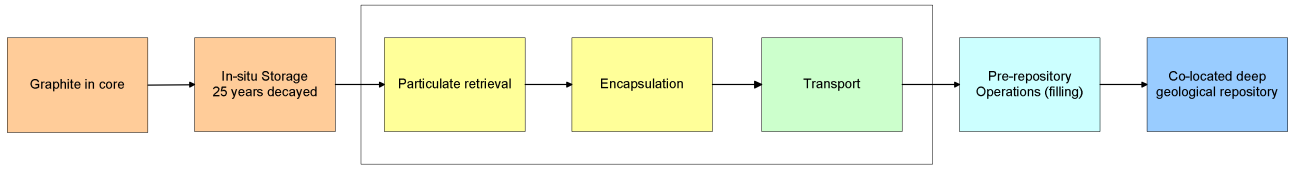
Option 5 differs from Option 4 in that it allows manually assisted retrieval to take place rather than assuming fully remote operation.

Option 6: Minimum processing with deferred start



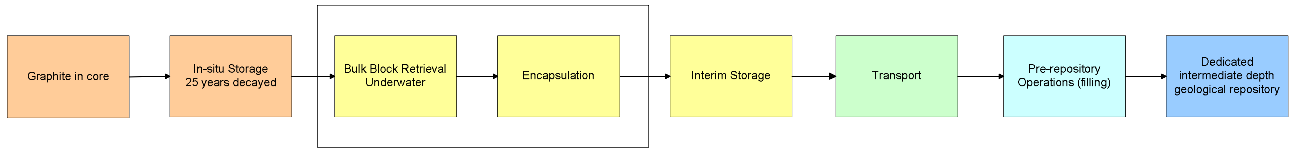
Option 6 differs from Option 3 in that it includes a longer in-situ storage period and then uses manually assisted retrieval rather than fully remote retrieval.

Option 7: Alternative retrieval and graphite form in package



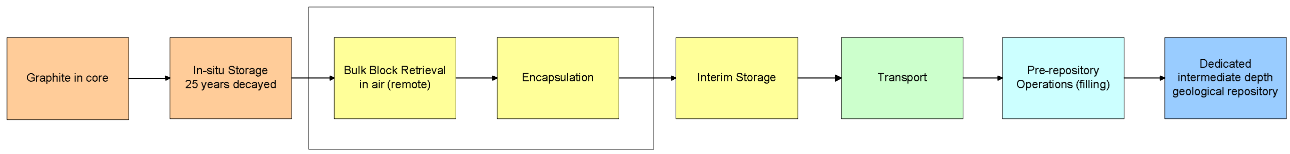
Option 7 differs from Option 1 in that the graphite material is retrieved as particulate and is finally disposed of to a deep geological repository in which graphite material shares a vault with other material.

Option 8: Alternative retrieval and repository



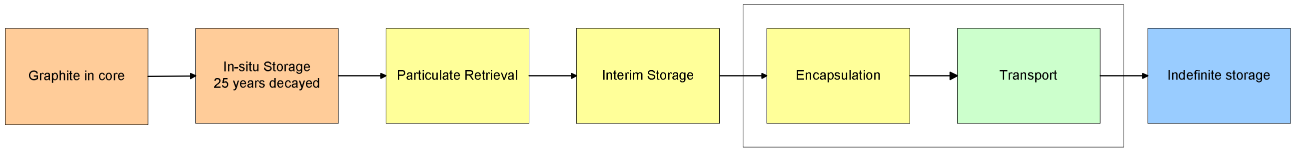
Option 8 differs from Option 1 in that the graphite material is retrieved underwater and interim storage is used to provide time for the provision of an intermediate depth waste repository.

Option 9: Interim storage and repository



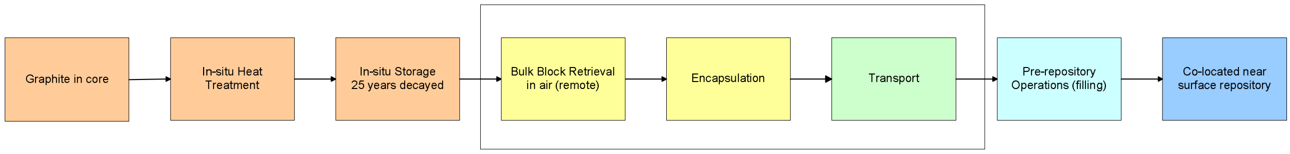
Option 9 differs from Option 1 in that interim storage is used to provide time for the provision of an intermediate depth waste repository.

Option 10: Alternative retrieval, encapsulation and intermediate storage



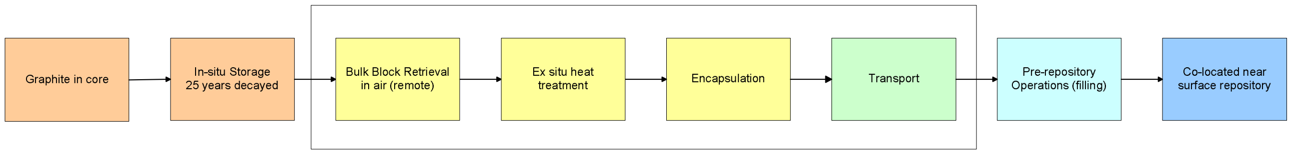
Option 10 differs from Option 7 in that it allows interim storage of graphite particles prior to encapsulation, and the final destination is a surface store (which requires replacing every 150 years).

Option 11: In situ treatment and near-surface repository



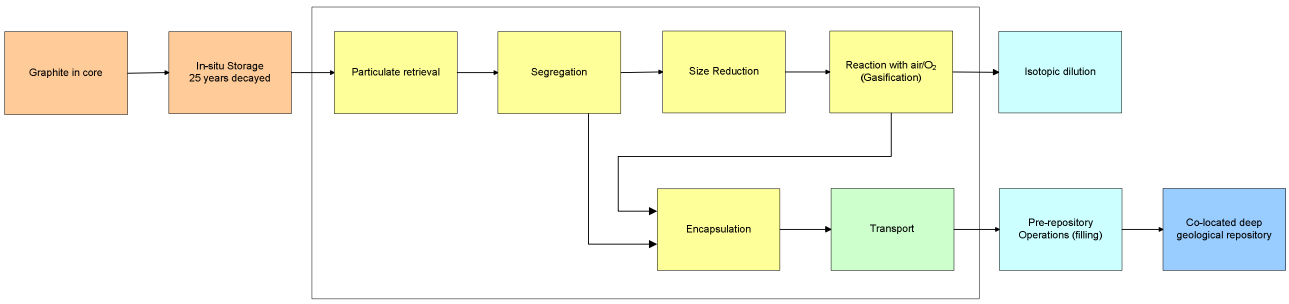
Option 11 differs from Option 1 in that in-situ heat treatment is used to condition the graphite at the end of operations. Also, a co-located near-surface repository is used in place of a dedicated deep repository.

Option 12: Ex situ treatment and near surface repository



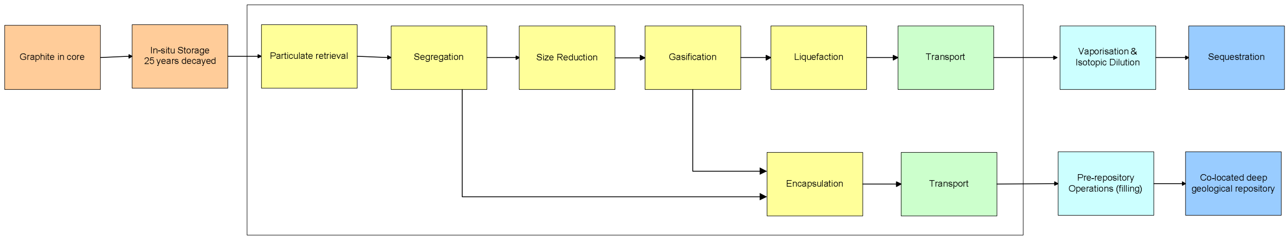
Option 12 differs from Option 1 in that ex-situ heat treatment is used to condition the graphite to remove ^{14}C. Also, a co-located near-surface repository is used in place of a dedicated deep repository.

Option 13: Gasification and isotopic dilution with conventional fossil fuel CO_2



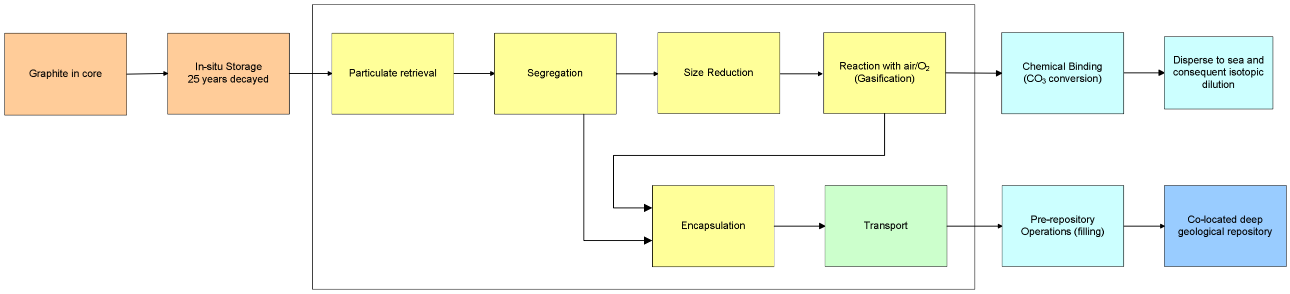
Option 13 differs from Option 1 in that particulate retrieval is used to recover the graphite. Metal components are segregated from the graphite and encapsulated before the graphite is further size reduced and gasified before isotopic dilution and release. Also, a co-located repository is used in place of a dedicated deep repository because only metal items and ash are now consigned to the repository.

Option 14: Gasification and isotopic dilution with conventional fossil fuel CO_2 as a result of sequestration



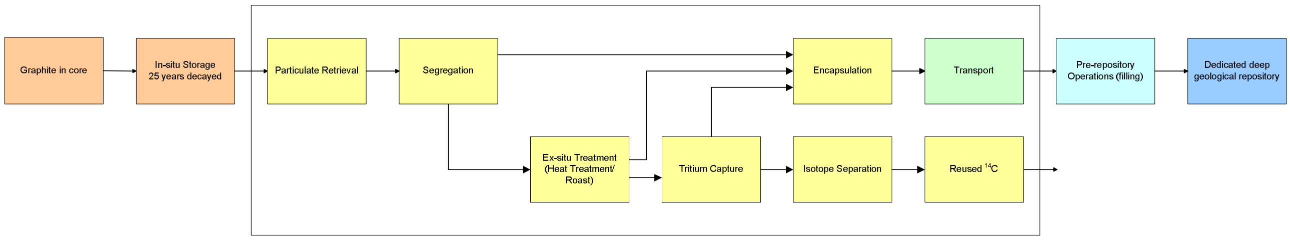
Option 14 differs from Option 13 in that it captures the off-gas from the gasification process and sequesters it along with gases from conventional fossil fuel processes.

Option 15: Gasification and isotopic dilution by dispersal as CO_3 in the sea



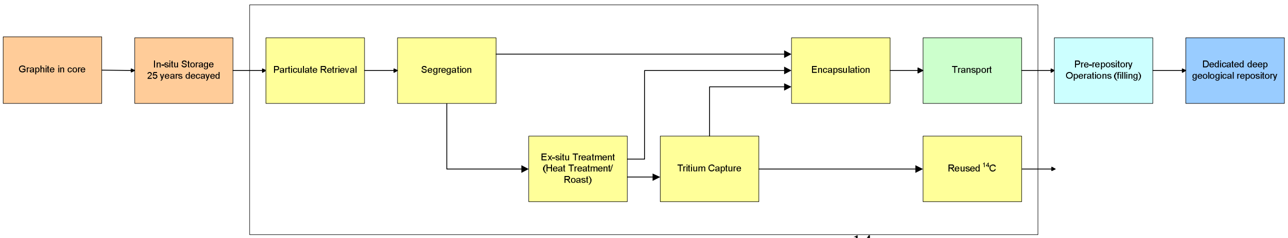
Option 15 differs from Option 13 in that it captures the off-gas from the gasification process and discharges it to sea.

Option 16: ^{14}C re-use



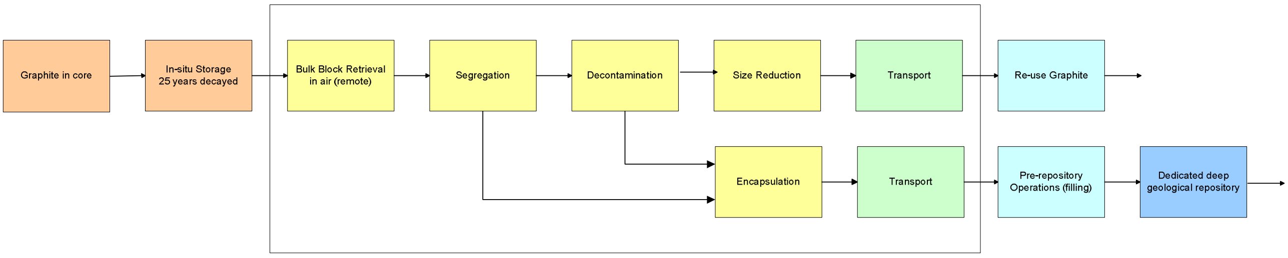
Option 16 differs from Option 1 in that it selects a portion of the graphite expected to contain high levels of ^{14}C and segregates it. This graphite is roasted to produce a gaseous stream rich in tritium and ^{14}C. The remaining solid material is then routed to encapsulation and repository. The tritium and ^{14}C are then separated with the ^{14}C subjected to further enrichment before reuse. The depleted ^{12}C rich stream is discharged.

Option 17: ^{14}C re-use with no isotope separation

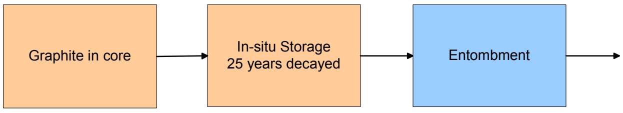


Option 17 differs from Option 16 in that it performs no additional ^{14}C enrichment.

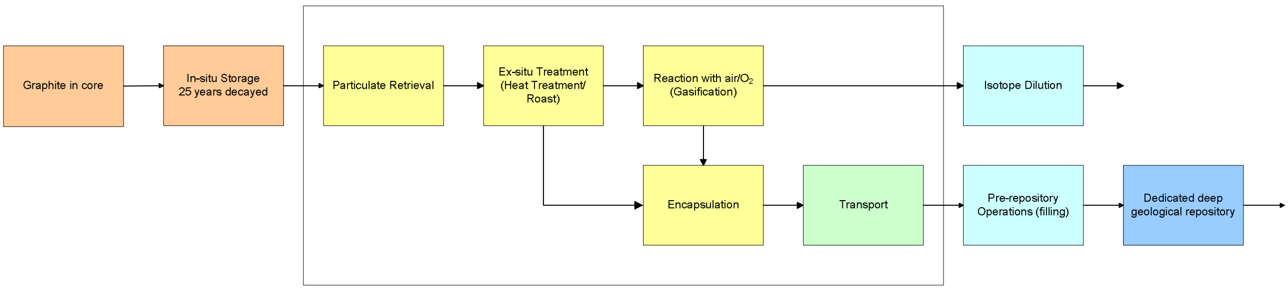
Option 18: Graphite re-use for nuclear application only



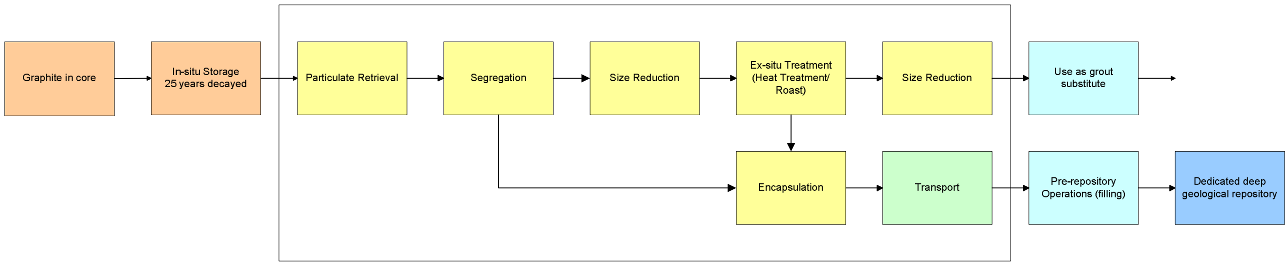
Option 19: In-situ entombment



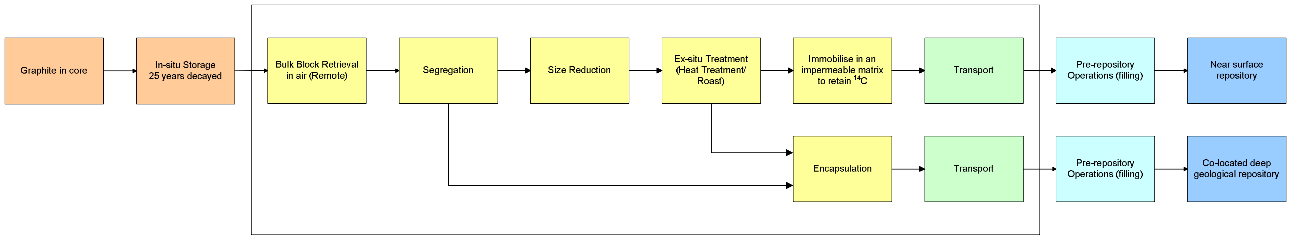
Option 20: Waste volume reduction and emission to atmosphere



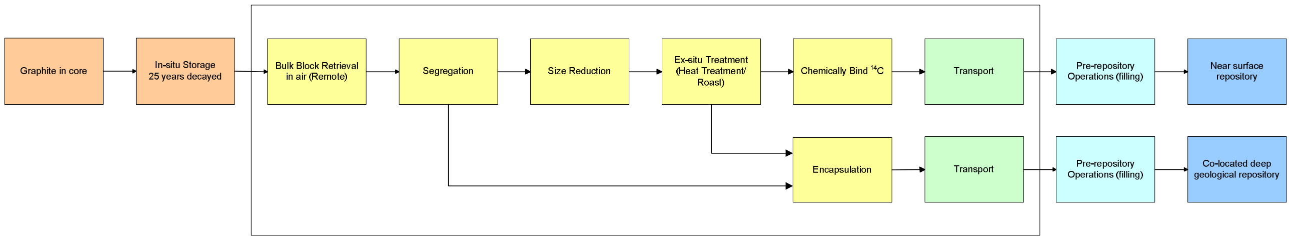
Option 21: Make use of graphite as inert filler, removing the need for some encapsulation



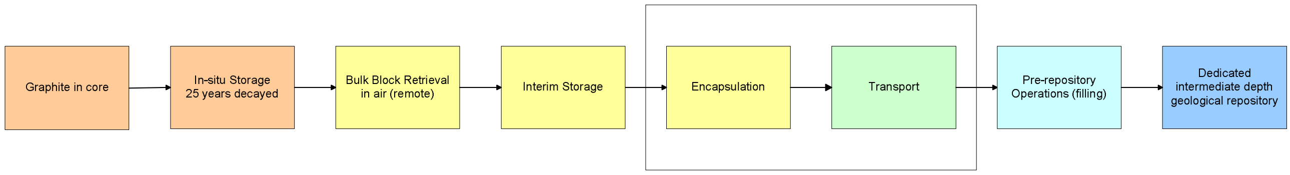
Option 22: Immobilise in medium impermeable to ^{14}C



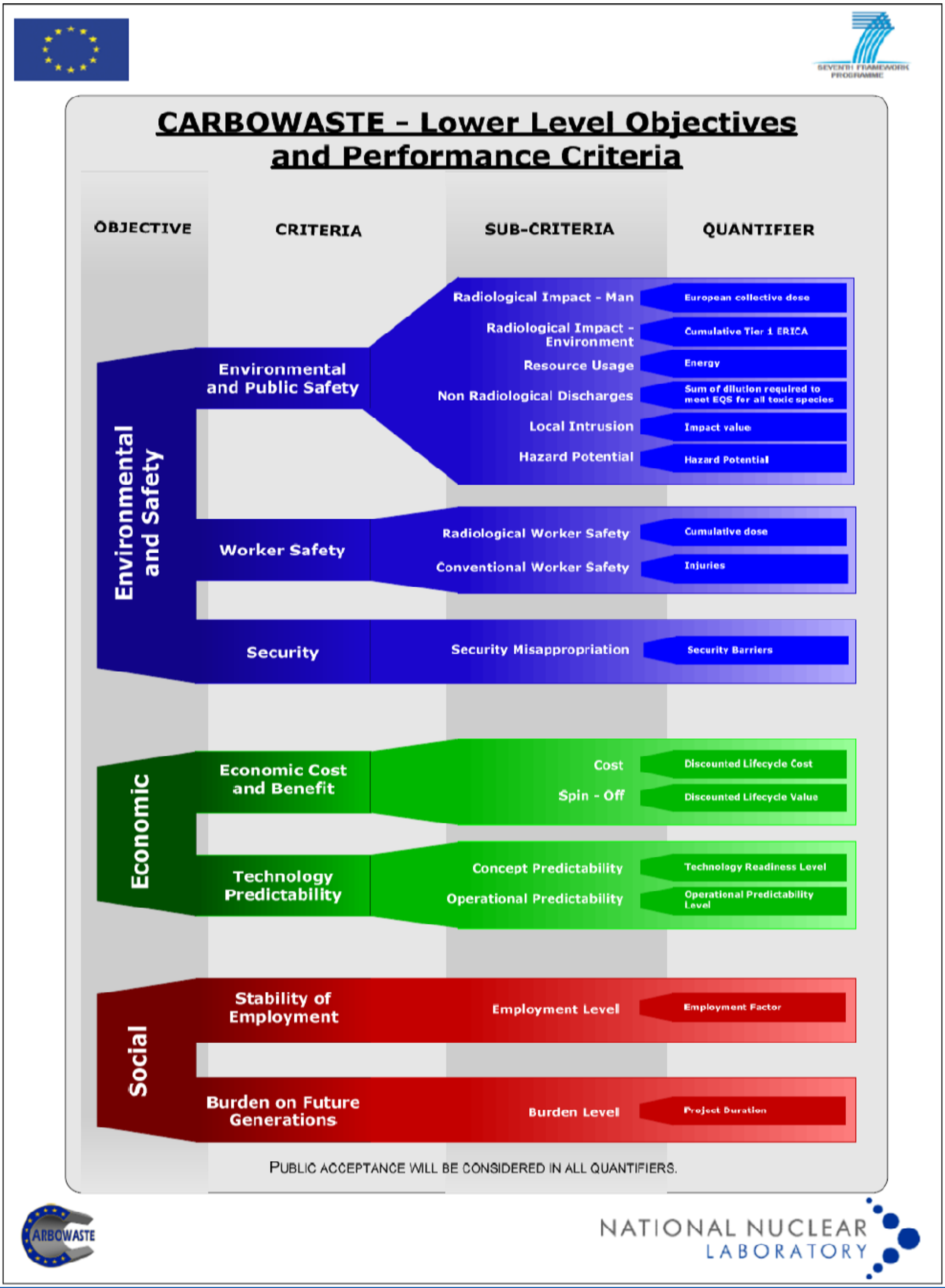
Option 23: Chemically bind ^{14}C



Option 24: Interim storage of raw waste and repository



Appendix 2 – Criteria and Sub-criteria Diagram



Appendix 3 – Flowsheet Outputs

		PROCESS OPERATION							
ASSESSMENT CRITERION	**Data (Units)**	**In-reactor Storage**	**Retrieval**	**Grouting**	**Transport**	**Repository Filling**	**Repository**	**Overall Total**	**Grand Total**
Public Safety: Routine Radioactive Discharges	H-3 (man Sv)	4.72E-06	6.37E-05	4.23E-09	8.62E-11	8.29E-13	0.00E+00	6.84E-05	1.18E-02
	C-14 (man Sv)	7.49E-04	8.55E-03	1.80E-06	2.99E-08	2.86E-09	9.56E-07	9.30E-03	
	Co-60 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	2.47E-03	
Environmental Safety: Routine Radioactive Discharges	H-3	1.55E+01	4.98E-01	2.50E-08	7.38E-02	1.99E-06	0.00E+00	1.60E+01	8.44E+01
	C-14	6.13E+01	1.67E+00	2.65E-07	6.40E-01	1.71E-04	5.91E-04	6.36E+01	
	Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.81E+00	4.81E+00	
Environment and Public Safety: Resource Usage	Energy (GJ)	45000	14907	467341	98	784177	0	1311523	1311523
Public Safety: Non Radioactive Discharges	Dilution required (m3)	0	0	0	0	0	0	0	0
Environment and Public Safety: Local Intrusion	Noise (decibel.years)	0	0	280	648.4	7220.3	0	8149	8149
	Land (hectares.years)	1625	487.5	0	0	3000	0	5113	5113
	Transport (truck journeys)	0	0	2963	763	9032	0	12758	12758
Environment and Public Safety: Hazard Potential (RHP)	H-3	1.70E+01	1.52E-02	0.00E+00	0.00E+00	3.60E+00	1.30E-02	2.06E+01	1.91E+04
	C-14	3.72E+01	1.14E-01	0.00E+00	0.00E+00	1.48E+02	1.21E+04	1.23E+04	
	Co-60	9.35E+02	1.62E+00	0.00E+00	0.00E+00	1.35E+01	2.64E-05	9.50E+02	
	Cl-36	4.90E-01	1.22E-03	0.00E+00	0.00E+00	1.96E+00	5.80E+03	5.81E+03	
Worker Safety: Radiological Safety	mSv (total)	17.1	12.83	8.55	4.20	4.53	0	47.20	47.20
Worker Safety: Conventional Safety	Injuries	0.65	0.49	2.65	0.35	9.24	1.61	14.99	14.99
Security Misappropriation	H-3	4.99E-02	5.20E-01	0.00E+00	1.04E+01	4.53E+00	0.00E+00	1.55E+01	3.12E+02
	C-14	7.47E-02	2.49E+00	0.00E+00	4.97E+01	3.31E+01	0.00E+00	8.54E+01	
	Co-60	2.93E+00	7.99E+00	0.00E+00	1.59E+02	3.96E+01	0.00E+00	2.10E+02	
	Cl-36	9.55E-04	3.28E-02	0.00E+00	6.54E-01	4.36E-01	0.00E+00	1.12E+00	
Economic Costs	Cost of constructing /operating /decommissioning the process (£M)	38.25	36.15	69.32	0.94	879.98	0.81	1025.45	1025.45
Economic Benefits (Reuse & spinoff)	Value of reuse of materials and spin-off opportunities from newly developed technologies (£M)	0	0	0	0	0	0	0	
Technology Predictability: Concept	TRL of technology to be used (TRL 1 to 9)	9.00	7.00	5.00	9.00	5.00	9.00	5.00	
	Cost to fully develop technology if not already mature (£M)	0	4	1.00	0.25	50.92	0	56.17	56.17
Technology Predictability: Operational	Potential cost to project as a result of risk (£M)	0	6.27	3.47	0	219.99	0	229.73	229.73
	Potential delay to project as a result of risk (yr)	0	1.13	0.38	0	2.50	0	4.00	4.00
Stability of Employment	Rapid Staffing Changes (jobs)	282.00	8.55	509	3	251.50	195.50	1249.55	1249.55
Burden on Future Generations	Decades until material no longer requires active management	2.5	0.75	0	0	10	10	23.25	23.25

Calculation Sheet Output for Option 1: Encapsulation and deep repository

		PROCESS OPERATION								
ASSESSMENT CRITERION	**Data (Units)**	**In-reactor Storage**	**Retrieval**	**Size Reduction**	**Grouting**	**Transport**	**Repository Filling**	**Repository**	**Overall Total**	**Grand Total**
Public Safety: Routine Radioactive Discharges	H-3 (man Sv)	4.73E-06	6.37E-05	5.28E-05	4.97E-09	1.66E-12	8.30E-13	0.00E+00	1.21E-04	3.62E-02
	C-14 (man Sv)	7.51E-04	8.65E-03	2.25E-02	2.11E-06	7.04E-10	1.49E-09	1.32E-05	3.19E-02	
	Co-60 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.15E-03	4.15E-03	
Environmental Safety: Routine Radioactive Discharges	H-3	1.55E+01	4.99E-01	4.14E-01	3.23E-08	1.66E-03	1.99E-06	0.00E+00	1.64E+01	9.68E+01
	C-14	6.14E+01	1.69E+00	4.40E+00	3.43E-07	1.77E-02	8.93E-05	1.30E-02	6.75E+01	
	Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.29E+01	1.29E+01	
Environment and Public Safety: Resource Usage	Energy (GJ)	45000	14907	257821	416897	83	617584	0	1352293	1352293
Public Safety: Non Radioactive Discharges	Dilution required (m3)	0	0	0	0	0	0	0	0	0
Environment and Public Safety: Local Intrusion	Noise (decibel.years)	0	0	0	280	648.4	7220.3	0	8149	8149
	Land (hectares.years)	1625	487.5	0	0	0	3000	0	5113	5113
	Transport (truck journeys)	0	0	1388.9032	2693	648	5520	0	10250	10250
Environment and Public Safety: Hazard Potential (RHP)	H-3	1.70E+01	1.79E-02	0.00E+00	0.00E+00	0.00E+00	3.61E+00	1.31E-02	2.06E+01	1.92E+04
	C-14	3.77E+01	1.35E-01	0.00E+00	0.00E+00	0.00E+00	1.49E+02	1.23E+04	1.25E+04	
	Co-60	9.35E+02	1.90E+00	0.00E+00	0.00E+00	0.00E+00	1.63E-01	2.64E-05	9.37E+02	
	Cl-36	4.90E-01	1.43E-03	0.00E+00	0.00E+00	0.00E+00	1.96E+00	5.80E+03	5.81E+03	
Worker Safety: Radiological Safety	mSv (total)	17.1	12.83	0.00	8.55	3.58	2.55	0	44.61	44.61
Worker Safety: Conventional Safety	Injuries	0.65	0.49	1.72	2.63	0.35	9.24	4.84	19.92	19.92
Security Misappropriation	H-3	2.41E-02	5.20E-01	0.00E+00	0.00E+00	1.22E+01	9.82E-02	0.00E+00	1.28E+01	2.74E+02
	C-14	7.50E-02	2.52E+00	0.00E+00	0.00E+00	5.90E+01	7.25E-01	0.00E+00	6.23E+01	
	Co-60	2.42E+00	7.99E+00	0.00E+00	0.00E+00	1.87E+02	8.58E-01	0.00E+00	1.98E+02	
	Cl-36	9.55E-04	3.28E-02	0.00E+00	0.00E+00	7.67E-01	9.44E-03	0.00E+00	8.11E-01	
Economic Costs	Cost of constructing /operating /decommissioning the process (£M)	38.25	36.15	30.00	63.24	0.94	799.88	0.69	969.15	969.15
Economic Benefits (Reuse & spinoff)	Value of reuse of materials and spin-off opportunities from newly developed technologies (£M)	0	0	0	0	0	0	0	0	
Technology Predictability: Concept	TRL of technology to be used (TRL 1 to 9)	9.00	7.00	7.00	5.00	9.00	5.00	2.50	2.50	
	Cost to fully develop technology if not already mature (£M)	0	4	0	0.14	0.25	46.29	0	50.68	50.68
Technology Predictability: Operational	Potential cost to project as a result of risk (£M)	0	6.27	0.90	3.16	0	199.97	0	210.30	210.30
	Potential delay to project as a result of risk (yr)	0	1.13	0.23	0.38	0	2.50	0	4.23	4.23
Stability of Employment	Rapid Staffing Changes (jobs)	282.00	8.55	257.85828	509	3	251.50	195.50	1507.41	1507.41
Burden on Future Generations	Decades until material no longer requires active management	2.5	0.75	0	0	0	10	10	23.25	23.25

Calculation Sheet Output for Option 2: Size reduce graphite for minimised waste package volume; local immobilisation

		PROCESS OPERATION							
ASSESSMENT CRITERION	**Data (Units)**	**In-reactor Storage**	**Retrieval**	**Place Waste in Box**	**Transport**	**Repository Filling**	**Repository**	**Overall Total**	**Grand Total**
Public Safety: Routine Radioactive Discharges	H-3 (man Sv)	4.73E-06	6.37E-05	4.24E-08	1.41E-12	8.30E-13	0.00E+00	6.85E-05	1.20E-02
	C-14 (man Sv)	7.51E-04	8.65E-03	1.81E-05	6.01E-10	1.49E-09	9.56E-07	9.42E-03	
	Co-60 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	2.47E-03	
Environmental Safety: Routine Radioactive Discharges	H-3	1.55E+01	4.99E-01	2.76E-06	1.21E-03	1.99E-06	0.00E+00	1.60E+01	7.92E+01
	C-14	6.14E+01	1.69E+00	2.95E-05	1.29E-02	8.93E-05	1.25E-05	6.31E+01	
	Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.02E-01	1.02E-01	
Environment and Public Safety: Resource Usage	Energy (GJ)	45000	14907	106611	96	679430	0	846044	846044
Public Safety: Non Radioactive Discharges	Dilution required (m3)	0	0	0	0	0	0	0	0
Environment and Public Safety: Local Intrusion	Noise (decibel.years)	0	0	0	648.4	7220.3	0	7869	7869
	Land (hectares.years)	1625	487.5	0	0	3000	0	5113	5113
	Transport (truck journeys)	0	0	0	748	5354	0	6102	6102
Environment and Public Safety: Hazard Potential (RHP)	H-3	1.70E+01	1.52E-02	0.00E+00	0.00E+00	3.61E+00	1.31E-02	2.06E+01	1.92E+04
	C-14	3.77E+01	1.15E-01	0.00E+00	0.00E+00	1.49E+02	1.23E+04	1.25E+04	
	Co-60	9.35E+02	1.62E+00	0.00E+00	0.00E+00	1.63E-01	2.64E-05	9.36E+02	
	Cl-36	4.90E-01	1.22E-03	0.00E+00	0.00E+00	1.96E+00	5.80E+03	5.81E+03	
Worker Safety: Radiological Safety	mSv (total)	17.1	12.83	8.55	4.20	2.65	0	45.33	45.33
Worker Safety: Conventional Safety	Injuries	0.65	0.49	0.33	0.35	9.24	1.61333333	12.67	12.67
Security Misappropriation	H-3	2.41E-02	5.20E-01	0.00E+00	1.04E+01	7.96E-02	0.00E+00	1.10E+01	2.36E+02
	C-14	7.50E-02	2.52E+00	0.00E+00	5.03E+01	5.88E-01	0.00E+00	5.35E+01	
	Co-60	2.42E+00	7.99E+00	0.00E+00	1.59E+02	6.95E-01	0.00E+00	1.71E+02	
	Cl-36	9.55E-04	3.28E-02	0.00E+00	6.55E-01	7.65E-03	0.00E+00	6.96E-01	
Economic Costs	Cost of constructing /operating /decommissioning the process (£M)	38.25	36.15	3.75	0.94	879.98	0.81	959.88	959.88
Economic Benefits (Reuse & spinoff)	Value of reuse of materials and spin-off opportunities from newly developed technologies (£M)	0	0	0	0	0	0	0	
Technology Predictability: Concept	TRL of technology to be used (TRL 1 to 9)	9.00	7.00	9.00	9.00	5.00	9.00	5.00	
	Cost to fully develop technology if not already mature (£M)	0	4	0.00	0.25	50.92	0	55.17	55.17
Technology Predictability: Operational	Potential cost to project as a result of risk (£M)	0	6.27	0.00	0	219.99	0	226.26	226.26
	Potential delay to project as a result of risk (yr)	0	1.13	0.00	0	2.50	0	3.63	3.63
Stability of Employment	Rapid Staffing Changes (jobs)	282.00	8.55	0	3	251.50	195.50	740.55	740.55
Burden on Future Generations	Decades until material no longer requires active management	2.5	0.75	0	0	10	10	23.25	23.25

Calculation Sheet Output for Option 3: Minimum processing

		PROCESS OPERATION								
ASSESSMENT CRITERION	**Data (Units)**	**In-reactor Storage**	**Retrieval**	**Size Reduction**	**Grouting**	**Transport**	**Repository Filling**	**Repository**	**Overall Total**	**Grand Total**
Public Safety: Routine Radioactive Discharges	H-3 (man Sv)	6.17E-06	3.83E-06	3.17E-06	2.98E-10	9.94E-14	4.98E-14	0.00E+00	1.32E-05	3.60E-02
	C-14 (man Sv)	2.25E-03	8.60E-03	2.23E-02	2.10E-06	7.00E-10	1.48E-09	2.99E-04	3.35E-02	
	Co-60 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	2.47E-03	
Environmental Safety: Routine Radioactive Discharges	H-3	6.73E+00	2.99E-02	2.48E-02	1.94E-09	9.97E-05	1.20E-07	0.00E+00	6.79E+00	7.94E+01
	C-14	6.12E+01	1.68E+00	4.37E+00	3.41E-07	1.76E-02	8.87E-05	4.22E-03	6.73E+01	
	Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.29E+00	5.29E+00	
Environment and Public Safety: Resource Usage	Energy (GJ)	135000	14907	257821	416897	83	617584	0	1442293	1442293
Public Safety: Non Radioactive Discharges	Dilution required (m3)	0	0	0	0	0	0	0	0	0
Environment and Public Safety: Local Intrusion	Noise (decibel.years)	0	0	0	280	648.4	7220.3	0	8149	8149
	Land (hectares.years)	4875	487.5	0	0	0	3000	0	8363	8363
	Transport (truck journeys)	0	0	1388.9032	2693	648	5520	0	10250	10250
Environment and Public Safety: Hazard Potential (RHP)	H-3	2.22E+01	1.07E-03	0.00E+00	0.00E+00	0.00E+00	2.17E-01	7.84E-04	2.24E+01	1.93E+04
	C-14	1.13E+02	1.34E-01	0.00E+00	0.00E+00	0.00E+00	1.49E+02	1.22E+04	1.25E+04	
	Co-60	9.71E+02	2.65E-03	0.00E+00	0.00E+00	0.00E+00	2.27E-04	3.68E-08	9.71E+02	
	Cl-36	1.47E+00	1.43E-03	0.00E+00	0.00E+00	0.00E+00	1.96E+00	5.80E+03	5.81E+03	
Worker Safety: Radiological Safety	mSv (total)	51.3	12.83	0.00	8.55	3.58	2.55	0	78.81	78.81
Worker Safety: Conventional Safety	Injuries	1.96	0.49	1.72	2.63	0.35	9.24	1.61333333	18.00	18.00
Security Misappropriation	H-3	7.23E-02	3.12E-02	0.00E+00	0.00E+00	7.30E-01	5.89E-03	0.00E+00	8.40E-01	7.12E+01
	C-14	2.25E-01	2.51E+00	0.00E+00	0.00E+00	5.86E+01	7.20E-01	0.00E+00	6.20E+01	
	Co-60	7.26E+00	1.12E-02	0.00E+00	0.00E+00	2.61E-01	1.20E-03	0.00E+00	7.53E+00	
	Cl-36	2.87E-03	3.28E-02	0.00E+00	0.00E+00	7.67E-01	9.44E-03	0.00E+00	8.12E-01	
Economic Costs	Cost of constructing /operating /decommissioning the process (£M)	70.75	36.15	30.00	63.24	0.94	799.88	0.69	1001.65	1001.65
Economic Benefits (Reuse & spinoff)	Value of reuse of materials and spin-off opportunities from newly developed technologies (£M)	0	0	0	0	0	0	0	0	
Technology Predictability: Concept	TRL of technology to be used (TRL 1 to 9)	9.00	7.00	7.00	5.00	9.00	5.00	9.00	5.00	
	Cost to fully develop technology if not already mature (£M)	0	4	0	0.14	0.25	46.29	0	50.68	50.68
Technology Predictability: Operational	Potential cost to project as a result of risk (£M)	0	6.27	0.90	3.16	0	199.97	0	210.30	210.30
	Potential delay to project as a result of risk (yr)	0	1.13	0.23	0.38	0	2.50	0	4.23	4.23
Stability of Employment	Rapid Staffing Changes (jobs)	282.00	8.55	257.85828	509	3	251.50	195.50	1507.41	1507.41
Burden on Future Generations	Decades until material no longer requires active management	7.5	0.75	0	0	0	10	10	28.25	28.25

Calculation Sheet Output for Option 4: Deferred start with remote retrieval

ASSESSMENT CRITERION	Data (Units)	PROCESS DESCRIPTION								
		In-reactor Storage	Retrieval	Size Reduction	Grouting	Transport	Repository Filling	Repository	Overall Total	Grand Total
Public Safety: Routine Radioactive Discharges	H-3 (man Sv)	6.17E-06	3.83E-06	3.17E-06	2.98E-10	9.94E-14	4.98E-14	0.00E+00	1.32E-05	3.60E-02
	C-14 (man Sv)	2.25E-03	8.60E-03	2.23E-02	2.10E-06	7.00E-10	1.48E-09	2.99E-04	3.35E-02	
	Co-60 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	2.47E-03	
Environmental Safety: Routine Radioactive Discharges	H-3	6.73E+00	2.99E-02	2.48E-02	1.94E-09	9.97E-05	1.20E-07	0.00E+00	6.79E+00	7.94E+01
	C-14	6.12E+01	1.68E+00	4.37E+00	3.41E-07	1.76E-02	8.87E-05	4.22E-03	6.73E+01	
	Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.29E+00	5.29E+00	
Environment and Public Safety: Resource Usage	Energy (GJ)	135000	14204	180359	416897	83	617584	0	1364127	1364127
Public Safety: Non Radioactive Discharges	Dilution required (m3)	0	0	0	0	0	0	0	0	0
Environment and Public Safety: Local Intrusion	Noise (decibel.years)	0	0	0	280	648.4	7220.3	0	8149	8149
	Land (hectares.years)	4875	487.5	0	0	0	3000	0	8363	8363
	Transport (truck journeys)	0	0	1388.9032	2693	648	5520	0	10250	10250
Environment and Public Safety: Hazard Potential (RHP)	H-3	2.22E+01	1.07E-03	0.00E+00	0.00E+00	0.00E+00	2.17E-01	7.84E-04	2.24E+01	1.93E+04
	C-14	1.13E+02	1.34E-01	0.00E+00	0.00E+00	0.00E+00	1.49E+02	1.22E+04	1.25E+04	
	Co-60	9.71E+02	2.65E-03	0.00E+00	0.00E+00	0.00E+00	2.27E-04	3.68E-08	9.71E+02	
	Cl-36	1.47E+00	1.43E-03	0.00E+00	0.00E+00	0.00E+00	1.96E+00	5.80E+03	5.81E+03	
Worker Safety: Radiological Safety	mSv (total)	51.3	979.76	0.00	8.55	3.58	2.55	0	1045.75	1045.75
Worker Safety: Conventional Safety	Injuries	1.96	0.49	1.72	2.63	0.35	9.24	1.61333333	18.00	18.00
Security Misappropriation	H-3	7.23E-02	3.12E-02	3.12E-02	3.12E-02	7.30E-02	2.04E-01	0.00E+00	4.43E-01	4.68E+01
	C-14	2.25E-01	2.51E+00	2.51E+00	2.50E+00	5.86E+00	2.49E+01	0.00E+00	3.85E+01	
	Co-60	7.26E+00	1.12E-02	1.12E-02	1.12E-02	2.61E-02	4.14E-02	0.00E+00	7.36E+00	
	Cl-36	2.87E-03	3.28E-02	3.28E-02	3.28E-02	7.67E-02	3.26E-01	0.00E+00	5.04E-01	
Economic Costs	Cost of constructing /operating /decommissioning the process (£M)	70.75	36.15	29.99	63.24	0.94	799.88	0.69	1001.63	1001.63
Economic Benefits (Reuse & spinoff)	Value of reuse of materials and spin-off opportunities from newly developed technologies (£M)	0	0	0	0	0	0	0	0	
Technology Predictability: Concept	TRL of technology to be used (TRL 1 to 9)	9.00	7.00	7.00	5.00	9.00	5.00	9.00	5.00	
	Cost to fully develop technology if not already mature (£M)	0	4	0	0.14	0.25	46.29	0	50.68	50.68
Technology Predictability: Operational	Potential cost to project as a result of risk (£M)	0	3.13	4.50	3.16	0	199.97	0	210.76	210.76
	Potential delay to project as a result of risk (yr)	0	0.56	1.13	0.38	0	2.50	0	4.56	4.56
Stability of Employment	Rapid Staffing Changes (jobs)	282.00	8.55	257.85828	509	3	251.50	195.50	1507.41	1507.41
Burden on Future Generations	Decades until material no longer requires active management	7.5	0.75	0	0	0	10	10	28.25	28.25

Calculation Sheet Output for Option 5: Deferred start with manual retrieval

ASSESSMENT CRITERION	Data (Units)	PROCESS OPERATION: In-reactor Storage	Retrieval	Waste in Box	Transport	Repository Filling	Repository	Overall Total	Grand Total
Public Safety: Routine Radioactive Discharges	H-3 (man Sv)	6.17E-06	3.83E-06	2.54E-09	8.48E-14	4.98E-14	0.00E+00	1.00E-05	1.33E-02
	C-14 (man Sv)	2.25E-03	8.60E-03	1.79E-05	5.97E-10	1.48E-09	9.56E-07	1.09E-02	
	Co-60 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	2.47E-03	
Environmental Safety: Routine Radioactive Discharges	H-3	6.73E+00	2.99E-02	1.66E-07	7.26E-05	1.20E-07	0.00E+00	6.76E+00	7.45E+01
	C-14	6.12E+01	1.68E+00	2.92E-05	1.28E-02	8.88E-05	5.91E-04	6.29E+01	
	Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.81E+00	4.81E+00	
Environment and Public Safety: Resource Usage	Energy (GJ)	135000	14907	106611	96	679430	0	936044	936044
Public Safety: Non Radioactive Discharges	Dilution required (m3)	0	0	0	0	0	0	0	0
Environment and Public Safety: Local Intrusion	Noise (decibel.years)	0	0	0	648.4	7220.3	0	7869	
	Land (hectares.years)	4875	487.5	0	0	3000	0	8363	
	Transport (truck journeys)	0	0	0	748	5354	0	6102	
Environment and Public Safety: Hazard Potential (RHP)	H-3	2.22E+01	9.15E-04	0.00E+00	0.00E+00	2.17E-01	7.84E-04	2.24E+01	1.93E+04
	C-14	1.13E+02	1.15E-01	0.00E+00	0.00E+00	1.49E+02	1.22E+04	1.25E+04	
	Co-60	9.71E+02	2.26E-03	0.00E+00	0.00E+00	2.27E-04	3.68E-08	9.71E+02	
	Cl-36	1.47E+00	1.22E-03	0.00E+00	0.00E+00	1.96E+00	5.80E+03	5.81E+03	
Worker Safety: Radiological Safety	mSv (total)	51.3	12.83	8.55	4.20	2.65	0	79.53	79.53
Worker Safety: Conventional Safety	Injuries	1.96	0.49	0.24	0.35	9.24	1.61333333	13.89	13.89
Security Misappropriation	H-3	7.23E-02	3.12E-02	0.00E+00	6.23E-01	4.78E-03	0.00E+00	7.31E-01	6.22E+01
	C-14	2.25E-01	2.51E+00	0.00E+00	5.00E+01	5.84E-01	0.00E+00	5.33E+01	
	Co-60	7.26E+00	1.12E-02	0.00E+00	2.23E-01	9.71E-04	0.00E+00	7.49E+00	
	Cl-36	2.87E-03	3.28E-02	0.00E+00	6.55E-01	7.65E-03	0.00E+00	6.98E-01	
Economic Costs	Cost of constructing /operating /decommissioning the process (£M)	70.75	36.15	3.75	0.94	879.98	0.81	992.38	992.38
Economic Benefits (Reuse & spinoff)	Value of reuse of materials and spin-off opportunities from newly developed technologies (£M)	0	0	0	0	0	0	0	
Technology Predictability: Concept	TRL of technology to be used (TRL 1 to 9)	9.00	7.00	9.00	9.00	5.00	9.00	5.00	
	Cost to fully develop technology if not already mature (£M)	0	4	0.00	0.25	50.92	0	55.17	
Technology Predictability: Operational	Potential cost to project as a result of risk (£M)	0	6.27	0.00	0	219.99	0	226.26	
	Potential delay to project as a result of risk (yr)	0	1.13	0.00	0	2.50	0	3.63	
Stability of Employment	Rapid Staffing Changes (jobs)	282.00	8.55	18	3	251.50	195.50	758.55	758.55
Burden on Future Generations	Decades until material no longer requires active management	7.5	0.75	0	0	10	10	28.25	28.25

Calculation Sheet Output for Option 6: Minimum processing with deferred start

ASSESSMENT CRITERION	Data (Units)	PROCESS OPERATION In-reactor Storage	Retrieval	Grouting	Transport	Repository Filling	Repository	Overall Total	Grand Total
Public Safety: Routine Radioactive Discharges	H-3 (man Sv)	4.73E-06	6.37E-05	4.24E-09	1.41E-12	8.30E-13	0.00E+00	6.84E-05	
	C-14 (man Sv)	7.51E-04	8.65E-03	1.80E-06	6.01E-10	1.49E-09	2.99E-04	9.70E-03	
	Co-60 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	2.47E-03	1.22E-02
Environmental Safety: Routine Radioactive Discharges	H-3	1.55E+01	4.99E-01	2.50E-08	1.21E-03	1.99E-06	0.00E+00	1.60E+01	
	C-14	6.14E+01	1.69E+00	2.66E-07	1.29E-02	8.93E-05	4.16E-03	6.31E+01	
	Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.81E+00	4.81E+00	8.39E+01
Environment and Public Safety: Resource Usage	Energy (GJ)	45000	20383	471110	106	679430	0	1216029	1216029
Public Safety: Non Radioactive Discharges	Dilution required (m3)	0	0	0	0	0	0	0	0
Environment and Public Safety: Local Intrusion	Noise (decibel.years)	0	0	280	648.4	7220.3	0	8149	8148.64
	Land (hectares.years)	1625	487.5	0	0	3000	0	5113	5112.50
	Transport (truck journeys)	0	0	2963	814	6470	0	10246	10246.48
Environment and Public Safety: Hazard Potential (RHP)	H-3	1.70E+01	1.52E-02	0.00E+00	0.00E+00	3.61E+00	1.31E-02	2.06E+01	
	C-14	3.77E+01	1.15E-01	0.00E+00	0.00E+00	1.49E+02	1.23E+04	1.25E+04	
	Co-60	9.35E+02	1.62E+00	0.00E+00	0.00E+00	1.63E-01	2.64E-05	9.36E+02	
	Cl-36	4.90E-01	1.22E-03	0.00E+00	0.00E+00	1.96E+00	5.80E+03	5.81E+03	1.92E+04
Worker Safety: Radiological Safety	mSv (total)	17.1	12.83	8.55	4.20	3.19	0	45.86	45.86
Worker Safety: Conventional Safety	Injuries	0.65	0.49	2.65	0.35	9.24	1.61333333	14.99	14.99
Security Misappropriation	H-3	2.41E-02	5.20E-01	0.00E+00	1.04E+01	1.09E-01	0.00E+00	1.10E+01	
	C-14	7.50E-02	2.52E+00	0.00E+00	5.03E+01	8.06E-01	0.00E+00	5.37E+01	
	Co-60	2.42E+00	7.99E+00	0.00E+00	1.59E+02	9.53E-01	0.00E+00	1.71E+02	
	Cl-36	9.55E-04	3.28E-02	0.00E+00	6.55E-01	1.05E-02	0.00E+00	6.99E-01	2.36E+02
Economic Costs	Cost of constructing /operating /decommissioning the process (£M)	38.25	21.98	69.32	0.95	879.98	0.81	1011.28	1011.28
Economic Benefits (Reuse & spinoff)	Value of reuse of materials and spin-off opportunities from newly developed technologies (£M)	0	0	0	0	0	0	0	
Technology Predictability: Concept	TRL of technology to be used (TRL 1 to 9)	9.00	4.00	5.00	9.00	5.00	2.50	2.50	
	Cost to fully develop technology if not already mature (£M)	0	7.073333	0.16	0.25	50.92	0	58.40	58.40
Technology Predictability: Operational	Potential cost to project as a result of risk (£M)	0	8.28	3.47	0	219.99	0	231.74	231.74
	Potential delay to project as a result of risk (yr)	0	2.25	0.38	0	2.50	0	5.13	5.13
Stability of Employment	Rapid Staffing Changes (jobs)	282.00	8.55	518	3	251.50	195.50	1258.55	1258.55
Burden on Future Generations	Decades until material no longer requires active management	2.5	0.75	0	0	10	10	23.25	23.25

Calculation Sheet Output for Option 7: Alternative retrieval and graphite form in package

		PROCESS OPERATION								
ASSESSMENT CRITERION	Data (Units)	In-reactor Storage	Retrieval	Grouting	Interim Storage (2)	Transport	Repository Filling	Repository	Overall Total	Grand Total
Public Safety: Routine Radioactive Discharges	H-3 (man Sv)	4.73E-06	6.37E-05	4.24E-09	1.00E-08	3.34E-15	2.99E-15	0.00E+00	6.85E-05	1.55E-02
	C-14 (man Sv)	7.51E-04	8.65E-03	1.80E-06	2.98E-05	5.93E-10	1.47E-09	7.36E-04	1.02E-02	
	Co-60 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.25E-03	5.25E-03	
Environmental Safety: Routine Radioactive Discharges	H-3	1.55E+01	8.88E+01	2.50E-08	6.44E-01	2.86E-06	7.18E-09	0.00E+00	1.05E+02	5.26E+02
	C-14	6.14E+01	3.01E+02	2.66E-07	4.78E+01	1.27E-02	8.82E-05	4.55E-01	4.11E+02	
	Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.02E+01	1.02E+01	
Environment and Public Safety: Resource Usage	Energy (GJ)	45000	107098	471110	330251	106	385419	0	1338983	1338983
Public Safety: Non Radioactive Discharges	Dilution required (m3)	0	0	0	0	0	0	0	0	0
Environment and Public Safety: Local Intrusion	Noise (decibel.years)	0	0	280	0	648.4	7220.3	0	8149	
	Land (hectares.years)	1625	487.5	0	6500	0	3000	0	11613	
	Transport (truck journeys)	0	763.9951	2963	0	814	3658	0	8199	
Environment and Public Safety: Hazard Potential (RHP)	H-3	1.70E+01	1.52E-02	0.00E+00	1.88E+01	0.00E+00	1.30E-02	4.71E-05	3.59E+01	1.94E+04
	C-14	3.77E+01	1.15E-01	0.00E+00	1.39E+02	0.00E+00	1.48E+02	1.21E+04	1.25E+04	
	Co-60	9.35E+02	1.62E+00	0.00E+00	1.65E+02	0.00E+00	3.17E-07	5.15E-11	1.10E+03	
	Cl-36	4.90E-01	1.22E-03	0.00E+00	1.81E+00	0.00E+00	1.96E+00	5.80E+03	5.81E+03	
Worker Safety: Radiological Safety	mSv (total)	17.1	12.83	8.55	6.84	4.20	3.19	0	52.70	52.70
Worker Safety: Conventional Safety	Injuries	0.65	0.98	2.65	0.19	0.35	9.24	4.84	18.91	18.91
Security Misappropriation	H-3	2.41E-02	5.20E-01	0.00E+00	4.55E-01	2.45E-02	3.94E-04	0.00E+00	1.02E+00	7.25E+01
	C-14	7.50E-02	2.52E+00	0.00E+00	3.36E+00	4.96E+01	7.96E-01	0.00E+00	5.64E+01	
	Co-60	2.42E+00	7.99E+00	0.00E+00	3.97E+00	1.16E-04	1.86E-06	0.00E+00	1.44E+01	
	Cl-36	9.55E-04	3.28E-02	0.00E+00	4.37E-02	6.54E-01	1.05E-02	0.00E+00	7.42E-01	
Economic Costs	Cost of constructing /operating /decommissioning the process (£M)	38.25	52.63	69.32	35.71	0.95	879.98	0.81	1077.65	1077.65
Economic Benefits (Reuse & spinoff)	Value of reuse of materials and spin-off opportunities from newly developed technologies (£M)	0	0	0	0	0	0	0	0	
Technology Predictability: Concept	TRL of technology to be used (TRL 1 to 9)	9.00	7.00	5.00	9.00	9.00	5.00	2.50	2.50	
	Cost to fully develop technology if not already mature (£M)	0	6	0.16	0.00	0.25	50.92	0	57.33	
Technology Predictability: Operational	Potential cost to project as a result of risk (£M)	0	17.48	3.47	0.00	0	219.99	0	240.94	
	Potential delay to project as a result of risk (yr)	0	2.25	0.38	0.00	0	2.50	0	5.13	
Stability of Employment	Rapid Staffing Changes (jobs)	282.00	137.4791	509	18.3	3	233.20	195.50	1378.48	1378.48
Burden on Future Generations	Decades until material no longer requires active management	2.5	0.75	0	10	0	10	10	33.25	33.25

Calculation Sheet Output for Option 8: Alternative retrieval and repository

ASSESSMENT CRITERION	Data (Units)	PROCESS OPERATION								Grand Total
		In-reactor Storage	Retrieval	Grouting	Interim Storage (2)	Transport	Repository Filling	Repository	Overall Total	
Public Safety: Routine Radioactive Discharges	H-3 (man Sv)	4.73E-06	6.37E-05	4.24E-09	5.66E-10	3.34E-15	2.99E-15	0.00E+00	6.84E-05	1.58E-02
	C-14 (man Sv)	7.51E-04	8.65E-03	1.80E-06	3.00E-07	5.93E-10	1.47E-09	1.03E-03	1.04E-02	
	Co-60 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.25E-03	5.25E-03	
Environmental Safety: Routine Radioactive Discharges	H-3	1.55E+01	4.99E-01	2.50E-08	3.63E-02	2.86E-06	7.18E-09	0.00E+00	1.60E+01	9.03E+01
	C-14	6.14E+01	1.69E+00	2.66E-07	4.80E-01	1.27E-02	8.82E-05	4.58E-01	6.41E+01	
	Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.02E+01	1.02E+01	
Environment and Public Safety: Resource Usage	Energy (GJ)	45000	14907	471110	47665	106	385419	0	964206	964206
Public Safety: Non Radioactive Discharges	Dilution required (m3)	0	0	0	0	0	0	0	0	0
Environment and Public Safety: Local Intrusion	Noise (decibel.years)	0	0	280	220	648.4	7220.3	0	8369	
	Land (hectares.years)	1625	487.5	0	6500	0	3000	0	11613	
	Transport (truck journeys)	0	0	2963	408.6011204	814	3658	0	7843	
Environment and Public Safety: Hazard Potential (RHP)	H-3	1.70E+01	1.52E-02	0.00E+00	1.88E+01	0.00E+00	1.30E-02	4.71E-05	3.59E+01	1.94E+04
	C-14	3.77E+01	1.15E-01	0.00E+00	1.39E+02	0.00E+00	1.48E+02	1.21E+04	1.25E+04	
	Co-60	9.35E+02	1.62E+00	0.00E+00	1.65E+02	0.00E+00	3.17E-07	5.15E-11	1.10E+03	
	Cl-36	4.90E-01	1.22E-03	0.00E+00	1.81E+00	0.00E+00	1.96E+00	5.80E+03	5.81E+03	
Worker Safety: Radiological Safety	mSv (total)	17.1	12.83	8.55	6.84	4.20	3.19	0	52.70	52.70
Worker Safety: Conventional Safety	Injuries	0.65	0.49	2.65	0.19	0.35	9.24	1.61333333	15.19	15.19
Security Misappropriation	H-3	2.41E-02	5.20E-01	0.00E+00	4.55E-01	2.45E-02	3.94E-04	0.00E+00	1.02E+00	7.25E+01
	C-14	7.50E-02	2.52E+00	0.00E+00	3.36E+00	4.96E+01	7.96E-01	0.00E+00	5.64E+01	
	Co-60	2.42E+00	7.99E+00	0.00E+00	3.97E+00	1.16E-04	1.86E-06	0.00E+00	1.44E+01	
	Cl-36	9.55E-04	3.28E-02	0.00E+00	4.37E-02	6.54E-01	1.05E-02	0.00E+00	7.42E-01	
Economic Costs	Cost of constructing /operating /decommissioning the process (£M)	38.25	36.15	69.32	35.71	0.95	879.98	0.81	1061.17	1061.17
Economic Benefits (Reuse & spinoff)	Value of reuse of materials and spin-off opportunities from newly developed technologies (£M)	0	0	0	0	0	0	0	0	
Technology Predictability: Concept	TRL of technology to be used (TRL 1 to 9)	9.00	7.00	5.00	9.00	9.00	5.00	9.00	5.00	
	Cost to fully develop technology if not already mature (£M)	0	4	0.16	0.00	0.25	50.92	0	55.33	
Technology Predictability: Operational	Potential cost to project as a result of risk (£M)	0	6.27	3.47	0.00	0	219.99	0	229.73	
	Potential delay to project as a result of risk (yr)	0	1.13	0.38	0.00	0	2.50	0	4.00	
Stability of Employment	Rapid Staffing Changes (jobs)	282.00	8.55	509	18.3	3	233.20	195.50	1249.55	1249.55
Burden on Future Generations	Decades until material no longer requires active management	2.5	0.75	0	10	0	10	10	33.25	33.25

Calculation Sheet Output for Option 9: Interim storage and repository

		PROCESS OPERATION							
ASSESSMENT CRITERION	**Data (Units)**	**In-reactor Storage**	**Retrieval**	**Interim Storage (2)**	**Grouting**	**Transport**	**Intermediate Storage**	**Overall Total**	**Grand Total**
Public Safety: Routine Radioactive Discharges	H-3 (man Sv)	4.73E-06	2.83E-04	1.53E-06	1.53E-11	1.41E-12	3.47E-07	2.89E-04	1.17E-01
	C-14 (man Sv)	7.51E-04	1.12E-01	2.98E-03	1.78E-06	6.00E-10	3.24E-04	1.16E-01	
	Co-60 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Environmental Safety: Routine Radioactive Discharges	H-3	1.55E+01	2.21E+00	1.25E+00	9.01E-11	1.21E-03	7.20E-04	1.89E+01	1.63E+02
	C-14	6.14E+01	2.20E+01	6.09E+01	2.63E-07	1.28E-02	1.17E-02	1.44E+02	
	Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Environment and Public Safety: Resource Usage	Energy (GJ)	45000	20383	330251	471110	106	1651255839	1652122689	1652122689
Public Safety: Non Radioactive Discharges	Dilution required (m3)	0	0	0	0	0	0	0	0
Environment and Public Safety: Local Intrusion	Noise (decibel.years)	0	0	0	280	648.4	0	928	1856.76471
	Land (hectares.years)	1625	487.5	6500	0	0	600000	608613	1217225
	Transport (truck journeys)	0	0	3360	2963	814	16800000	16807137	33614273.7
Environment and Public Safety: Hazard Potential (RHP)	H-3	1.70E+01	1.52E-02	2.87E+05	0.00E+00	0.00E+00	3.62E+00	2.87E+05	2.23E+06
	C-14	3.77E+01	1.15E-01	1.35E+06	0.00E+00	0.00E+00	1.24E+04	1.36E+06	
	Co-60	9.35E+02	1.62E+00	5.62E+05	0.00E+00	0.00E+00	1.35E+01	5.63E+05	
	Cl-36	4.90E-01	1.22E-03	1.80E+04	0.00E+00	0.00E+00	5.81E+03	2.39E+04	
Worker Safety: Radiological Safety	mSv (total)	17.1	12.83	6.84	8.55	4.20	171000	171049.51	171049.51
Worker Safety: Conventional Safety	Injuries	0.65	0.49	0.19	2.65	0.35	4840	4844.33	4844.33
Security Misappropriation	H-3	2.41E-02	5.20E-01	6.93E+00	0.00E+00	1.04E+01	2.27E+03	2.28E+03	3.94E+04
	C-14	7.50E-02	2.52E+00	3.36E+01	0.00E+00	5.02E+01	1.67E+04	1.68E+04	
	Co-60	2.42E+00	7.99E+00	1.07E+02	0.00E+00	1.59E+02	1.98E+04	2.01E+04	
	Cl-36	9.55E-04	3.28E-02	4.37E-01	0.00E+00	6.55E-01	2.18E+02	2.19E+02	
Economic Costs	Cost of constructing /operating /decommissioning the process (£M)	38.25	21.98	35.71	69.32	0.95	86750.00	86916.21	86916.21
Economic Benefits (Reuse & spinoff)	Value of reuse of materials and spin-off opportunities from newly developed technologies (£M)	0	0	0	0	0	0	0	
Technology Predictability: Concept	TRL of technology to be used (TRL 1 to 9)	9.00	4.00	9.00	5.00	9.00	9.00	4.00	
	Cost to fully develop technology if not already mature (£M)	0	7.073333	0.00	0.16	0.25	0	7.48	7.48
Technology Predictability: Operational	Potential cost to project as a result of risk (£M)	0	8.28	0.00	3.47	0	0	11.75	11.75
	Potential delay to project as a result of risk (yr)	0	2.25	0.00	0.38	0	0	2.63	2.63
Stability of Employment	Rapid Staffing Changes (jobs)	282.00	8.55	10.8	509	3	5.30	818.65	818.65
Burden on Future Generations	Decades until material no longer requires active management	2.5	0.75	10	0	0	50000	50013.25	50013.25

Calculation Sheet Output for Option 10: Alternative retrieval, encapsulation and intermediate storage

		PROCESS OPERATION								
ASSESSMENT CRITERION	**Data (Units)**	**In-reactor Storage**	**Heat Treatment**	**Retrieval**	**Grouting**	**Transport**	**Repository Filling**	**Repository**	**Overall Total**	**Grand Total**
Public Safety: Routine Radioactive Discharges	H-3 (man Sv)	4.73E-06	6.37E-02	1.81E-05	2.74E-09	9.14E-13	4.61E-13	0.00E+00	6.37E-02	4.27E+01
	C-14 (man Sv)	7.51E-04	4.32E+00	1.01E-02	1.64E-06	5.48E-10	1.34E-09	3.83E+01	4.26E+01	
	Co-60 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.14E-03	7.14E-03	
Environmental Safety: Routine Radioactive Discharges	H-3	1.55E+01	4.99E+02	1.42E-01	1.63E-08	7.90E-04	1.11E-06	0.00E+00	5.14E+02	2.81E+03
	C-14	6.14E+01	8.47E+02	1.99E+00	2.44E-07	1.19E-02	8.06E-05	1.37E+03	2.28E+03	
	Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E+01	1.40E+01	
Environment and Public Safety: Resource Usage	Energy (GJ)	45000	0	14907	467596	104	29055	0	556662	556662
Public Safety: Non Radioactive Discharges	Dilution required (m3)	0	22228849.6	0	0	0	0	0	22228850	22228850
Environment and Public Safety: Local Intrusion	Noise (decibel.years)	0	0	0	280	648.4	7220.3	0	8149	8148.64
	Land (hectares.years)	1625	0	487.5	0	0	3000	0	5113	5112.50
	Transport (truck journeys)	0	0	0	2944	805	2568	0	6317	6317.24
Environment and Public Safety: Hazard Potential (RHP)	H-3	1.70E+01	2.33E+00	1.22E+00	0.00E+00	0.00E+00	2.01E+00	7.26E-03	2.26E+01	1.86E+04
	C-14	3.77E+01	1.44E+01	1.30E+01	0.00E+00	0.00E+00	1.35E+02	1.11E+04	1.13E+04	
	Co-60	9.35E+02	3.17E+02	2.02E+02	0.00E+00	0.00E+00	1.63E-01	2.64E-05	1.45E+03	
	Cl-36	4.90E-01	1.52E-01	1.52E-01	0.00E+00	0.00E+00	1.96E+00	5.80E+03	5.81E+03	
Worker Safety: Radiological Safety	mSv (total)	17.1	12.83	12.83	8.55	4.15	3.16	0	58.61	58.61
Worker Safety: Conventional Safety	Injuries	0.65	1.09	0.49	2.65	0.35	9.24	1.61333333	16.08	16.08
Security Misappropriation	H-3	2.41E-02	1.04E-03	3.33E-01	0.00E+00	6.71E+00	6.07E-02	0.00E+00	7.13E+00	2.29E+02
	C-14	7.50E-02	5.04E-03	2.27E+00	0.00E+00	4.59E+01	7.27E-01	0.00E+00	4.90E+01	
	Co-60	2.42E+00	1.60E-02	7.99E+00	0.00E+00	1.61E+02	9.54E-01	0.00E+00	1.73E+02	
	Cl-36	9.55E-04	6.56E-05	3.28E-02	0.00E+00	6.62E-01	1.05E-02	0.00E+00	7.06E-01	
Economic Costs	Cost of constructing /operating /decommissioning the process (£M)	38.25	90.00	36.15	68.89	0.95	874.32	0.80	1109.36	1109.36
Economic Benefits (Reuse & spinoff)	Value of reuse of materials and spin-off opportunities from newly developed technologies (£M)	0	0	0	0	0	0	0	0	
Technology Predictability: Concept	TRL of technology to be used (TRL 1 to 9)	9.00	4.00	7.00	5.00	9.00	5.00	2.50	2.50	
	Cost to fully develop technology if not already mature (£M)	0	42.44	4	0.15	0.25	50.60	0	97.44	97.44
Technology Predictability: Operational	Potential cost to project as a result of risk (£M)	0	2.70	6.27	3.44	0	218.58	0	230.99	230.99
	Potential delay to project as a result of risk (yr)	0	0	1.13	0.38	0	2.50	0	4.23	4.23
Stability of Employment	Rapid Staffing Changes (jobs)	282.00	0.00	8.55	509	3	251.50	195.50	1249.55	1249.55
Burden on Future Generations	Decades until material no longer requires active management	2.5	0	0.75	0	0	10	10	23.25	23.25

Calculation Sheet Output for Option 11: In situ treatment and near-surface repository

		PROCESS OPERATION								
ASSESSMENT CRITERION	**Data (Units)**	**In-reactor Storage**	**Retrieval**	**Heat Treatment**	**Grouting**	**Transport**	**Repository Filling**	**Repository**	**Overall Total**	**Grand Total**
Public Safety: Routine Radioactive Discharges	H-3 (man Sv)	4.73E-06	6.37E-05	5.28E-07	2.57E-09	8.57E-13	4.98E-13	0.00E+00	6.90E-05	4.55E+01
	C-14 (man Sv)	7.51E-04	8.65E-03	2.25E-04	1.64E-06	5.47E-10	1.34E-09	4.55E+01	4.55E+01	
	Co-60 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.14E-03	7.14E-03	
Environmental Safety: Routine Radioactive Discharges	H-3	1.55E+01	4.99E-01	4.14E-03	1.53E-08	7.41E-04	1.19E-06	0.00E+00	1.60E+01	1.62E+03
	C-14	6.14E+01	1.69E+00	4.40E-02	2.44E-07	1.18E-02	8.04E-05	1.52E+03	1.58E+03	
	Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.91E+01	1.91E+01	
Environment and Public Safety: Resource Usage	Energy (GJ)	45000	14907	5184	467596	104	270549	0	803340	803340
Public Safety: Non Radioactive Discharges	Dilution required (m3)	0	0	0	0	0	0	0	0	0
Environment and Public Safety: Local Intrusion	Noise (decibel.years)	0	0	0	280	648.4	7220.3	0	8149	8149
	Land (hectares.years)	1625	487.5	0	0	0	3000	0	5113	5113
	Transport (truck journeys)	0	0	0	2944	805	2568	0	6317	6317
Environment and Public Safety: Hazard Potential (RHP)	H-3	1.70E+01	1.90E+00	2.10E+00	0.00E+00	0.00E+00	2.16E+00	7.83E-03	2.32E+01	1.85E+04
	C-14	3.77E+01	1.44E+01	1.33E+01	0.00E+00	0.00E+00	1.35E+02	1.11E+04	1.13E+04	
	Co-60	9.35E+02	2.02E+02	3.17E+02	0.00E+00	0.00E+00	1.63E-01	2.64E-05	1.45E+03	
	Cl-36	4.90E-01	1.52E-01	1.37E-01	0.00E+00	0.00E+00	1.96E+00	5.80E+03	5.81E+03	
Worker Safety: Radiological Safety	mSv (total)	17.1	12.83	17.10	8.55	4.15	3.16	0	62.89	62.89
Worker Safety: Conventional Safety	Injuries	0.65	0.49	1.45	2.65	0.35	9.24	1.61333333	16.44	16.44
Security Misappropriation	H-3	2.41E-02	5.20E-01	1.04E+00	0.00E+00	6.29E+00	6.55E-02	0.00E+00	7.94E+00	2.51E+02
	C-14	7.50E-02	2.52E+00	5.04E+00	0.00E+00	4.58E+01	7.25E-01	0.00E+00	5.41E+01	
	Co-60	2.42E+00	7.99E+00	1.60E+01	0.00E+00	1.61E+02	9.54E-01	0.00E+00	1.88E+02	
	Cl-36	9.55E-04	3.28E-02	6.56E-02	0.00E+00	6.62E-01	1.05E-02	0.00E+00	7.72E-01	
Economic Costs	Cost of constructing /operating /decommissioning the process (£M)	38.25	36.15	48.23	68.89	0.95	874.32	0.80	1067.59	1067.59
Economic Benefits (Reuse & spinoff)	Value of reuse of materials and spin-off opportunities from newly developed technologies (£M)	0	0	0	0	0	0	0	0	
Technology Predictability: Concept	TRL of technology to be used (TRL 1 to 9)	9.00	7.00	4.00	5.00	9.00	5.00	2.50	2.50	
	Cost to fully develop technology if not already mature (£M)	0	4	42.44	0.15	0.25	50.60	0	97.44	97
Technology Predictability: Operational	Potential cost to project as a result of risk (£M)	0	6.55	1.45	3.44	0	218.58	0	230.02	230
	Potential delay to project as a result of risk (yr)	0	1.50	0.23	0.38	0	2.50	0	4.60	5
Stability of Employment	Rapid Staffing Changes (jobs)	282.00	8.55	19	509	3	266.50	195.50	1283.55	1283.55
Burden on Future Generations	Decades until material no longer requires active management	2.5	0.75	0	0	0	10	10	23.25	23.25

Calculation Sheet Output for Option 12: Ex situ treatment and near surface repository

		PROCESS OPERATION											
ASSESSMENT CRITERION	**Data (Units)**	**In-reactor Storage**	**Retrieval**	**Separation**	**Size Reduction**	**Gasification**	**Grouting**	**Transport**	**Dilution**	**Repository Filling**	**Repository**	**Overall Total**	**Grand Total**
Public Safety: Routine Radioactive Discharges	H-3 (man Sv)	4.73E-06	2.83E-05	5.28E-05	5.28E-05	0.00E+00	5.28E-05	7.55E-13	1.27E+05	1.56E-08	0.00E+00	1.27E+05	1.69E+05
	C-14 (man Sv)	7.51E-04	1.12E-02	2.25E-02	2.18E-02	0.00E+00	2.25E-02	6.38E-10	4.06E+04	4.44E-08	2.99E-04	4.06E+04	
	Co-60 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.17E+03	0.00E+00	0.00E+00	1.17E+03	
	Cl-36 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.32E+02	0.00E+00	1.40E-04	4.32E+02	
Environmental Safety: Routine Radioactive Discharges	H-3	1.55E+01	2.21E-01	4.14E-01	4.14E-01	0.00E+00	4.14E-01	1.15E-02	9.72E+06	5.97E-08	0.00E+00	9.72E+06	1.07E+08
	C-14	6.14E+01	2.20E+00	4.40E+00	4.26E+00	0.00E+00	4.40E+00	2.43E-01	9.75E+07	5.33E-06	6.87E-03	9.75E+07	
	Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.19E+04	0.00E+00	0.00E+00	3.19E+04	
	Cl-36	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.88E+04	0.00E+00	1.54E+00	5.88E+04	
Environment and Public Safety: Resource Usage	Energy (GJ)	45000	17801.86	4.63E+03	6.88E+05	2.01E+05	63912	7	0	120713	0	1141207	1141207
Public Safety: Non Radioactive Discharges	Dilution required (m3)	0	0	0	0	0	0	0	477729	0	0	477729	955458
Environment and Public Safety: Local Intrusion	Noise (decibel.years)	0	0	0	0.00E+00	0	280	648.4	0.0	7220.3	0	8149	8149
	Land (hectares.years)	1625	487.5	0	0.00E+00	0	0	0.0	0.0	3000	0	5113	5113
	Transport (truck journeys)	0	0	0	1.38E+03	1382.5092	526	50.0	0.0	1566	0	4907	4907
Environment and Public Safety: Hazard Potential (RHP)	H-3	1.70E+01	2.71E-01	2.33E+00	0.00E+00	2.33E+00	0.00E+00	0.00E+00	9.87E-01	3.90E-04	3.92E-04	2.29E+01	2.32E+03
	C-14	3.77E+01	2.06E+00	1.44E+01	0.00E+00	1.09E+01	0.00E+00	0.00E+00	7.07E+00	8.81E+00	7.32E+02	8.13E+02	
	Co-60	9.35E+02	2.88E+01	3.17E+02	0.00E+00	4.52E+00	0.00E+00	0.00E+00	1.09E+00	2.78E-07	2.32E-05	1.29E+03	
	Cl-36	4.90E-01	2.17E-02	1.52E-01	0.00E+00	1.46E-01	0.00E+00	0.00E+00	9.46E-02	6.60E-02	1.96E+02	1.97E+02	
Worker Safety: Radiological Safety	mSv (total)	17.1	12.83	12.83	0.00	12.83	8.55	0.24	4.28	0.25	0	68.89	68.89
Worker Safety: Conventional Safety	Injuries	0.65	0.49	0.36	1.61	1.49	2.46	0.35	0.12	9.24	4.84	21.61	21.61
Security Misappropriation	H-3	5.28E+00	5.20E-01	5.20E-01	5.33E-01	1.07E+00	2.90E-01	5.54E-01	7.84E+00	3.67E-04	0.00E+00	1.66E+01	1.04E+03
	C-14	6.34E+00	2.52E+00	2.52E+00	2.50E+00	5.01E+00	2.80E+00	5.34E+00	5.61E+01	1.48E+00	0.00E+00	8.46E+01	
	Co-60	5.32E+02	7.99E+00	7.99E+00	1.04E+00	2.07E+00	1.30E+02	2.49E+02	8.66E+00	5.07E-05	0.00E+00	9.39E+02	
	Cl-36	8.22E-02	3.28E-02	3.28E-02	3.35E-02	6.70E-02	2.06E-02	3.93E-02	7.51E-01	1.10E-02	0.00E+00	1.07E+00	
Economic Costs	Cost of constructing /operating /decommissioning the process (£M)	38.25	33.09	0.12	29.95	75.50	14.69	0.90	1.88	156.34	0.05	350.78	350.78
Economic Benefits (Reuse & spinoff)	Value of reuse of materials and spin-off opportunities from newly developed technologies (£M)	0	0	0	0	0	0	0	0	0	0	0	
Technology Predictability: Concept	TRL of technology to be used (TRL 1 to 9)	9.00	4.00	7.00	7.00	4.00	5.00	9.00	9.00	5.00	9.00	4.00	4
	Cost to fully develop technology if not already mature (£M)	0	7.07	0.012	0.000	42.44	0.03	0.25	0	9.05	0	58.85	59
Technology Predictability: Operational	Potential cost to project as a result of risk (£M)	0	11.61	0.01	4.49	2.27	0.73	0	0.005	39.09	0	58.21	58
	Potential delay to project as a result of risk (yr)	0	2.25	0.75	1.13	0.23	0.38	0	0.0125	2.50	0	7.24	7
Stability of Employment	Rapid Staffing Changes (jobs)	282.00	8.55	0	233.295511	247.545511	509	3	7.125	268.38	195.50	1754.39	1754.39
Burden on Future Generations	Decades until material no longer requires active management	2.5	0.75	0	0	0	0	0	0	10	10	23.25	23.25

Calculation Sheet Output for Option 13: Gasification and isotopic dilution with conventional fossil fuel CO_2

		PROCESS OPERATION													
ASSESSMENT CRITERION	**Data (Units)**	**In-reactor Storage**	**Retrieval**	**Separation**	**Gasification**	**Liquefaction**	**Transport**	**Grouting**	**Transport (2)**	**Vaporisation & Dilution**	**Sequestration**	**Repository Filling**	**Repository**	**Overall Total**	**Grand Total**
Public Safety: Routine Radioactive Discharges	H-3 (man Sv)	4.73E-06	2.83E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.52E-11	0.00E+00	0.00E+00	5.19E-07	0.00E+00	3.35E-05	2.31E-02
	C-14 (man Sv)	7.51E-04	1.12E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.31E-10	7.18E-03	1.37E-03	3.00E-08	3.07E-05	2.06E-02	
	Co-60 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	2.47E-03	
Environmental Safety: Routine Radioactive Discharges	H-3	1.55E+01	2.21E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.83E-01	0.00E+00	0.00E+00	1.99E-06	0.00E+00	1.61E+01	1.13E+02
	C-14	6.14E+01	2.20E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.64E-01	5.88E+00	3.29E-05	3.60E-06	3.66E-03	6.97E+01	
	Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.71E+01	2.71E+01	
Environment and Public Safety: Resource Usage	Energy (GJ)	45000	2.04E+04	1.71E+05	2.01E+05	6.57E+03	67	63912	7	2442	5288	120713	0	636526	636526
Public Safety: Non Radioactive Discharges	Dilution required (m3)	0	0	0	0	0	0	0	0	165856014	0	0	0	165856014	331712028
Environment and Public Safety: Local Intrusion	Noise (decibel.years)	0	0	0	0	0	648.4	280	648.4	0.0	0.0	7220.3	0	8797	8797
	Land (hectares.years)	1625	487.5	0	0	0	0	0	0.0	33.0	0.0	3000	0	5146	5146
	Transport (truck journeys)	0	0	1382.5092	1382.5092	0	462	526	50.0	0.0	0.0	1566	0	5369	5369
Environment and Public Safety: Hazard Potential (RHP)	H-3	1.70E+01	2.71E-01	2.33E+00	2.33E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-02	1.31E-02	2.20E+01	7.29E+05
	C-14	3.77E+01	2.06E+00	1.44E+01	1.09E+01	1.08E+01	0.00E+00	0.00E+00	0.00E+00	7.21E+00	7.21E+05	5.95E+00	4.95E+02	7.22E+05	
	Co-60	9.35E+02	2.88E+01	3.17E+02	4.52E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.17E-07	2.64E-05	1.28E+03	
	Cl-36	4.90E-01	2.17E-02	1.52E-01	1.46E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.96E+00	5.80E+03	5.81E+03	
Worker Safety: Radiological Safety	mSv (total)	17.1	12.83	12.83	12.83	12.83	5.18	8.55	0.24	8.55	0.00	0.25	0	91.17	91.17
Worker Safety: Conventional Safety	Injuries	0.65	0.49	1.49	1.49	0.36	0.35	2.46	0.35	0.24	0.24	9.24	4.84	22.20	22.20
Security Misappropriation	H-3	2.41E-02	5.20E-01	5.20E-01	1.07E+00	0.00E+00	0.00E+00	0.00E+00	4.12E+03	0.00E+00	0.00E+00	6.59E-04	0.00E+00	4.13E+03	7.06E+03
	C-14	7.50E-02	2.52E+00	2.52E+00	5.01E+00	5.11E+00	3.91E+01	0.00E+00	1.62E+00	2.60E+00	0.00E+00	5.37E-02	0.00E+00	5.86E+01	
	Co-60	2.42E+00	7.99E+00	7.99E+00	2.07E+00	0.00E+00	0.00E+00	0.00E+00	2.84E+03	0.00E+00	0.00E+00	3.11E-06	0.00E+00	2.86E+03	
	Cl-36	9.55E-04	3.28E-02	3.28E-02	6.70E-02	0.00E+00	0.00E+00	0.00E+00	1.17E+01	0.00E+00	0.00E+00	1.76E-02	0.00E+00	1.18E+01	
Economic Costs	Cost of constructing /operating /decommissioning the process (£M)	38.25	27.52	33.18	75.50	8.40	0.93	14.79	0.90	3.93	0.57	156.34	0.05	360.37	360.37
Economic Benefits (Reuse & spinoff)	Value of reuse of materials and spin-off opportunities from newly developed technologies (£M)	0	0	0	0	0	0	0	0	0	0	0	0	0	
Technology Predictability: Concept	TRL of technology to be used (TRL 1 to 9)	9.00	4.00	7.00	4.00	8.00	9.00	5.00	9.00	9.00	4.00	5.00	2.50	2.50	68.81
	Cost to fully develop technology if not already mature (£M)	0	7.07	3.318	42.44	6.40	0.25	0.03	0.25	0	0	9.05	0	68.81	
Technology Predictability: Operational	Potential cost to project as a result of risk (£M)	0	9.94	3.32	2.27	0.25	0	0.74	0	0.020	0	39.09	0	55.62	55.62
	Potential delay to project as a result of risk (yr)	0	2.25	0.75	0.23	0.23	0	0.38	0	0.025	0	2.50	0	6.35	6.35
Stability of Employment	Rapid Staffing Changes (jobs)	282.00	8.55	233.295511	247.545511	0	3	509	3	14.25	12.75	265.00	195.50	1773.89	1773.89
Burden on Future Generations	Decades until material no longer requires active management	2.5	0.75	0	0	0	0	0	0	0	0	10	10	23.25	23.25

Calculation Sheet Output for Option 14: Gasification and isotopic dilution with conventional fossil fuel CO_2 as a result of sequestration

ASSESSMENT CRITERION	Data (Units)	PROCESS OPERATION											Grand Total
		In-reactor Storage	Retrieval	Separation	Gasification	Grouting	Transport	Dilution	Disperse to Sea	Repository Filling	Repository	Overall Total	
Public Safety: Routine Radioactive Discharges	H-3 (man Sv)	4.73E-06	2.83E-05	5.28E-05	0.00E+00	5.28E-05	7.55E-13	0.00E+00	1.20E-04	1.56E-08	0.00E+00	2.58E-04	3.61E+01
	C-14 (man Sv)	7.51E-04	1.12E-02	2.25E-02	0.00E+00	2.25E-02	6.38E-10	0.00E+00	3.61E+01	4.44E-08	3.07E-05	3.61E+01	
	Co-60 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-04	1.40E-04	
Environmental Safety: Routine Radioactive Discharges	H-3	1.55E+01	2.21E-01	4.14E-01	0.00E+00	4.14E-01	1.15E-02	0.00E+00	0.00E+00	5.97E-08	0.00E+00	1.65E+01	9.07E+01
	C-14	6.14E+01	2.20E+00	4.40E+00	0.00E+00	4.40E+00	2.43E-01	0.00E+00	0.00E+00	5.33E-06	3.67E-03	7.27E+01	
	Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.54E+00	1.54E+00	
Environment and Public Safety: Resource Usage	Energy (GJ)	45000	2.04E+04	1.71E+05	2.01E+05	63912	7	4481	69	120713	0	626707	626707
Public Safety: Non Radioactive Discharges	Dilution required (m3)	0	0	0	0	0	0	0	0	0	0	0	0
Environment and Public Safety: Local Intrusion	Noise (decibel.years)	0	0	0	0	280	648.4	0.0	0.0	7220.3	0	8149	8149
	Land (hectares.years)	1625	487.5	0	0	0	0.0	247.5	0.0	3000	0	5360	5360
	Transport (truck journeys)	0	0	1382.5092	1382.5092	526	50.0	0.0	0.0	1566	0	4907	4907
Environment and Public Safety: Hazard Potential (RHP)	H-3	1.70E+01	1.90E+00	2.33E+00	2.33E+00	0.00E+00	0.00E+00	1.48E+00	9.71E-01	3.90E-04	3.92E-04	2.60E+01	2.52E+03
	C-14	3.77E+01	1.44E+01	1.44E+01	1.09E+01	0.00E+00	0.00E+00	1.06E+01	1.06E+01	8.81E+00	7.32E+02	8.40E+02	
	Co-60	9.35E+02	2.02E+02	3.17E+02	4.52E+00	0.00E+00	0.00E+00	1.64E+00	6.10E-01	2.78E-07	2.32E-05	1.46E+03	
	Cl-36	4.90E-01	1.52E-01	1.52E-01	1.46E-01	0.00E+00	0.00E+00	1.42E-01	1.42E-01	6.60E-02	1.96E+02	1.97E+02	
Worker Safety: Radiological Safety	mSv (total)	17.1	12.83	12.83	12.83	8.55	0.24	6.41	6.41	0.25	0	77.44	77.44
Worker Safety: Conventional Safety	Injuries	0.65	0.49	1.49	1.49	2.46	0.35	0.18	0.18	9.24	1.61333333	18.14	18.14
Security Misappropriation	H-3	2.41E-02	5.20E-01	5.20E-01	1.07E+00	0.00E+00	5.54E+00	1.18E+01	1.18E+01	1.98E-05	0.00E+00	3.12E+01	2.80E+03
	C-14	7.50E-02	2.52E+00	2.52E+00	5.01E+00	0.00E+00	5.34E+01	8.41E+01	8.41E+01	7.95E-02	0.00E+00	2.32E+02	2.32E+02
	Co-60	2.42E+00	7.99E+00	7.99E+00	2.07E+00	0.00E+00	2.49E+03	1.30E+01	1.30E+01	2.73E-06	0.00E+00	2.54E+03	2.54E+03
	Cl-36	9.55E-04	3.28E-02	3.28E-02	6.70E-02	0.00E+00	3.93E-01	1.13E+00	1.13E+00	5.92E-04	0.00E+00	2.78E+00	2.78E+00
Economic Costs	Cost of constructing /operating /decommissioning the process (£M)	38.25	27.52	33.18	75.50	14.65	0.90	3.08	9.49	156.34	0.05	358.96	358.96
Economic Benefits (Reuse & spinoff)	Value of reuse of materials and spin-off opportunities from newly developed technologies (£M)	0	0	0	0	0	0	0	0	0	0	0	
Technology Predictability: Concept	TRL of technology to be used (TRL 1 to 9)	9.00	4.00	7.00	4.00	5.00	9.00	9.00	9.00	5.00	2.50	2.50	
	Cost to fully develop technology if not already mature (£M)	0	7.07	3.318	42.44	0.03	0.25	0	0	9.05	0	62.15	6.22E+01
Technology Predictability: Operational	Potential cost to project as a result of risk (£M)	0	9.94	3.32	2.27	0.73	0	0.008	0.024	39.09	0	55.38	5.54E+01
	Potential delay to project as a result of risk (yr)	0	2.25	0.75	0.23	0.38	0	0.01875	0.01875	2.50	0	6.14	6.14E+00
Stability of Employment	Rapid Staffing Changes (jobs)	282.00	8.55	233.295511	247.545511	509	3	7.125	0	268.38	195.50	1754.39	1754.39
Burden on Future Generations	Decades until material no longer requires active management	2.5	0.75	0	0	0	0	0	0	10	10	23.25	23.25

Calculation Sheet Output for Option 15: Gasification and isotopic dilution by dispersal as CO_3 in the sea

ASSESSMENT CRITERION	Data (Units)	PROCESS OPERATION												
		In-reactor Storage	Retrieval	Separation	Heat Treatment	Tritium Capture	Isotope Separation	Reused C14	Grouting	Transport	Repository Filling	Repository	Overall Total	Grand Total
Public Safety: Routine Radioactive Discharges	H-3 (man Sv)	4.73E-06	2.83E-05	5.28E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.26E-09	1.42E-12	8.30E-13	0.00E+00	3.83E-05	9.30E-02
	C-14 (man Sv)	7.51E-04	1.12E-02	2.25E-03	0.00E+00	0.00E+00	7.62E-02	1.96E-06	1.65E-06	5.51E-10	1.36E-09	3.07E-05	9.05E-02	
	Co-60 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	2.47E-03	
Environmental Safety: Routine Radioactive Discharges	H-3	1.55E+01	2.21E-01	4.14E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.52E-08	1.22E-03	1.99E-06	0.00E+00	1.57E+01	8.46E+01
	C-14	6.14E+01	2.20E+00	4.40E-01	0.00E+00	0.00E+00	1.13E-02	2.90E-07	2.45E-07	1.18E-02	8.14E-05	9.50E-04	6.41E+01	
	Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.83E+00	4.83E+00	
Environment and Public Safety: Resource Usage	Energy (GJ)	45000	20383	171448	172001	86544	4034	93	469354	105	677248	0	1646210	1646210
Public Safety: Non Radioactive Discharges	Dilution required (m3)	0	0	0	0	0	0	0	0	0	0	0	0	0
Environment and Public Safety: Local Intrusion	Noise (decibel.years)	0	0	0	0	0	0	0.0	280	648.4	7220.3	0	8149	
	Land (hectares.years)	1625	487.5	0	0	0	0	0	0	0	3000	0	5113	
	Transport (truck journeys)	0	0	1382.5092	1382.5092	0	0	0	2953	809	6448	0	12976	
Environment and Public Safety: Hazard Potential (RHP)	H-3	1.70E+01	1.53E-02	2.33E+00	1.23E+01	4.93E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.61E+00	1.31E-02	4.02E+01	1.87E+04
	C-14	3.77E+01	1.16E-01	1.44E+01	9.95E+01	9.95E+00	9.95E+00	9.95E+00	0.00E+00	0.00E+00	1.36E+02	1.12E+04	1.15E+04	
	Co-60	9.35E+02	1.63E+00	3.17E+02	4.02E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.63E-01	2.64E-05	1.29E+03	
	Cl-36	4.90E-01	1.23E-03	1.52E-01	1.22E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.96E+00	5.80E+03	5.81E+03	
Worker Safety: Radiological Safety	mSv (total)	17.1	12.83	12.83	12.83	12.83	12.83	12.83	8.55	4.17	3.17	0	109.95	109.95
Worker Safety: Conventional Safety	Injuries	0.65	0.49	1.49	1.49	0.36	0.36	0.36	2.65	0.35	9.24	1.61333333	19.05	19.05
Security Misappropriation	H-3	2.41E-02	5.20E-01	5.20E-01	1.00E+00	8.02E-01	0.00E+00	0.00E+00	0.00E+00	1.04E+01	1.09E-01	0.00E+00	1.34E+01	2.77E+02
	C-14	7.50E-02	2.52E+00	2.52E+00	8.08E+00	1.62E+00	1.62E+00	1.66E+01	0.00E+00	4.61E+01	7.35E-01	0.00E+00	7.99E+01	
	Co-60	2.42E+00	7.99E+00	7.99E+00	3.27E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E+02	9.53E-01	0.00E+00	1.83E+02	
	Cl-36	9.55E-04	3.28E-02	3.28E-02	9.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.58E-01	1.05E-02	0.00E+00	8.34E-01	
Economic Costs	Cost of constructing /operating /decommissioning the process (£M)	38.25	21.98	33.18	63.83	15.32	96.32	5.63	69.11	0.95	877.15	0.80	1222.51	1222.51
Economic Benefits (Reuse & spinoff)	Value of reuse of materials and spin-off opportunities from newly developed technologies (£M)	0	0	0	0	0	0	0	0	0	0	0	0	
Technology Predictability: Concept	TRL of technology to be used (TRL 1 to 9)	9.00	4.00	7.00	4.00	3.50	4.00	0.00	5.00	9.00	5.00	2.50	0.00	
	Cost to fully develop technology if not already mature (£M)	0	7.073333	3.32	42.44	1.53	19.26	0	0.15	0.25	50.76	0	124.79	124.79
Technology Predictability: Operational	Potential cost to project as a result of risk (£M)	0	8.28	3.32	1.92	0.92	5.78	0	3.46	0	219.29	0	242.96	242.96
	Potential delay to project as a result of risk (yr)	0	2.25	0.75	0.23	0.45	0.45	0	0.38	0	2.50	0	7.00	7.00
Stability of Employment	Rapid Staffing Changes (jobs)	282.00	8.55	233.295511	247.545511	0	0	0	509	3	262.75	195.50	1741.64	1741.64
Burden on Future Generations	Decades until material no longer requires active management	2.5	0.75	0	0	0	0	0	0	0	10	10	23.25	23.25

Calculation Sheet Output for Option 16: ^{14}C re-use

		PROCESS OPERATION											
ASSESSMENT CRITERION	**Data (Units)**	**In-reactor Storage**	**Retrieval**	**Separation**	**Heat Treatment**	**Tritium Capture**	**Grouting**	**Transport**	**Reused C14**	**Repository Filling**	**Repository**	**Overall Total**	**Grand Total**
Public Safety: Routine Radioactive Discharges	H-3 (man Sv)	4.73E-06	2.83E-05	5.28E-06	0.00E+00	0.00E+00	4.26E-09	1.42E-12	0.00E+00	8.30E-13	0.00E+00	3.83E-05	1.67E-02
	C-14 (man Sv)	7.51E-04	1.12E-02	2.25E-03	0.00E+00	0.00E+00	1.65E-06	5.51E-10	1.98E-06	1.36E-09	9.56E-07	1.42E-02	
	Co-60 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	2.47E-03	
Environmental Safety: Routine Radioactive Discharges	H-3	1.55E+01	2.21E-01	4.14E-02	0.00E+00	0.00E+00	2.52E-08	1.22E-03	0.00E+00	1.99E-06	0.00E+00	1.57E+01	8.46E+01
	C-14	6.14E+01	2.20E+00	4.40E-01	0.00E+00	0.00E+00	2.45E-07	1.18E-02	2.93E-07	8.14E-05	5.93E-04	6.41E+01	
	Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.83E+00	4.83E+00	
Environment and Public Safety: Resource Usage	Energy (GJ)	45000	17802	171448	172001	86544	469354	105	93	677248	0	1639594	1639594
Public Safety: Non Radioactive Discharges	Dilution required (m3)	0	0	0	0	0	0	0	0	0	0	0	0
Environment and Public Safety: Local Intrusion	Noise (decibel.years)	0	0	0	0	0	280	648.4	0.0	7220.3	0	8149	
	Land (hectares.years)	1625	487.5	0	0	0	0	0	0	3000	0	5113	
	Transport (truck journeys)	0	0	1382.5092	1382.5092	0	2953	809	0	6448	0	12976	
Environment and Public Safety: Hazard Potential (RHP)	H-3	1.70E+01	1.90E+00	2.33E+00	1.23E+01	4.93E+00	0.00E+00	0.00E+00	0.00E+00	3.61E+00	1.31E-02	4.21E+01	1.89E+04
	C-14	3.77E+01	1.44E+01	1.44E+01	9.95E+01	9.95E+00	0.00E+00	0.00E+00	9.95E+00	1.36E+02	1.12E+04	1.15E+04	
	Co-60	9.35E+02	2.02E+02	3.17E+02	4.02E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.63E-01	2.64E-05	1.49E+03	
	Cl-36	4.90E-01	1.52E-01	1.52E-01	1.22E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.96E+00	5.80E+03	5.81E+03	
Worker Safety: Radiological Safety	mSv (total)	17.1	12.83	12.83	12.83	12.83	8.55	4.17	12.83	3.17	0	97.12	97.12
Worker Safety: Conventional Safety	Injuries	0.65	0.49	1.49	1.49	0.36	2.65	0.35	0.36	9.24	1.61333333	18.69	18.69
Security Misappropriation	H-3	5.28E+00	5.20E-01	5.20E-01	1.00E+00	8.02E-01	5.23E-01	1.04E+00	0.00E+00	3.39E+00	0.00E+00	1.31E+01	6.86E+02
	C-14	6.34E+00	2.52E+00	2.52E+00	8.08E+00	1.62E+00	2.31E+00	4.61E+00	1.66E+01	2.28E+01	0.00E+00	6.74E+01	
	Co-60	5.32E+02	7.99E+00	7.99E+00	3.27E+00	0.00E+00	8.03E+00	1.60E+01	0.00E+00	2.97E+01	0.00E+00	6.05E+02	
	Cl-36	8.22E-02	3.28E-02	3.28E-02	9.91E-02	0.00E+00	3.30E-02	6.58E-02	0.00E+00	3.26E-01	0.00E+00	6.72E-01	
Economic Costs	Cost of constructing /operating /decommissioning the process (£M)	38.25	27.55	33.18	63.83	15.32	69.11	0.95	5.63	877.15	0.80	1131.77	1131.77
Economic Benefits (Reuse & spinoff)	Value of reuse of materials and spin-off opportunities from newly developed technologies (£M)	0	0	0	0	0	0	0	0	0	0	0	
Technology Predictability: Concept	TRL of technology to be used (TRL 1 to 9)	9.00	4.00	7.00	4.00	3.50	5.00	9.00	6.00	5.00	9.00	3.50	
	Cost to fully develop technology if not already mature (£M)	0	7.073333	3.31826455	42.4373333	1.53172018	0.15	0.25	0	50.76	0	105.53	105.53
Technology Predictability: Operational	Potential cost to project as a result of risk (£M)	0	9.95	3.32	1.92	0.92	3.46	0	0	219.29	0	238.85	238.85
	Potential delay to project as a result of risk (yr)	0	2.25	0.75	0.23	0.45	0.38	0	0	2.50	0	6.55	6.55
Stability of Employment	Rapid Staffing Changes (jobs)	282.00	8.55	233.295511	247.545511	0	509	3	0	262.75	195.50	1741.64	1741.64
Burden on Future Generations	Decades until material no longer requires active management	2.5	0.75	0	0	0	0	0	0	10	10	23.25	23.25

Calculation Sheet Output for Option 17: ^{14}C re-use with no isotope separation

ASSESSMENT CRITERION	Data (Units)	PROCESS OPERATION											
		In-reactor Storage	Retrieval	Segregation	Decontamination	Size Reduction	Transport (Re-use)	Grouting	Transport	Repository Filling	Repository	Overall Total	Grand Total
Public Safety: Routine Radioactive Discharges	H-3 (man Sv)	4.73E-06	6.37E-05	5.28E-06	5.28E-05	5.18E-05	1.45E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.78E-04	5.11E-02
	C-14 (man Sv)	7.51E-04	8.65E-03	2.25E-03	2.18E-02	1.74E-02	4.88E-10	1.21E-06	4.04E-10	4.55E-11	9.47E-07	5.09E-02	
	Co-60 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.62E-05	1.62E-05	
Environmental Safety: Routine Radioactive Discharges	H-3	1.55E+01	4.99E-01	4.14E-02	1.99E-03	4.05E-01	2.73E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.65E+01	8.40E+01
	C-14	6.14E+01	1.69E+00	4.40E-01	2.05E-02	3.41E+00	2.30E-01	1.14E-06	1.90E-01	2.73E-06	3.74E-03	6.74E+01	
	Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.02E-01	2.02E-01	
Environment and Public Safety: Resource Usage	Energy (GJ)	45000	14907	171448	682163	515346	31	60948	5	106339	0	1596187	1596187
Public Safety: Non Radioactive Discharges	Dilution required (m3)	0	0	0	0	0	0	0	0	0	0	0	0
Environment and Public Safety: Local Intrusion	Noise (decibel.years)	0	0	0	0	0	648.4	280	648.4	7220.3	0	8797	8797
	Land (hectares.years)	1625	487.5	0	0	0	0	0	0	3000	0	5113	5113
	Transport (truck journeys)	0	0	1382.5092	1382.5092	0	210	464	36	682	0	4157	4157
Environment and Public Safety: Hazard Potential (RHP)	H-3	1.70E+01	3.35E-01	2.33E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.97E+01	1.76E+03
	C-14	3.77E+01	2.54E+00	1.44E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.57E+00	3.76E+02	4.35E+02	
	Co-60	9.35E+02	3.56E+01	3.17E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.42E-01	2.31E-05	1.29E+03	
	Cl-36	4.90E-01	2.68E-02	1.52E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.53E-03	2.23E+01	2.30E+01	
Worker Safety: Radiological Safety	mSv (total)	17.1	12.83	12.83	12.83	0.00	2.36E+00	8.55	0.19	0.10	0	66.77	66.77
Worker Safety: Conventional Safety	Injuries	0.65	0.49	1.49	1.49	0.00	0.35	2.45	0.35	9.24	1.61333333	18.12	18.12
Security Misappropriation	H-3	2.41E-02	5.20E-01	5.20E-01	0.00E+00	0.00E+00	2.24E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.25E+02	4.65E+03
	C-14	7.50E-02	2.52E+00	2.52E+00	0.00E+00	0.00E+00	8.58E+02	0.00E+00	3.38E+01	1.28E-02	0.00E+00	8.97E+02	
	Co-60	2.42E+00	7.99E+00	7.99E+00	0.00E+00	0.00E+00	4.35E+02	0.00E+00	3.06E+03	4.31E-01	0.00E+00	3.52E+03	
	Cl-36	9.55E-04	3.28E-02	3.28E-02	0.00E+00	0.00E+00	1.41E+01	0.00E+00	5.54E-02	2.09E-05	0.00E+00	1.42E+01	
Economic Costs	Cost of constructing /operating /decommissioning the process (£M)	38.25	36.15	33.18	29.93	0.11	0.91	13.30	0.90	137.73	0.04	290.50	290.50
Economic Benefits (Reuse & spinoff)	Value of reuse of materials and spin-off opportunities from newly developed technologies (£M)	0	0	0	0	0	0	0	0	0	0	0	
Technology Predictability: Concept	TRL of technology to be used (TRL 1 to 9)	9.00	7.00	7.00	7.00	7.00	9.00	5.00	9.00	5.00	2.50	2.50	
	Cost to fully develop technology if not already mature (£M)	0	4	3.32	0.00	0	0.25	0.02	0.25	7.97	0	15.81	16
Technology Predictability: Operational	Potential cost to project as a result of risk (£M)	0	6.27	3.32	0.90	0.00	0.00	0.66	0	34.43	0	45.58	46
	Potential delay to project as a result of risk (yr)	0	1.13	0.75	0.23	0.23	0.00	0.38	0	2.50	0	5.20	5
Stability of Employment	Rapid Staffing Changes (jobs)	282.00	8.55	233.30	233.30	0	3	518	3	253.75	195.50	1730.39	1730.39
Burden on Future Generations	Decades until material no longer requires active management	2.5	0.75	0	0	0	0	0	0	10	10	23.25	23.25

Calculation Sheet Output for Option 18: Graphite re-use for nuclear application only

ASSESSMENT CRITERION	Data (Units)	PROCESS OPERATION: In-reactor Storage	PROCESS OPERATION: Entombment	PROCESS OPERATION: Overall Total	Grand Total
Public Safety: Routine Radioactive Discharges	H-3 (man Sv)	4.73E-06	0.00E+00	4.73E-06	7.98E+00
	C-14 (man Sv)	7.51E-04	7.97E+00	7.97E+00	
	Co-60 (man Sv)	0.00E+00	0.00E+00	0.00E+00	
	Cl-36 (man Sv)	0.00E+00	7.14E-03	7.14E-03	
Environmental Safety: Routine Radioactive Discharges	H-3	1.55E+01	0.00E+00	1.55E+01	7.95E+02
	C-14	6.14E+01	7.16E+02	7.78E+02	
	Co-60	0.00E+00	0.00E+00	0.00E+00	
	Cl-36	0.00E+00	2.02E+00	2.02E+00	
Environment and Public Safety: Resource Usage	Energy (GJ)	45000	92137	137137	137137
Public Safety: Non Radioactive Discharges	Dilution required (m3)	0	0	0	0
Environment and Public Safety: Local Intrusion	Noise (decibel.years)	0	0	0	0.00
	Land (hectares.years)	1625	13000	14625	14625.00
	Transport (truck journeys)	0	1719	1719	1719.00
Environment and Public Safety: Hazard Potential (RHP)	H-3	1.70E+01	5.52E+00	2.25E+01	1.93E+04
	C-14	3.77E+01	1.24E+04	1.25E+04	
	Co-60	9.35E+02	3.63E+01	9.71E+02	
	Cl-36	4.90E-01	5.81E+03	5.81E+03	
Worker Safety: Radiological Safety	mSv (total)	17.1	19.95	37.05	37.05
Worker Safety: Conventional Safety	Injuries	0.65	0.564666667	1.22	1.22
Security Misappropriation	H-3	2.41E-02	1.21E+03	1.21E+03	2.57E+04
	C-14	7.50E-02	5.86E+03	5.86E+03	
	Co-60	2.42E+00	1.86E+04	1.86E+04	
	Cl-36	9.55E-04	7.63E+01	7.63E+01	
Economic Costs	Cost of constructing /operating /decommissioning the process (£M)	38.25	17.69	55.94	55.94
Economic Benefits (Reuse & spinoff)	Value of reuse of materials and spin-off opportunities from newly developed technologies (£M)	0	0	0	
Technology Predictability: Concept	TRL of technology to be used (TRL 1 to 9)	9.00	2.50	2.50	
	Cost to fully develop technology if not already mature (£M)	0	200	200.00	200.00
Technology Predictability: Operational	Potential cost to project as a result of risk (£M)	0	0.26775	0.27	0.27
	Potential delay to project as a result of risk (yr)	0	0.175	0.18	0.18
Stability of Employment	Rapid Staffing Changes (jobs)	282.00	101.00	383.00	383.00
Burden on Future Generations	Decades until material no longer requires active management	2.5	0.35	2.85	2.85

Calculation Sheet Output for Option 19: In-situ entombment

		PROCESS OPERATION										
ASSESSMENT CRITERION	**Data (Units)**	**In-reactor Storage**	**Retrieval**	**Heat Treatment**	**Gasification**	**Grouting**	**Transport**	**Dilution**	**Repository Filling**	**Repository**	**Overall Total**	**Grand Total**
Public Safety: Routine Radioactive Discharges	H-3 (man Sv)	4.73E-06	2.83E-05	0.00E+00	0.00E+00	2.38E-09	7.93E-11	0.00E+00	2.17E-07	0.00E+00	3.32E-05	6.74E-02
	C-14 (man Sv)	7.51E-04	1.12E-02	0.00E+00	0.00E+00	1.64E-06	5.47E-08	0.00E+00	9.45E-08	2.14E-06	1.20E-02	
	Co-60 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.54E-02	5.54E-02	
Environmental Safety: Routine Radioactive Discharges	H-3	1.55E+01	2.21E-01	0.00E+00	0.00E+00	1.11E-07	2.11E+00	0.00E+00	8.33E-07	0.00E+00	1.78E+01	1.18E+02
	C-14	6.14E+01	2.20E+00	0.00E+00	0.00E+00	1.91E-06	3.65E+01	0.00E+00	1.13E-05	2.57E-05	1.00E+02	
	Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.06E-02	1.06E-02	
Environment and Public Safety: Resource Usage	Energy (GJ)	450000	1.42E+05	1.72E+05	2.01E+05	45627	4	0	86284	0	1097099	1097099
Public Safety: Non Radioactive Discharges	Dilution required (m3)	0	0	0	0	0	0	146166414	0	0	146166414	292332829
Environment and Public Safety: Local Intrusion	Noise (decibel.years)	0	0	0	0	280	648.4	0.0	7220.3	0	8149	
	Land (hectares.years)	1625	487.5	0	0	0	0.0	165.0	3000	0	5278	
	Transport (truck journeys)	0	0	1382.5092	1382.5092	376	29.0	0.0	1119	0	4289	
Environment and Public Safety: Hazard Potential (RHP)	H-3	1.70E+01	4.75E-01	2.33E+00	1.40E+00	0.00E+00	0.00E+00	5.93E-01	5.44E-03	5.46E-03	2.18E+01	3.19E+03
	C-14	3.77E+01	3.60E+00	1.44E+01	1.02E+01	0.00E+00	0.00E+00	6.36E+00	1.88E+01	1.56E+03	1.65E+03	
	Co-60	9.35E+02	5.04E+01	3.17E+02	3.58E+01	0.00E+00	0.00E+00	1.09E+00	9.52E-09	7.92E-07	1.34E+03	
	Cl-36	4.90E-01	3.80E-02	1.52E-01	1.47E-01	0.00E+00	0.00E+00	9.46E-02	5.87E-02	1.74E+02	1.75E+02	
Worker Safety: Radiological Safety	mSv (total)	17.1	12.83	12.83	12.83	8.55	0.13	4.28	1.94	0	70.47	70.47
Worker Safety: Conventional Safety	Injuries	0.65	0.49	1.49	1.49	2.45	0.35	0.12	9.24	1.61333333	17.89	17.89
Security Misappropriation	H-3	2.41E-02	5.20E-01	1.04E+00	2.10E+01	0.00E+00	1.35E+02	8.23E+00	2.75E-03	0.00E+00	1.66E+02	1.35E+03
	C-14	7.50E-02	2.52E+00	5.04E+00	1.53E+02	0.00E+00	1.99E+02	8.84E+01	1.69E+00	0.00E+00	4.50E+02	
	Co-60	2.42E+00	7.99E+00	1.60E+01	5.38E+02	0.00E+00	1.49E+02	1.52E+01	9.33E-07	0.00E+00	7.28E+02	
	Cl-36	9.55E-04	3.28E-02	6.56E-02	2.21E+00	0.00E+00	6.12E-01	1.31E+00	5.27E-03	0.00E+00	4.24E+00	
Economic Costs	Cost of constructing /operating /decommissioning the process (£M)	38.25	29.88	76.18	70.31	11.35	0.90	1.88	111.75	0.03	340.51	340.51
Economic Benefits (Reuse & spinoff)	Value of reuse of materials and spin-off opportunities from newly developed technologies (£M)	0	0	0	0	0	0	0	0	0	0	
Technology Predictability: Concept	TRL of technology to be used (TRL 1 to 9)	9.00	4.00	4.00	4.00	5.00	9.00	9.00	5.00	2.50	2.50	
	Cost to fully develop technology if not already mature (£M)	0	7.07	42.437	42.44	0.02	0.25	0	6.47	0	98.68	98.68
Technology Predictability: Operational	Potential cost to project as a result of risk (£M)	0	10.65	2.29	2.11	0.57	0	0.005	27.94	0	43.56	43.56
	Potential delay to project as a result of risk (yr)	0	2.25	0.23	0.23	0.38	0	0.0125	2.50	0	5.59	5.59
Stability of Employment	Rapid Staffing Changes (jobs)	282.00	8.55	247.545511	233.295511	509	3	7.125	268.38	195.50	1754.39	1754.39
Burden on Future Generations	Decades until material no longer requires active management	2.5	0.75	0	0	0	0	0	10	10	23.25	23.25

Calculation Sheet Output for Option 20: Waste volume reduction and emission to atmosphere

		PROCESS OPERATION												
ASSESSMENT CRITERION	**Data (Units)**	**In-reactor Storage**	**Retrieval**	**Separation**	**Size Reduction**	**Heat Treatment**	**Size Reduction (2)**	**Grouting**	**Transport**	**Re-use Grout**	**Repository Filling**	**Repository**	**Overall Total**	**Grand Total**
Public Safety: Routine Radioactive Discharges	H-3 (man Sv)	4.73E-06	2.83E-05	5.28E-05	5.28E-05	0.00E+00	5.28E-05	5.28E-05	2.11E-09	1.48E-08	2.07E-07	0.00E+00	2.45E-04	1.01E-01
	C-14 (man Sv)	7.51E-04	1.12E-02	2.25E-02	2.18E-02	0.00E+00	2.18E-02	2.25E-02	2.86E-07	1.31E-05	9.49E-08	9.54E-07	1.00E-01	
	Co-60 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.62E-05	1.62E-05	
Environmental Safety: Routine Radioactive Discharges	H-3	1.55E+01	2.21E-01	4.14E-01	4.14E-01	0.00E+00	4.14E-01	4.14E-01	6.76E+01	7.10E-01	7.96E-07	0.00E+00	8.57E+01	4.12E+02
	C-14	6.14E+01	2.20E+00	4.40E+00	4.26E+00	0.00E+00	4.26E+00	4.40E+00	2.29E+02	1.57E+01	1.14E-05	5.18E-03	3.26E+02	
	Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.77E-01	2.77E-01	
Environment and Public Safety: Resource Usage	Energy (GJ)	450000	1.42E+05	4.63E+03	6.88E+05	1.72E+05	5.18E+05	40885	3	0	77343	0	2093690	2093690
Public Safety: Non Radioactive Discharges	Dilution required (m3)	0	0	0	0	0	0	0	0	0	0	0	0	0
Environment and Public Safety: Local Intrusion	Noise (decibel.years)	0	0	0	0	0	0	280	648.4	0.0	7220.3	0	8149	
	Land (hectares.years)	1625	487.5	0	0	0	0	0	0.0	0.0	3000	0	5113	
	Transport (truck journeys)	0	0	0	1382.5092	1382.5092	0	337	24.0	0.0	1003	0	4129	
Environment and Public Safety: Hazard Potential (RHP)	H-3	1.70E+01	5.70E-01	2.33E+00	0.00E+00	2.33E+00	0.00E+00	0.00E+00	0.00E+00	6.11E-01	5.20E-03	5.22E-03	2.29E+01	3.02E+03
	C-14	3.77E+01	4.32E+00	1.44E+01	0.00E+00	1.09E+01	0.00E+00	0.00E+00	0.00E+00	6.56E+00	1.88E+01	1.57E+03	1.66E+03	
	Co-60	9.35E+02	6.05E+01	3.17E+02	0.00E+00	4.52E+00	0.00E+00	0.00E+00	0.00E+00	1.12E+00	2.77E-07	2.31E-05	1.32E+03	
	Cl-36	4.90E-01	4.56E-02	1.52E-01	0.00E+00	1.46E-01	0.00E+00	0.00E+00	0.00E+00	9.75E-02	7.53E-03	2.23E+01	2.33E+01	
Worker Safety: Radiological Safety	mSv (total)	17.1	12.83	12.83	0.00	12.83	0.00	8.55	0.11	4.28	1.61	0	70.13	70.13
Worker Safety: Conventional Safety	Injuries	0.65	0.49	1.09	1.49	1.49	0.36	2.44	0.35	0.12	9.24	1.61333333	19.33	19.33
Security Misappropriation	H-3	2.41E-02	5.20E-01	5.20E-01	0.00E+00	1.07E+00	0.00E+00	0.00E+00	1.55E+02	1.02E+01	2.63E-03	0.00E+00	1.68E+02	5.78E+03
	C-14	7.50E-02	2.52E+00	2.52E+00	0.00E+00	5.01E+00	0.00E+00	0.00E+00	2.40E+02	1.09E+02	1.70E+00	0.00E+00	3.61E+02	
	Co-60	2.42E+00	7.99E+00	7.99E+00	0.00E+00	2.07E+00	0.00E+00	0.00E+00	5.21E+03	1.87E+01	2.72E-05	0.00E+00	5.25E+03	
	Cl-36	9.55E-04	3.28E-02	3.28E-02	0.00E+00	6.70E-02	0.00E+00	0.00E+00	9.42E-02	1.63E+00	6.76E-04	0.00E+00	1.85E+00	
Economic Costs	Cost of constructing /operating /decommissioning the process (£M)	38.25	29.88	0.12	29.95	75.50	0.11	10.48	0.90	1.88	100.17	0.02	287.28	287.28
Economic Benefits (Reuse & spinoff)	Value of reuse of materials and spin-off opportunities from newly developed technologies (£M)	0	0	0	0	0	0	0	0	0	0	0	0	
Technology Predictability: Concept	TRL of technology to be used (TRL 1 to 9)	9.00	4.00	7.00	7.00	4.00	7.00	5.00	9.00	0.00	5.00	9.00	0.00	
	Cost to fully develop technology if not already mature (£M)	0	7.07	0.012	0.000	42.437	0.000	0.02	0.25	0	5.80	0	55.59	55.59
Technology Predictability: Operational	Potential cost to project as a result of risk (£M)	0	10.65	0.01	0.90	2.27	0.00	0.52	0	0	25.04	0	39.40	39.40
	Potential delay to project as a result of risk (yr)	0	2.25	0.75	0.23	0.23	0.23	0.38	0	0	2.50	0	6.55	6.55
Stability of Employment	Rapid Staffing Changes (jobs)	282.00	8.55	0	233.295511	247.545511	0	509	3	7.125	268.38	195.50	1754.39	1754.39
Burden on Future Generations	Decades until material no longer requires active management	2.5	0.75	0	0	0	0	0	0	0	10	10	23.25	23.25

Calculation Sheet Output for Option 21: Make use of graphite as inert filler, removing the need for some encapsulation

		PROCESS OPERATION														
ASSESSMENT CRITERION	Data (Units)	In-reactor Storage	Retrieval	Separation	Size Reduction	Heat Treatment	Immobilisation	Transport (Immobilised)	Grouting	Transport	Repository Filling (Immob)	Repository (Immob)	Repository Filling	Repository	Overall Total	Grand Total
Public Safety: Routine Radioactive Discharges	H-3 (man Sv)	4.73E-06	2.83E-05	5.28E-05	5.28E-05	0.00E+00	3.09E-09	3.17E-08	5.28E-05	1.63E-09	2.07E-07	0.00E+00	2.07E-07	0.00E+00	1.92E-04	4.28E-01
	C-14 (man Sv)	7.51E-04	1.12E-02	2.25E-02	2.18E-02	0.00E+00	1.91E-06	1.96E-05	2.25E-02	2.20E-07	9.49E-08	3.42E-01	9.49E-08	2.99E-04	4.21E-01	
	Co-60 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.07E-03	0.00E+00	1.62E-05	7.09E-03	
Environmental Safety: Routine Radioactive Discharges	H-3	1.55E+01	2.21E-01	4.14E-01	4.14E-01	0.00E+00	2.42E-05	2.48E-04	4.14E-01	4.00E+01	7.96E-07	0.00E+00	7.96E-07	0.00E+00	5.69E+01	5.22E+02
	C-14	6.14E+01	2.20E+00	4.40E+00	4.26E+00	0.00E+00	3.74E-04	3.84E-03	4.40E+00	1.36E+02	1.14E-05	2.37E+02	1.14E-05	4.23E-03	4.50E+02	
	Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.55E+01	0.00E+00	3.54E-02	1.55E+01	
Environment and Public Safety: Resource Usage	Energy (GJ)	450000	1.42E+05	1.71E+05	5.22E+05	1.72E+05	8.10E+05	8.11E+01	47880	4	242357	0	90529	0	2647970	2647970
Public Safety: Non Radioactive Discharges	Dilution required (m3)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Environment and Public Safety: Local Intrusion	Noise (decibel.years)	0	0	0	0.00E+00	0.00E+00	2.80E+02	6.48E+02	280	648.4	7220.3	0.0	7220.3	0	16297	
	Land (hectares.years)	1625	487.5	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.0	3000.0	0.0	3000	0	8113	
	Transport (truck journeys)	0	0	1382.5092	0.00E+00	1.38E+03	2.64E+03	6.30E+02	395	31.0	3133.0	0.0	1174	0	10766	
Environment and Public Safety: Hazard Potential (RHP)	H-3	1.70E+01	1.78E-02	2.33E+00	0.00E+00	2.33E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.2E-03	7.83E-03	5.20E-03	5.22E-03	2.17E+01	1.95E+04
	C-14	3.77E+01	1.34E-01	1.44E+01	0.00E+00	1.09E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.9E+01	1.07E+04	1.88E+01	1.57E+03	1.24E+04	
	Co-60	9.35E+02	1.88E+00	3.17E+02	0.00E+00	4.52E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.8E-07	3.34E-06	2.77E-07	2.31E-05	1.26E+03	
	Cl-36	4.90E-01	1.42E-03	1.52E-01	0.00E+00	1.46E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.5E-03	5.78E+03	7.53E-03	2.23E+01	5.81E+03	
Worker Safety: Radiological Safety	mSv (total)	17.1	12.83	12.83	0.00	12.83	8.55	3.46	8.55	0.15	49.72	0.00	2.10	0	128.10	128.10
Worker Safety: Conventional Safety	Injuries	0.65	0.49	1.49	0.00	1.49	7.26	0.35	2.45	0.35	9.24	1.61	9.24	1.61333333	36.22	36.22
Security Misappropriation	H-3	2.41E-02	5.20E-01	5.20E-01	0.00E+00	1.07E+00	0.00E+00	7.56E+00	0.00E+00	1.19E+02	2.63E-03	0.00E+00	2.63E-03	0.00E+00	1.29E+02	4.43E+03
	C-14	7.50E-02	2.52E+00	2.52E+00	0.00E+00	5.01E+00	0.00E+00	5.33E+01	0.00E+00	1.84E+02	1.70E+00	0.00E+00	1.70E+00	0.00E+00	2.51E+02	
	Co-60	2.42E+00	7.99E+00	7.99E+00	0.00E+00	2.07E+00	0.00E+00	2.45E+01	0.00E+00	4.01E+03	2.72E-05	0.00E+00	2.72E-05	0.00E+00	4.05E+03	
	Cl-36	9.55E-04	3.28E-02	3.28E-02	0.00E+00	6.70E-02	0.00E+00	7.92E-01	0.00E+00	7.25E-02	6.76E-04	0.00E+00	6.76E-04	0.00E+00	9.99E-01	
Economic Costs	Cost of constructing /operating /decommissioning the process (£M)	38.25	29.88	33.18	0.11	75.50	77.47	0.94	11.76	0.90	783.21	0.03	117.25	0.03	1168.52	1168.52
Economic Benefits (Reuse & spinoff)	Value of reuse of materials and spin-off opportunities from newly developed technologies (£M)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Technology Predictability: Concept	TRL of technology to be used (TRL 1 to 9)	9.00	4.00	7.00	7.00	4.00	5.00	9.00	5.00	9.00	5.00	9.00	5.00	9.00	4.00	
	Cost to fully develop technology if not already mature (£M)	0	7.07	3.318	0.000	42.437	0.138	0.250	0.02	0.25	45.32479014	0	6.79	0	105.60	105.60
Technology Predictability: Operational	Potential cost to project as a result of risk (£M)	0	10.65	3.32	0.00	2.27	3.87	0.00	0.59	0	195.803	0.000	29.31	0	245.82	245.82
	Potential delay to project as a result of risk (yr)	0	2.25	0.75	0.23	0.23	0.38	0.00	0.38	0	2.5	0	2.50	0	9.20	9.20
Stability of Employment	Rapid Staffing Changes (jobs)	282.00	8.55	233.295511	0	247.545511	509.5	3	509	3	230.5	195.5	265.00	195.50	2682.39	2682.39
Burden on Future Generations	Decades until material no longer requires active management	2.5	0.75	0	0	0	0	0	0	0	10	10	10	10	43.25	43.25

Calculation Sheet Output for Option 22: Immobilise in medium impermeable to ^{14}C

		PROCESS OPERATION														
ASSESSMENT CRITERION	Data (Units)	In-reactor Storage	Retrieval	Separation	Size Reduction	Heat Treatment	Chemically Bind C14	Transport (Immobilised)	Grouting	Transport	Repository Filling (Immob)	Repository (Immob)	Repository Filling	Repository	Overall Total	Grand Total
Public Safety: Routine Radioactive Discharges	H-3 (man Sv)	4.73E-06	2.83E-05	5.28E-05	5.28E-05	0.00E+00	3.09E-09	3.17E-08	5.28E-05	1.63E-09	2.07E-07	0.00E+00	2.07E-07	0.00E+00	1.92E-04	4.28E-01
	C-14 (man Sv)	7.51E-04	1.12E-02	2.25E-02	2.18E-02	0.00E+00	1.91E-06	1.96E-05	2.25E-02	2.20E-07	9.49E-08	3.42E-01	9.49E-08	2.99E-04	4.21E-01	
	Co-60 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.07E-03	0.00E+00	1.62E-05	7.09E-03	
Environmental Safety: Routine Radioactive Discharges	H-3	1.55E+01	2.21E-01	4.14E-01	4.14E-01	0.00E+00	2.42E-05	2.48E-04	4.14E-01	4.00E+01	7.96E-07	0.00E+00	7.96E-07	0.00E+00	5.69E+01	5.22E+02
	C-14	6.14E+01	2.20E+00	4.40E+00	4.26E+00	0.00E+00	3.74E-04	3.84E-03	4.40E+00	1.36E+02	1.14E-05	2.37E+02	1.14E-05	7.99E-03	4.50E+02	
	Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.55E+01	0.00E+00	2.37E-01	1.57E+01	
Environment and Public Safety: Resource Usage	Energy (GJ)	450000	1.42E+05	1.71E+05	5.22E+05	1.72E+05	1.04E+07	8.11E+01	47880	4	242357	0	90529	0	12206834	12206834
Public Safety: Non Radioactive Discharges	Dilution required (m3)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Environment and Public Safety: Local Intrusion	Noise (decibel.years)	0	0	0	0.00E+00	0.00E+00	2.80E+02	6.48E+02	280	648.4	7220.3	0.0	7220.3	0	16297	
	Land (hectares.years)	1625	487.5	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.0	3000.0	0.0	3000	0	8113	
	Transport (truck journeys)	0	0	1382.5092	0.00E+00	1.38E+03	2.64E+03	6.30E+02	395	31.0	3133.0	0.0	1174	0	10766	
Environment and Public Safety: Hazard Potential (RHP)	H-3	1.70E+01	1.78E-02	2.33E+00	0.00E+00	2.33E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.2E-03	7.83E-03	5.20E-03	5.22E-03	2.17E+01	1.95E+04
	C-14	3.77E+01	1.34E-01	1.44E+01	0.00E+00	1.09E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.9E+01	1.07E+04	1.88E+01	1.57E+03	1.24E+04	
	Co-60	9.35E+02	1.88E+00	3.17E+02	0.00E+00	4.52E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.8E-07	3.34E-06	2.77E-07	2.31E-05	1.26E+03	
	Cl-36	4.90E-01	1.42E-03	1.52E-01	0.00E+00	1.46E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.5E-03	5.78E+03	7.53E-03	2.23E+01	5.81E+03	
Worker Safety: Radiological Safety	mSv (total)	17.1	12.83	12.83	0.00	12.83	8.55	3.46	8.55	0.15	49.72	0.00	2.10	0	128.10	128.10
Worker Safety: Conventional Safety	Injuries	0.65	0.49	1.49	1.49	1.49	7.26	0.35	2.45	0.35	9.24	1.61	9.24	1.61333333	37.71	37.71
Security Misappropriation	H-3	2.41E-02	5.20E-01	5.20E-01	0.00E+00	1.07E+00	0.00E+00	7.56E+00	0.00E+00	1.19E+02	2.63E-03	0.00E+00	2.63E-03	0.00E+00	1.29E+02	4.43E+03
	C-14	7.50E-02	2.52E+00	2.52E+00	0.00E+00	5.01E+00	0.00E+00	5.33E+01	0.00E+00	1.84E+02	1.70E+00	0.00E+00	1.70E+00	0.00E+00	2.51E+02	
	Co-60	2.42E+00	7.99E+00	7.99E+00	0.00E+00	2.07E+00	0.00E+00	2.45E+01	0.00E+00	4.01E+03	2.72E-05	0.00E+00	2.72E-05	0.00E+00	4.05E+03	
	Cl-36	9.55E-04	3.28E-02	3.28E-02	0.00E+00	6.70E-02	0.00E+00	7.92E-01	0.00E+00	7.25E-02	6.76E-04	0.00E+00	6.76E-04	0.00E+00	9.99E-01	
Economic Costs	Cost of constructing /operating /decommissioning the process (£M)	38.25	29.88	33.18	0.11	75.50	77.47	0.94	11.76	0.90	783.21	0.03	117.25	0.03	1168.52	1168.52
Economic Benefits (Reuse & spinoff)	Value of reuse of materials and spin-off opportunities from newly developed technologies (£M)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Technology Predictability: Concept	TRL of technology to be used (TRL 1 to 9)	9.00	4.00	7.00	7.00	4.00	5.00	9.00	5.00	9.00	5.00	9.00	5.00	9.00	4.00	
	Cost to fully develop technology if not already mature (£M)	0	7.07	3.318	0.000	42.437	0.138	0.250	0.02	0.25	45.32479014	0	6.79	0	105.60	105.60
Technology Predictability: Operational	Potential cost to project as a result of risk (£M)	0	10.65	3.32	0.00	2.27	3.87	0.00	0.59	0	195.803	0.000	29.31	0	245.82	245.82
	Potential delay to project as a result of risk (yr)	0	2.25	0.75	0.23	0.23	0.38	0.00	0.38	0	2.5	0	2.50	0	9.20	9.20
Stability of Employment	Rapid Staffing Changes (jobs)	282.00	8.55	233.295511	0	247.545511	509.5	3	509	3	230.5	195.5	265.00	195.50	2682.39	2682.39
Burden on Future Generations	Decades until material no longer requires active management	2.5	0.75	0	0	0	0	0	0	0	10	10	10	10	43.25	43.25

Calculation Sheet Output for Option 23: Chemically bind ^{14}C

		PROCESS OPREATION								
ASSESSMENT CRITERION	Data (Units)	In-reactor Storage	Retrieval	Interim Storage (2)	Grouting	Transport	Repository Filling	Repository	Overall Total	Grand Total
Public Safety: Routine Radioactive Discharges	H-3 (man Sv)	4.73E-06	6.37E-05	1.53E-06	1.53E-11	1.41E-10	3.46E-07	0.00E+00	7.03E-05	1.51E-02
	C-14 (man Sv)	7.51E-04	8.65E-03	2.98E-03	1.78E-06	6.01E-08	2.25E-04	9.56E-07	1.26E-02	
	Co-60 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36 (man Sv)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	2.47E-03	
Environmental Safety: Routine Radioactive Discharges	H-3	1.55E+01	4.99E-01	1.25E+00	9.01E-11	1.21E-01	1.66E-04	0.00E+00	1.73E+01	1.47E+02
	C-14	6.14E+01	1.69E+00	6.09E+01	2.63E-07	1.29E+00	2.69E-03	5.91E-04	1.25E+02	
	Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
	Cl-36	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.80E+00	4.80E+00	
Environment and Public Safety: Resource Usage	Energy (GJ)	450000	136407	330251	471110	106	385419	0	1773292	1773292
Public Safety: Non Radioactive Discharges	Dilution required (m3)	0	0	0	0	0	0	0	0	0
Environment and Public Safety: Local Intrusion	Noise (decibel.years)	0	0	0	280	648.4	7220.3	0	8149	
	Land (hectares.years)	1625	487.5	6500	0	0	3000.0	0	11613	
	Transport (truck journeys)	0	0	0	2963	814	3657.8	0	7435	
Environment and Public Safety: Hazard Potential (RHP)	H-3	1.70E+01	1.52E-02	2.87E+05	0.00E+00	0.00E+00	3.61E+00	1.31E-02	2.87E+05	2.24E+06
	C-14	3.77E+01	1.15E-01	1.35E+06	0.00E+00	0.00E+00	1.49E+02	1.19E+04	1.36E+06	
	Co-60	9.35E+02	1.62E+00	5.62E+05	0.00E+00	0.00E+00	1.63E-01	4.26E-02	5.63E+05	
	Cl-36	4.90E-01	1.22E-03	1.80E+04	0.00E+00	0.00E+00	1.96E+00	5.78E+03	2.38E+04	
Worker Safety: Radiological Safety	mSv (total)	17.1	12.83	6.84	8.55	4.20	42.55	0	92.06	92.06
Worker Safety: Conventional Safety	Injuries	0.65	0.49	0.19	2.65	0.35	9.24	1.613333333	15.19	15.19
Security Misappropriation	H-3	2.41E-02	6.09E-01	6.93E-01	0.00E+00	1.04E+01	1.09E+00	0.00E+00	1.28E+01	2.70E+02
	C-14	7.50E-02	2.95E+00	3.36E+00	0.00E+00	5.03E+01	8.06E+00	0.00E+00	6.47E+01	
	Co-60	2.42E+00	9.35E+00	1.07E+01	0.00E+00	1.59E+02	9.53E+00	0.00E+00	1.91E+02	
	Cl-36	9.55E-04	3.84E-02	4.37E-02	0.00E+00	6.55E-01	1.05E-01	0.00E+00	8.43E-01	
Economic Costs	Cost of constructing /operating /decommissioning the process (£M)	38.25	36.15	35.71	69.32	0.95	880.0	0.81	1061.17	1061.17
Economic Benefits (Reuse & spinoff)	Value of reuse of materials and spin-off opportunities from newly developed technologies (£M)	0	0	0	0	0	0	0	0	
Technology Predictability: Concept	TRL of technology to be used (TRL 1 to 9)	9.00	7.00	9.00	5.00	9.00	5.00	9.00	5.00	
	Cost to fully develop technology if not already mature (£M)	0	4	0.00	0.16	0.25	50.9	0	55.33	55.33
Technology Predictability: Operational	Potential cost to project as a result of risk (£M)	0	6.27	0.00	3.47	0	220.0	0	229.73	229.73
	Potential delay to project as a result of risk (yr)	0	1.13	0.00	0.38	0	2.5	0	4.00	4.00
Stability of Employment	Rapid Staffing Changes (jobs)	282.00	8.55	10.8	509	3	240.7	195.5	1249.55	1249.55
Burden on Future Generations	Decades until material no longer requires active management	2.5	0.75	10	0	0	10	10	33.25	33.25

Calculation Sheet Output for Option 24: Interim storage of raw waste and repository

Appendix 4 – Flowsheet Basis Document

The assumptions made and methods used to calculate a numerical value for each of the sub-criteria across all options are explained below.

Environmental and Public Safety

This criterion considers the potential impact of an option on the environment, with both regulated and accidental discharges considered. Radiological and non-radiological discharges, resource usage, local intrusion and effects on the local ecosystem are all covered.

Public Safety: Routine Radioactive Discharges

The impact of discharges on the public is assessed through a collective dose. The Sellafield collective dose commitment is used to convert the aerial discharges to the total collective dose. Sellafield collective doses are also used to assess the impact of liquid discharges. The impact of each radionuclide is calculated individually, and then these are totalled to provide an overall dose.

Environmental Safety: Routine Radioactive Discharges

The first tier assessment defined by 'Environmental Risk from Ionising Contaminants: Assessment and Management' (ERICA) is used to analyse the impact discharges have on the environment.

The radiological impact is assessed using the Risk Quotient (RQ) calculated using the activity concentration of the discharged material for a given radionuclide divided by the Environmental Media Concentration Limit (EMLC) for that nuclide.

Environment and Public Safety: Resource Usage

An overall resource usage is considered for each operation, including consideration of construction of facilities and equipment, operation and running of processes and the embodied energy. The overall value for each stage encompasses the entire life cycle of the operation, calculated in terms of energy used.

Public Safety: Non Radioactive Discharges

Non-radiological discharges can be considered by using the Environmental Quality Standards to give references for different discharge levels. Non-radioactive discharges resulting from construction are not included to avoid double counting, having been included in resource usage considerations.

Environmental and Public Safety: Local Intrusion

The impacts of Noise, Light and Vibration on the local community are assessed. The magnitude of the noise is calculated and multiplied by the time period over which it is apparent. Throughout the operations in all scenarios, it is considered that any light and vibrations are minimal and would only have an impact within the site.

The land use of the site is included in the local intrusion, and is the area of an existing reactor site multiplied by the time period over which it is in use. The total site area is used for calculations and processing steps are assumed to be within the site boundaries, resulting in no additional land usage.

Transport is included as an impact on the local community. The number of truck journeys completed is considered using a consistent volume of material transported per trip.
Journeys completed by workers to get to any processing site are not included. These are directly related to the number of workers and hence the stability of employment, thus are not included to avoid double counting. Only journeys off site are included and journeys within the site boundary are neglected.

Environmental and Public Safety: Hazard Potential

The Radiological Hazard Potential (RHP) is calculated using the inventory, form factor and control factor and time over which it is apparent. Inventory is calculated by multiplying the activity by the specific toxic potential and aerial correction values.

$$Inventory = Activity \times AerialCorrection \times SpecificToxicPotential$$

$$RHP = Time \times \frac{Inventory \times FormFactor}{ControlFactor}$$

Worker Safety: Radiological Safety

This is the cumulative dose to the whole workforce over the entire process operation. During remote operations, this is set as equal to the average dose received at reactor stations. It is adjusted to reflect the nature of the process where received dose would vary from this figure.

Worker Safety: Conventional Safety

This is calculated using the number of workers and the injury rate in related operations over the entire project.
It is assumed that the rate of injuries for nuclear operations (construction, manufacturing) is 3 times less than general figures. The safety record within the nuclear industry tends to be better than average.

Security Misappropriation

The total security score is calculated from the Potential Dose (PD), number of barriers and time over which any misappropriation may occur. The PD is calculated from the activity of the material that could be stolen multiplied by the dose from inhalation.

The total security is calculated thus:

$$TotalSecurityScore = (PD \times 0.1^{Barriers}) \times Years$$

The percentage of material taken is normally given in terms of number of boxes. This is generally assumed to be between 2 – 5 boxes.

Economic Costs

This includes capital costs and all aspects of the operation and operating costs, including wages, research and design and eventual decommissioning. Decommissioning is assumed to be equal to 30% of the capital costs. Employee wages are dependent on the task, but are in the range of £40 – 50k per year.

Economic Benefits (Reuse and Spin-off)

In some cases, technology developed may be of use in other fields and hence allow for income to be generated or the constructed facilities and equipment may be used for processing additional material.

Technology Predictability: Concept

This criterion considers both the design uncertainty associated with untested equipment, and the flexibility and robustness of the equipment to variations in the feed and operating conditions. The Technology Readiness Level (TRL) is used to distinguish between mature technologies and those that still require development and the extent to which it is required.

A cost to develop the process to a fully mature state is also calculated.

Technology Predictability: Operational

This is measured by assessing the likelihood of the operation failing and the additional costs and time delays incurred as a consequence of such failure.

Stability of Employment

The total amount of jobs lost and created throughout the processing options is calculated. In similar processing operations, it is assumed the same workers would have the required skills and experience to complete multiple operations. A natural wastage value is included to account for people leaving jobs. This sub-criterion considers rapid changes in jobs (both created and lost) as detrimental. No benefit is considered for job creation.

Burden on Future Generations

The time over which an operation will require staff is included. This is measured in decades and is defined from the waste management option.

Constants for All Options

Various values are constant throughout the various process operations and across all scenarios.

The energy calculated for the construction of facilities (grouting plants, repository, etc) use constant values for energy per mass used [Ref 1]. For all transportation, the energy required for fuel is included and is constant for all options [Ref 2].

Deliveries and transportation of material and waste is required across all options. The mass transported on each occasion is assumed to be limited to 20 tonnes.

Doses from inhalation of all isotopes used to calculate security scores remain constant through all options. Adult doses are used. [Ref 3]

Specific Toxic Potential and Aerial Correction values used to calculate the hazard potential of all processes remain the same across processes and options.

EU collective doses, which are based on Sellafield site data [Ref 4], are used to calculate the radiological impact on man from discharges and are constant for all operations and across all options. They are split for aerial and liquid discharges.

The impact on the environment calculation involves the limits of concentration values of discharges. This is taken from the ERICA tier 1 screening values based on a screening dose of 0.01 mGy/hr [Ref 5]. This is constant throughout all options and processing operations. It should be noted that whilst collective doses are calculated based on the total activity (in Bq) released, environmental impacts are based on the concentration of discharges.

Baseline

Graphite in Core

Inventory

The inventory in the first case study is a typical inventory from a Magnox/UNGG reactor. It consists of the moderator and reflector graphite and metal elements.

Through the process four radioisotopes are assessed - ^{3}H, ^{14}C, ^{36}Cl and $^{60}C0$. These isotopes are assessed against all processing stages.

The fractional aerial discharge is on this sheet. This is used in subsequent sheets to calculate the discharges for each process stage. This is from the total inventory and average discharge at a reactor station. Throughout the process, aerial discharge is split between graphite and metal streams in the ratio of activity present at the start of the process stage. This is done individually for each species.

Half lives are used to calculate the decay constants from which decay is calculated [Ref 6].

In-situ Storage

Radiological impact on man and the environment are calculated from the aerial discharge. Both graphite and metal are included in the aerial discharge calculation. Average discharges from a reactor station per year [Ref 7] are used to calculate a fractional discharge from the total activity present. This is then used to calculate the discharge over the total interim storage period, incorporating decay.

Values for impact on the environment are calculated from the air exchange in the reactor during storage. The volume change per year is 2934 m^3/yr. This is calculated from an estimated purge volume per year (from an estimated volume purged occurring every five years as for a typical Magnox reactor during decommissioning [Ref 8]) and estimated pressure leak.

During storage in a reactor the power usage is calculated from the power usage for decommissioning of a reactor station [Ref 8]. It is further assumed that the reactor requires 10% of the total power usage, and will only occur for the first ten years of the interim storage period.

Non-radiological discharges are set as zero. CO_2 generated as a result of power usage is included in Resource Usage and therefore neglected here to avoid double counting. No other discharges are assumed.

During storage it is not expected that there will be any noise generated which impacts beyond the site boundary and on the community. The land usage is not expected to increase beyond the existing facility and the final number is calculated from an assumed 65 hectare site. No transport is included during this stage. Minimal off site journeys will be included as a result of sampling, but are infrequent and hence not considered here. Worker journeys are not included to avoid double counting with the employment values.

Constant specific toxic potential and aerial correction values and monolithic form factors (for both graphite and metal) with a control factor of 100,000 decades are used to give the hazard potential from the activity of the material present. Decay is included in the calculation.

The number of employees during reactor storage is assumed to be six [Ref 9]. The average dose per person at a station (0.114 mSv/yr from the average dose at reactor stations [Ref 10] is used to calculate the received worker dose. The number of injuries per 100,000 workers per year for construction is used to calculate the number of conventional worker injuries. One third of the value from the Health and Safety Executive (HSE) statistics [Ref 11] is used to convert to a nuclear specific operation and account for the nuclear industry safety record being better than average. The construction safety record is used due to the nature of work required during storage incorporating a large maintenance component.

A security score is calculated for both reactor and sampling. It is assumed that one lorry load could be taken from the reactor, which is assumed to be 20 tonnes. For this case there are assumed to be six barriers- site boundary, site security and manning, reactor building, bioshield, radiation, bulk to be extracted. Sampling is assumed to consist of two 100 g moderator samples each year. It is assumed that only one year's sample could be taken before security would be increased, preventing further misappropriation. There is only one barrier- the transport.

The cost is calculated from staffing costs, assumed to be £50k per employee over the storage period. Electricity costs (calculated at 7p per kWhr [Ref 12]) are included from the resource usage calculated. A cost of £22m for weather cladding of the reactor is included [Ref 13].

No spin-off is included in this stage from reactor monitoring. Spin off in this instance would be a possible financial gain from technology developed, but it is considered to be negligible in this instance.

Monitoring of a reactor is a current process and thus has been assigned a Technology Readiness Level (TRL) value of 9. No development costs are required.

The storage stage is expected to require no more than routine maintenance and the risk is negligible. A probability of failure of 0% is assigned to this stage, with no delay and no additional cost expected.

The change in employment is calculated from the value of six employees assigned decreasing from 570 employees (assumed) at a reactor station. It is assumed that this decrease in jobs can occur over a 10 year period. This period is used to calculate a natural wastage. The natural wastage assumes there is a figure of 5% of employee turnaround each year.

The burden on future generations is calculated from the period of storage.

Decay is calculated over this interim storage period from the material present.

In-situ Storage Variation

The possible variations of the interim storage are the time period for which it occurs. Storage occurs for either 25 or 75 years. The increased time period increases the material released aerially and hence the impact on man and the environmental measures. The resource usage is assumed to occur for the first 10 years and doesn't increase. After this period the resource usage is considered to be negligible and neglected. A longer time period increases the land usage. The increased time over which workers are required increases the safety measures due to an increased dose received and additional injuries. The staffing costs increase the overall costs.
Measures for hazard potential, security and burden on future generations are increased by the longer time period.

Retrieval

The aerial discharge is calculated from the amount of material arising as dust as a result of drilling. A total of 0.04% of the material is assumed to be removed through this process, with 50% of the total ^{3}H activity and 25% of ^{14}C discharged aerially [Ref 14]. Again, the discharges are calculated for both graphite and metal and split between the two in the ratio of activity, and split between the four isotopes assessed. Due to the remote handling, an air exchange for the reactor of one per day is assumed.

There are assumed to be no liquid discharges in this process.

Resource usage for remote retrieval is assumed to include the same amount of power requirements as for quiescent storage of the reactor, scaled to the total processing time. There is also a hoist power requirement included [Ref 15]. The same power requirement is assumed for the use of manipulators. It is assumed that a crane is in place for use in retrieval operations, thus no resource usage is required for its construction.

There are assumed to be no non-radiological discharges. Again CO_2 generated through energy requirements is neglected to avoid double counting.

Retrievals will result in noise through operation of machinery; however, due to the location within the reactor building and bioshield on site, it is assumed to have no impact on the local community. The footprint of the site is unchanged from interim storage. The calculated value incorporates the processing time for all processing stages and is included in the retrieval process, but zeroed in future processing occurring in the same continuous processing envelope to avoid double-counting. There will be minimal off-site transport. Transportation of machinery is the only possible source.

The hazard potential is calculated assuming a maximum of three boxes' worth of material present at any time.

The number of workers required for retrieval is based on retrieval at GLEEP. This process involved the removal of 550 tonnes over five months. It is assumed that 15 people would be capable of removing 4400 tonnes of graphite and metal to allow all continuous processing to be completed in the 7.5 year period specified.

The average dose at worker stations is calculated using the average dose at reactor stations [Ref 10]. The remote retrieval process should not increase the received dose above the average. For manual retrieval it is higher.

Conventional worker safety is calculated using construction figures [Ref 11]. Again, one third of the given value is used to incorporate the better-than-average safety record in the nuclear industry.

The security score assumes a quantity of five boxes are vulnerable. There are four boundaries – the site boundary, site security and manning, reactor building and the bulk to be extracted.

The cost for retrieval is calculated based on the cost for decommissioning WAGR. This cost £80m [Ref 16]. The retrieval cost calculated incorporates a factor of 2/9, as only two of the nine decommissioning phases were to retrieve graphite. It is assumed that the total cost is split equally between all phases [Ref 9]. A 'learning from experience' factor has been included, decreasing the cost by a factor of three to reflect any advances. The cost is scaled on the mass of material retrieved, with 210 tonnes removed at WAGR.

It is assumed that there will be no financial benefit from this operation. This is a pessimistic estimate, with the possibility of remote handling and manipulation techniques developed as a result.

A TRL score of 7 has been given to this operation. Similar retrievals have been performed previously.

It is assumed that it will cost £4m to transfer the existing technology to a position in which it could be used in this case.

There is a possibility of graphite not accepting the tooling and additional effort required. It is assumed that there is a 25% chance of adding 20% to the total cost and duration, and a 10% chance that the total cost and duration will double.

It is assumed that the six workers in interim storage will have the skills required to undertake retrievals, thus only nine additional workers are required. This increase will be required to occur over one year, with a natural wastage calculated. Loss of jobs is assessed together with all processes in the continuous process envelope when all are complete.

The continuous phase envelope of processes occurs over 7.5 years. This figure is included in the retrievals process and neglected in other processes occurring in the same period to avoid double counting. The time is not split between processing stages, due to multiple stages occurring at the same time.

Retrieval Variation - Manual

This variation considers a method of retrieval using a greater degree of manual graphite handling. Drill and Tap technique will be used, producing the same size of blocks.

With the same tools and technology of retrieval used, the volume of material (dust) removed through drilling will be the same, hence aerial discharge will be unchanged from remote retrieval. The same air exchange is used as for remote. The change is the degree to which retrieval is remote.

Resource usage is decreased with the use of manipulators no longer required.

The radiological worker safety is increased to the maximum received from the same reference as used for remote. Conventional safety is assumed the same, and the same number of workers would be required.

Manual retrieval is more reliable than remote, with the risk set at half that used for remote. It is assumed that there is a 12.5% chance of adding 20% to the total cost and duration, and a 5% chance that the total cost and duration will double.

All other differences between the two methods are due to differences in previous processing stages, such as a longer interim storage period, which would be required for manual retrieval to allow for decay of shorter-lived nuclides. The time for this process is the same as for remote retrieval.

Retrieval Variation – (Particulate) Nibble and Vacuum

Particulate retrieval will be in the form of the Nibble and Vacuum method. This will produce much smaller graphite blocks, reducing or potentially removing the requirement for a size reduction stage.

The aerial discharge is assumed the same as for remote retrieval. The same air exchange is used as for remote retrieval.

Resource usage is increased from Remote Retrieval, with a robotic arm (1.6 kW [Ref 17]) and Earth moving Vacuum (75 kW [Ref 18]) replacing Hoist and Manipulator requirements. These are assumed to be used for eight hours per day for 260 days per year. This occurs over the total 7.5 year processing period, as used in remote retrieval.

The same number of people would be required for this process as for remote retrieval, with the same values used for both radiological and conventional safety. It is assumed that the workers for interim storage will be able to use the Nibble and Vacuum retrieval process and hence the stability on employment is unchanged from remote retrieval. Hazard potential and security scores are unchanged.

The cost for Particulate Retrieval is taken from Costain [Ref 19]. The capital costs and operating costs are scaled on throughput using the 0.6 power law [Ref 20], as follows:

$$\frac{CostPlant1}{CostPlant2} = \left(\frac{CapacityPlant1}{CapacityPlant2}\right)^{0.6}$$

The cost also includes wage (£50k per employee per year), decommissioning (at 30% of capital) and energy costs. No spin off costs are included, however there may be a benefit for developed technology and methods able to be used in a wide range of applications.

A TRL of 4 has been set for this process, with development costs of £7.1m calculated from information indicated in [Ref 19].

The risk associated with this process is greater than remote retrieval, and is assumed to be double that for remote, with a 50% chance of adding 20% to the total cost and duration, and a 20% chance that the total cost and duration will double.

Other variations between remote and particulate retrieval are due to changes in previous stages. The same period of 7.5 years is used for both processes.

Retrieval Variation - Underwater

During retrieval, the reactor will be underwater. Bulk block retrieval will be used.

There will be no aerial discharges, but instead there will be in the liquid stream and there will be discharges as water is released. The activity released in the water stream is assumed to be the same as the activity removed through aerial discharge of remote retrieval. Water is assumed to be released over one year, and the additional water stream is included in the radiological impact calculations.

The same retrieval method as for remote retrieval will be used, with the same quiescent, hoist and manipulator power requirements as for remote retrieval, with the addition of a pumping requirement to fill the reactor to a depth of 2m [Ref 21] over the reactor footprint [Ref 22]. To convert to a fully water tight facility, an additional resource usage equal to half that of an additional building is included. The additional building requirements depend on the total number of additional facilities required, and the ability to contain multiple processes in the same facility.

The additional facility requirement also increases the number of injuries, and the transport, cost and employment values. The increase is assumed to be half that of an additional facility, due to modifications to an existing facility rather than an additional building construction.

The number of people required is assumed to be the same as for remote retrieval, with the same radiological and conventional safety. The process will occur over the same time period and the security and hazard potential values are unchanged.

The cost includes the additional facility cost, but otherwise remains unchanged from remote retrieval. The cost to develop is increased by 50% from that of remote retrieval.

The risk is assumed to be double the value of the remote retrieval, with a 50% chance of adding 20% to the total cost and duration, and a 20% chance that the total cost and duration will double.

Encapsulation

Waste is encapsulated with grout in a 4m box, containing 200mm shielding. This box has a total volume of 21.5m^3, containing 9.4m^3 of waste. Grout is included to increase the volume to 11m^3 [Ref 23].

Aerial discharge is calculated using the fraction of material discharged as in quiescent storage, incorporating decay and an air exchange of five volume changes per hour for the grout plant. A total of three boxes will be present at any time, which is included in the aerial discharge calculation.

Resource usage includes the metal and concrete considerations for the construction of the boxes and the grout required. The construction of facilities is included in the resource usage calculation. Values for the volume and mass of various steel and concrete components are included, scaled from a shielded waste encapsulation plant. The amount of each material required is calculated from scaling the required building volume using the 0.6 power law. The building volume is calculated from the throughput of waste packages, hence changes between options. An energy requirement for operations is included.

Indirect CO_2 discharge of materials is assumed to be represented by resource use, and no other non-radiological discharges are present.

Noise is incurred through the construction of facilities [Ref 24]. The noise is calculated over the total time period. Noise generated through construction of other facilities on this same site is assumed to be covered in this value and neglected elsewhere.

The grouting facility is on the reactor site; as such no land usage is included in addition to that apparent in the previous processing stages.

Transport of materials required for facilities is included and assumes each transport takes the maximum amount of material (20 tonnes).

A total of ten workers are assumed required for this process. These are different to those employed in retrieval. Radiological worker safety is assumed at an average value and conventional safety uses a manufacturing safety value divided by three to represent the nuclear industry's better safety record. There are 200 construction employees, with injuries calculated using nuclear construction injury rates (normal injury rates /3) and drivers injuries calculated from the number of trips required and normal driving injuries. There are 50 demolition workers required with the number of injuries calculated using nuclear construction values.

Hazard Potential is neglected and assumed to be included in retrieval.

The cost is scaled from the costs for a shield Intermediate Level Waste (ILW) encapsulation plant using the throughput of waste packages. It includes capital costs from which decommissioning costs are calculated at 30%, operating costs and R&D costs. Wages for truck drivers at £30k per year and plant employees at £40k per year are also included. Waste packages are assumed at £2k per box.

No spin off is expected from this facility or process.

The distribution of grout at a large scale requires demonstration and a TRL value of 5 has been used with a cost to develop of £1m.

It is assumed that there is a 50% chance that 10% of the boxes will require rework. This is used to calculate the cost and delay of failure.

The stability of employment is calculated from the increase in grout plant employees and jobs created and lost from construction and demolition. Construction and demolition jobs occur instantaneously and plant employees increase over two years. The loss of plant employee jobs when encapsulation is complete is assessed when all continuous processes are complete.

This process is undertaken at the same time as others in the continuous processing phase, with the burden on future generations included in only one process to avoid double counting.

Encapsulation Variations – No Encapsulation

In stages where no encapsulation occurs, retrieved material is still placed in the same boxes, with the same waste per box.

Aerial discharges are the same as for encapsulation.

No grouting facility is required for this stage, thus the resource usage, noise, transport and cost decrease. The construction of waste packages remains the same and is the only resource usage consideration.

No construction workers are required so the conventional worker safety and stability of employment are calculated only from process workers. No additional employees will be required, with those completing retrieval operations used to place waste in the boxes.

Size Reduction

A total voidage of 36% can be achieved by size reducing graphite. Using a box volume of $11m^3$, this produces a total of $7.04m^3$ of graphite per box (Option 2). This is a decrease from the $9.4m^3$ of graphite per box without size reduction. Size reduction reduces the packing efficiency and increases the number of waste disposal boxes. Instead, only part of the material will be size reduced and inserted into the fuel channels.

Using this method it is possible to increase the volume of waste in each box to a value equal to $11m^3$ of original retrieved graphite. The reduction in number of boxes is from 374 boxes in the baseline option, to 319 boxes in Option 2.

For the material undergoing size reduction, it is assumed that the aerial discharge is 100 times greater than that for quiescent storage. The air exchange for size reduction is the same as that used for retrieval. There is no liquid discharge.

An additional building is required for the size reduction process. This increases the resource usage, transport and cost, and the construction workers required increase the conventional worker safety and stability of employment measures.

The resource usage for size reduction is calculated from a milling machine [Ref 25]. The power requirement is scaled on the throughput using the 0.6 power law.

It is assumed that the 15 people undertaking retrieval operations will be able to complete size reduction operations. Hence there is no contribution to the stability of employment measure from this means, but they are included in radiological and conventional worker safety calculations. Nuclear construction injury rates are used for size reduction process safety and the average received dose.

The cost is taken for a milling machine of $250k [Ref 25]. Also included in the cost are facility, power and decommissioning (30% of capital) costs. There are no wage costs as the same people as for retrieval are used.

A TRL of 7 is used for size reduction; however there is no cost to develop.

The risk associated with this process is assumed the same as for remote retrieval, i.e. there is a 25% chance of adding 20% to the total cost and duration, and a 10% chance that the total cost and duration will double.

Size Reduction - Variation

There is no variation with size reduction, it is dependent on preceding stages.

Interim Storage

Waste is stored in boxes (before or after encapsulation) in a facility for 100 years.

Aerial discharge is calculated in relation to retrieval. After encapsulation, discharges are assumed to be 100 times smaller than retrieval discharges or the same extent if interim storage is undertake before encapsulation. The air exchange is also dependent on whether or not it is packaged.

Resource usage is calculated to include construction usage for the additional facilities required. The mass of concrete is taken from the Trawsfynydd site [Ref 26]. Power and water requirements are also included in this calculation, with 5% of the total power assumed to be for the store [Ref 27].

The power requirement for this site is calculated from scaling the quoted values with the volume of waste at Trawsfynydd using the 0.6 power law [Ref 27].

The construction of the facility produces an additional noise measure and further transport is required. This is the same as the noise for construction of an additional facility. The impacts of construction of various other criteria are consistent with additional facility construction. Although it is assumed the store will be located on site, the additional 100-year time period over which it occurs results in an increased land usage measure.

It is assumed that the same of the number of people required for interim storage in the reactor are required, i.e. six people. As in interim storage in the reactor, the average dose received by workers at reactor stations is assumed and the injury rate for nuclear manufacturing used.

Security scores are calculated using five barriers: Site boundary; site security and manning; store building; box; encapsulant.

The cost includes the staff (£50k/employee/year), decommissioning (30% of capital), cost of the store and power costs.

There is not expected to be any spin off from storing waste.

This is an existing practice, thus a TRL score of 9 is assigned and there will be no development costs. There is no risk associated with this process.

The interim storage period may occur after a continuous processing phase. In this case the loss of jobs when previous phases have been completed are assessed, and assumed to occur over a five year period.

The burden on future generations includes the 100 year interim storage period.

Decay is calculated for this process stage. It is calculated for both graphite and metal streams.

Interim storage will break up the continuous processing envelope. There will only be one processing stage either before or after interim storage (retrieval or transportation). Decay will only be calculated for processing options on one side of the interim storage.

Interim Storage Variations

There are no process variables for this stage and the various criteria depend on the preceding processing stages. Storage always occurs for 100 years on site. Differences depend on whether the waste is encapsulated or not.

Heat Treatment – Ex Situ

Graphite is heated after removal from the reactor in a process similar to the Studsvik THOR process [Ref 28].

The amount of material removed is from CW1107 - Graphite Treatment Methods. D Vulpius, W von Lensa:

	Gaseous	Solid
H3	40.0%	60.0%
C14	10.0%	90.0%
Co60	0.0%	100.0%
Cl36	0.0%	100.0%
Volume / Mass	1.0%	99.0%

Aerial Discharge is assumed to be 100 times greater than for quiescent storage.

The gas released is also included in calculations of the radiological impact on man and the environment.

The resource usage consists of a power requirement for a furnace, assumed at 40kW, and assumed to be in use for 16 hrs/day, 300 days/yr.

Released gases are not diluted and there are no non-radiological discharges included.

An additional facility is required for this process and the impact this has on the relevant criteria is included.

The only noise, land and transport considerations are from the additional facility construction.

There are 15 people required, with an average dose used for radiological worker safety and a nuclear manufacturing injury rate used to calculate the non-radiological worker safety.

There are three barriers used to calculate the security score: site boundary, site security and building.

The cost is taken from Costain [Ref 19]. It includes capital and operating costs. It is calculated from scaling using the 0.6 power law on the weight of graphite. Decommissioning costs are 30% of the capital costs and wages of workers set at £50k/year.

The above reference quotes a TRL score of 4 and indicates a requirement for a demonstration plant costing £42.44m.

Although the overall technology is new, each part has been used before. Thus a low risk is assumed. A 25% chance of adding 20% to total time/cost estimate and 10% chance of doubling time/cost estimate are used for calculating the risk measures.

Heat Treatment Variations – In Situ Heat Treatment

In this process operation the graphite is heat treated before it is retrieved. It is not expected that this will affect the ability to retrieve graphite blocks.

For this instance, the amount of activity and material released is assumed to be half that released for the ex situ heat treatment.

In situ heat treatment is assumed to occur for 90 days prior to reactor shutdown. The cost is calculated as the loss of profit over this period.

Segregation

Segregation of the graphite from the metal is required for certain stages such as gasification and heat treatment. Separation is assumed to be 100% efficient, with all graphite and metal separated.

The aerial discharge is assumed to be 100 times greater than for quiescent storage.

A resource usage is calculated from the power requirements of a dense media separation plant [Ref 29]. It is assumed that the process is run for eight hours per day, 260 days per year. The 0.6 power law used to find the resource usage on the ratio of throughputs.

A new facility will be required for this process, but will be located on site. The noise of the separation is therefore assumed not to impact outside of the site boundary, and there will be no additional land usage outside of the existing site. There will also be no additional transport considerations.

The same people as for retrieval or size reduction will be used for this process operation, thus there is no further impact on the stability of employment. These people will have a further average dose, contributing to the radiological worker safety, and contributing to conventional worker safety using nuclear manufacturing injury rates.

Security barriers are the same as for similar process operations.

The cost of a separation plant [Ref 30] is used to find the cost for a plant required for this process, scaled using the 0.6 power law on the throughputs. A decommissioning cost at 30% of the capital cost is included, but wage costs are neglected, with the same people as for previous operation stages employed to avoid double counting.

A TRL of 7 has been assigned to this process operation. The cost to develop is included as 10% of the process costs.

The densities of the graphite and metal to be separated are similar and separation could be poor, thus it is assumed that there is a 50% chance of adding 20% to the process cost and duration.

The process is included in the continuous processing phase so there is no additional contribution to the burden on future generations.

Gasification

A total of 97% of the graphite is gasified, with the remaining 3% as an ash stream [Ref 29].

There is no aerial discharge with this process, as the gas stream is collected and sent to a new process.

An additional building will be used for this process. The resource usage, transport, conventional worker safety measure, cost and stability on employment measure are increased as a result. There is no increase in noise or land use from the new facility as it is contained within the site boundary.

There will be 15 people required for this process as for retrieval. These are assumed to be different people to those undertaking retrieval. These contribute to radiological worker safety with the dose at the average value, and conventional worker safety using nuclear construction injury rates.

The cost for the process is taken from Costain [Ref 19]. The cost of the process is scaled on throughput using the 0.6 power law. A cost for decommissioning at 30% of the capital and wages at £50k per employee per year are included and a cost for the additional facilities required.

It is possible that there could be spin-off for this process from the gasification of other waste; however it is pessimistically set to zero.

A demonstration plant would be required for this process. A TRL of 4 is used and a cost to develop of £42 million [Ref 19].

The overall technology is new but each part of this process has been used before, so the risk associated with this process is low. There is a 10% chance of adding 20% and a 1% chance of doubling the total cost and time given.

The stability of employment for this process is calculated to include the jobs created and lost from construction of the facility and its demolition when the process has been completed. These jobs are created and lost over one year. It also includes the process worker jobs created. The loss of these jobs when the process is completed is included with other processes in the continuous processing envelope, at repository filling.

The gasification process occurs simultaneously with other process options and the burden on future generation contribution is neglected and included at the start of the process.

Transportation

Transport of the product boxes will be by lorry. This includes transport of the empty boxes to and the full boxes from the site. Transport is considered to be between the reactor and disposal site.

Transport of grout to the site is also included and all journey lengths are assumed to be to and from the site.

Aerial discharge is assumed to be 1000 times smaller than quiescent discharge as a result of the addition of encapsulant. A nominal figure of 0.1m^3 per box is assumed to be lost for a packaged air exchange. This is used for calculations of the radiological impact.

Resource usage is calculated from the fuel used. This is calculated for delivery of boxes and, if applicable, grout to the site and for delivery of waste packages to the repository. Separate fuel consumption figures are used for loaded and unloaded lorries. It is assumed that each journey is over 100 miles.

The release of CO_2 is neglected to avoid double counting, as it is included in calculations of the resource usage. There is no non-radiological discharge.

A noise value is included for a truck and the number of journeys required calculated.

It is assumed that there are three drivers required. The dose received is calculated from trips containing active material, using a typical dose per driver of 0.37mSv/yr [Ref 31].

The conventional worker safety uses normal injuries to drivers. It is not expected to be safer as a result of the nuclear considerations.

The cost for transportation is calculated from the total fuel used [Ref 32] and from wages for drivers at £40k per year.

Transportation is an existing process, thus no spin off is expected and a TRL score of 9 is used. A figure of £250k is assumed to be required for various safety cases and tie-downs to enable the process.

There is expected to be no delay or additional cost due to failure of this stage.

The three jobs created are used to calculate the stability of employment, with the loss when the process is complete assessed with the loss of all other jobs when continuous processes are complete.

Transportation - Variation

There are no variations of transportation.

Repository Filling – Dedicated Deep Geological Repository.

A repository is assumed to be available as soon as the waste is generated. The repository filling is the period from which waste is first received to the time where the repository is backfilled. The period lasts for 100 years. Not all of this period will be spent receiving waste from the particular site considered here, other sites will also contribute, however it is assumed that the material from this site will be placed immediately as it is processed and over the 7.5 years.

Construction of the repository is included in this stage. This includes construction of underground facilities and surface buildings. Transport of required materials for construction is also included.

The total volume of all waste in the repository is assumed at 200,000 m^3.

Aerial discharges are assumed to be 1,000,000 times smaller than for quiescent discharge after emplacement in the repository.

Resource usage includes the energy usage in the repository. This is calculated from the cost given for energy usage [Ref 33] and the cost for energy [Ref 12].

A list of surface buildings and cost for each is taken from Nirex [Ref 33]. This is converted to a building area using a cost per square foot [Ref 34]. A resource usage for the concrete and metal required is calculated from an assumed thickness for floor and building height, using the calculated building area. The thickness of the concrete panel walls and roof is 0.175m [Ref 35], the height of the warehouse is assumed at 10m and the floor a thickness of 0.2m.

Below ground construction is calculated from an assumed thickness of concrete on the walls and floor of the various drifts, shafts and vaults [Ref 33]. In total 14 vaults of dimension 16m x 16m x 300m (height x width x length) with 0.3m thick concrete floor and 0.1m thick concrete walls and ceiling are used. A 4km long, 5.5m diameter drift is used, with a 0.5m thick concrete on the central 3m of the base, with the remaining walls having a concrete thickness of 0.1m. The two 650m deep access shafts are assumed to have a 0.1m thick concrete layer all around. One tunnel is 8m diameter, the other 5m [Ref 33].

It is assumed that the remaining volume of the repository is due to other tunnels and ventilation, split equally in volume between the two. The tunnels are assumed to be 5m in diameter with a concrete thickness of 0.1m all around.

Backfill of the vaults will use NIREX reference Vault Backfill (NRVB) [Ref 33]. A resource usage for this is included. It is assumed only vaults are backfilled with NRVB, and remaining drifts and shafts with excavated rock spoil. Dimensions of vaults are as above.

Transport fuel use is included as part of the resource usage. The mass of concrete and metal required for below and above ground facilities and the mass of backfill is used to calculate the number of journeys required. Separate fuel economies are used for loaded and unloaded lorry journeys, with each journey assumed to be over 100 miles.

The resource usage contribution from this waste is calculated using the 0.6 power law on the volume contribution of the waste in the repository.

There is no non-radiological discharge included in this stage. All CO_2 discharges from construction and transport are neglected to avoid double counting, after inclusion in resource usage.

A noise measure is included to cover that resulting as a consequence of construction.
The land use of the repository is calculated from the 30 hectare footprint of the repository [Ref 33] over the 100 year lifetime.
Transport considerations include transportation of construction materials for below and above ground facilities and backfill. Transportation of waste to the repository is assessed separately as part of the ‘Transport’ stage.

There will be 140 construction employees required, with 30 underground. There will be 130 disposal employees required, with 20 underground [Ref 33]. It is assumed that construction workers will receive no dose, underground disposal employees 0.2mSv/yr and above ground disposal workers 0.1mSv/yr. This is used to calculate the radiological worker safety.

Conventional worker safety is calculated using nuclear construction values for construction workers and nuclear manufacturing values for disposal employees. Construction is assumed to take 10 years, and disposal lasting for the full 100 years.

The security score is calculated using four barriers - the site boundary, security, building and box bulk.

The cost of the repository is scaled from the cost of a non-dedicated deep geological repository using the volumes of waste to be disposed and the 0.6 power law.

There is no spin off expected from this stage. Surplus excavated rock is assumed to be used for landscaping of the site.

A TRL of 5 is given to this stage. The cost of development is calculated from an assumed amount of R&D required. A total of 700 employees at £50k per employee per year are assumed to be required for 10 years. The total cost is scaled using the volume of waste contributed from this disposal and the 0.6 power law.

A 25% chance of over run is given to this process, from which the cost and delay associated with this risk is calculated.

The stability of employment measures for construction and disposal workers are calculated separately. Construction workers are assumed over one year. An increase in disposal workers will occur over a longer period of five years. Workers on site during complete process stages are not the same as those in the repository. Repository filling occurs at the end of the continuous processing operations (retrieval, encapsulation etc). The loss of jobs due to the completion of this is assessed here.

Repository filling lasts for 100 years, which gives the burden on future generations.

Decay is calculated for the 100 year repository filling period.

Repository Variation – Near Surface

Rather than a deep geological repository, waste is placed in a near surface repository.

Aerial discharge is the same as for a deep geological repository during filling.

The resource usage for a near surface repository is calculated from a deep geological repository, assuming various comparisons. It is assumed that the same above ground facilities will be required, but that there will be no underground facilities required. Backfill is assumed at 50% of the amount used by a deep repository.
The transport values are recalculated for the new volume of material present. The new transport value is used for the resource usage calculation and in calculating the number of trips required.

The same noise and land use measures are given for a near surface repository as for a deep repository, as are the values used to calculate the scoring and hazard potential.

There is not a lot of difference between costs of disposing of all low-level wastes in a deep repository when costed on a marginal basis with the average total costs for disposal in a near surface repository [Ref 36].

The value for TRL and cost to develop calculation are the same as for a deep repository, as is the risk associated with this process. The stability on employment is the same as for the deep repository, and the burden on future generations is 100 years as for the deep geological repository.

Repository Variation – Intermediate Depth

An intermediate depth geological repository is used.

Aerial discharge is the same as for a deep geological repository.

As for a near surface geological repository, the resource usage is recalculated using the various factors. The same surface buildings are required. 50% of the below ground facilities are assumed to be required and 50% of the backfill required as for a deep geological repository.

Transport resource usage and journeys are recalculated with the new figures.

All other contributions are calculated in the same way as above. The same considerations are given as for a deep repository for hazard potential, security, noise and land use, cost, concept maturity, risk, stability of employment and burden on future generations.

Repository Variation - Co located

Whether a repository contains graphite waste only or is co-located with other types of waste, the repository design will be the same and the same contributions for each criterion are used. However, the type of waste in the repository can affect discharges in a longer time scale and have an impact on the repository stage after it is closed.

Repository Closure

After closure of the repository, with all vaults, shafts and drifts back filled, the repository is monitored for a further 100 years. The various discharges are assessed for 500,000 years post closure.

Both aerial and liquid discharges occur from the repository. Decay, aerial and liquid discharges are calculated using decay, aerial and liquid time constants and the time to peak aerial and liquid discharge.

Initially only decay occurs, followed by aerial discharge and finally liquid discharge.

The time to peak discharge and discharge constants depend on the depth of the repository, other wastes present and the processes stages involved [Ref 37].

Both aerial and liquid discharges are used to calculate the radiological impact on man and the environment.

It is assumed that five people will be required for monitoring and security of the repository post closure. It is not expected that there will be any dose received with the waste buried deep underground. Nuclear manufacturing worker safety is used to calculate a conventional worker safety measure.

A security score of zero has been set with it not being credible that waste could be accessed.

The cost of this process is due only to the workers, at £40k per employee per year.

Uncertainties with the process are all associated with the repository filling stage, thus a TRL of 9 has been given to this process. There is no cost to develop and the risk of the process, for both cost and delay, is 0.

The five workers in this process are assumed to be from the disposal workers. Stability of employment is calculated from the decrease in construction employees used for repository construction over one year and the decrease in disposal workers over ten years. The loss of jobs when monitoring is complete is included.

The process is modelled for 500,000 years post closure, but the burden on future generations is from the 100 year monitoring period.

Repository Variation – Near Surface, Interim Depth, Dedicated & Co-located

All repositories will have the same repository monitoring period regardless of the depth and waste present. The same number of workers will be required for all types of repository, and all the measures are calculated as described above, with the only difference being the discharges.

The discharges depend on the waste present and depth. These are calculated from Paksy *et al*. [Ref 37].

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