EUROPEAN COMMISSION

Community Research

SEVENTH FRAMEWORK PROGRAMME

# CARBOWASTE

*Treatment and Disposal of Irradiated Graphite and Other Carbonaceous Waste*

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## Deliverable (D-1.4.3)

## - Identify High Level Objectives (End Points) - for all Key Stages -


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# Identify High Level Objectives (End Points) for all Key Stages

**Executive summary**

The report identifies objectives, criteria and end-points for the assessment of options for the management of irradiated graphite (i-graphite).

**Three objectives are defined:**

1. Safety and Environmental
2. Economic
3. Social

**Seven criteria are defined in support of these three objectives:**

1. Environment and Public Safety
2. Worker Safety
3. Security
4. Economic Costs and Benefits
5. Technology Predictability
6. Stability of Employment
7. Burden on Future Generations

**Four end points are defined:**

1. Graphite in-situ
2. Graphite ex-situ
3. Ex-situ treated graphite
4. Graphite in final destination

**The principal conclusions of this report are:**

- Objectives and criteria have been identified which are consistent with the requirements of the CARBOWASTE project scope, the MCDA process, relevant EU Directives and IAEA Principles; and
- End points for the various stages in i-graphite retrieval, treatment and disposal have been defined.

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# Glossary

Terminology

The table below provides a definition of key words and phrases for the manner in which they are used in this report.

| Terminology | Description and application in this report |
|---|---|
| Conditioning | Processing to achieve passive safety for interim storage and/or to prepare it for eventual disposal. |
| Constraint | Condition which must be met for an option to be evaluated further. |
| Disposal | The emplacement of waste in a suitable facility without intent to retrieve it at a later date. |
| End Point | Distinct stages in the processing of i-graphite wastes. |
| Ex-situ | Graphite and components external to their original location. |
| Criteria | Criteria which support the project objectives and which allow options to be compared. |
| i-graphite | Irradiated graphite |
| In-situ | Graphite and components in their original location. |
| Sub-criteria | Criteria which enable ranking of options. |
| Options | i-graphite waste processing alternatives. |
| Ranking | The ordering of options according to preference, from least to most preferred. |
| Recycle | Processing of waste materials to form new products. |
| Retrieval | The process of extraction of i-graphite from reactor cores or waste storage facilities. |
| Re-use | Use of waste materials in their original form. |
| Segregation | Separation of i-graphite wastes according to characteristics. |
| Treatment | Any operation that changes the chemical or physical characteristics of i-graphite. |

Abbreviations

| | |
|---|---|
| ENSREG | European Group on Nuclear Safety and Waste Management |
| EU | European Union |
| IAEA | International Atomic Energy Agency |
| ILW | Intermediate Level Waste |
| LLW | Low Level Waste |
| MCDA | Multi-Criteria Decision Analysis |
| NNL | The National Nuclear Laboratory |
| UK | United Kingdom |
| WAC | Waste Acceptance Criteria |
| WP | Work Package |

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# 1 Introduction

## 1.1 Background

The stated[1] overall CARBOWASTE project aim is:

> *"The development of best practices in the retrieval, treatment and disposal of irradiated graphite (i-graphite) including other carbonaceous waste like structural material made of graphite or non-graphitised carbon bricks and fuel coatings (pyrocarbon, silicon carbide)."*

The achievement of this overall aim is supported by a Multiple Criteria Decision Analysis (MCDA) process.

Development of the MCDA process is delivered through a series of tasks of which this present study is one, as shown in Figure 1 below.

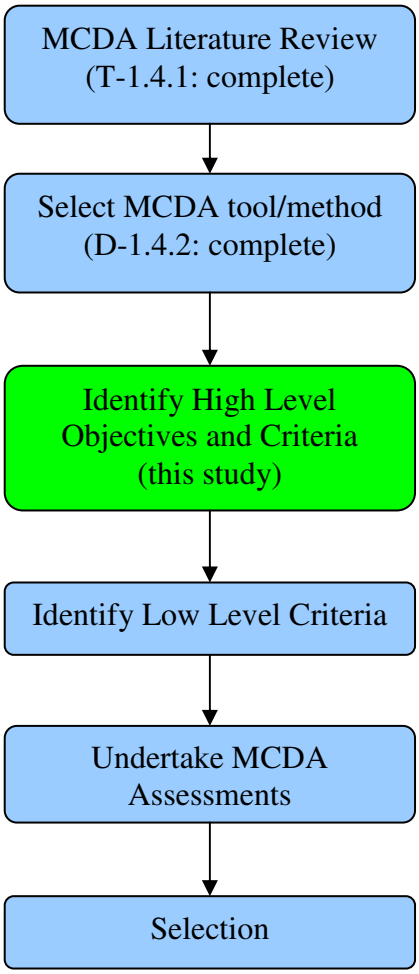


Figure 1: Tasks underpinning development and implementation of the CARBOWASTE MCDA Process

## 1.2 Purpose

This report identifies objectives and criteria for the ranking of strategy options for treating i-graphite using MCDA. It also identifies end points for all key stages of i-graphite retrieval, segregation, treatment and disposal.

This report:

- Takes full account of the requirements for MCDA in the CARBOWASTE work scope[1];
- Is consistent with the development of the CARBOWASTE route map[2];
- Builds on previous work[3,4] in the MCDA area under the CARBOWASTE project;
- Is consistent with IAEA principles[5], EU Guidelines[6] and Directives[7]
- Takes account of feedback[8] raised at the WP2 Workshop in Gateshead, UK on 14-16 July 2009;
- Contributes to the effective integration of CARBOWASTE work packages; and
- Contributes toward establishing an MCDA compartment of the CARBOWASTE toolbox.

# 2 Objectives and Criteria

## 2.1 Hierarchy

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'. 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 criteria and sub-criteria as shown in Figure 2 below.

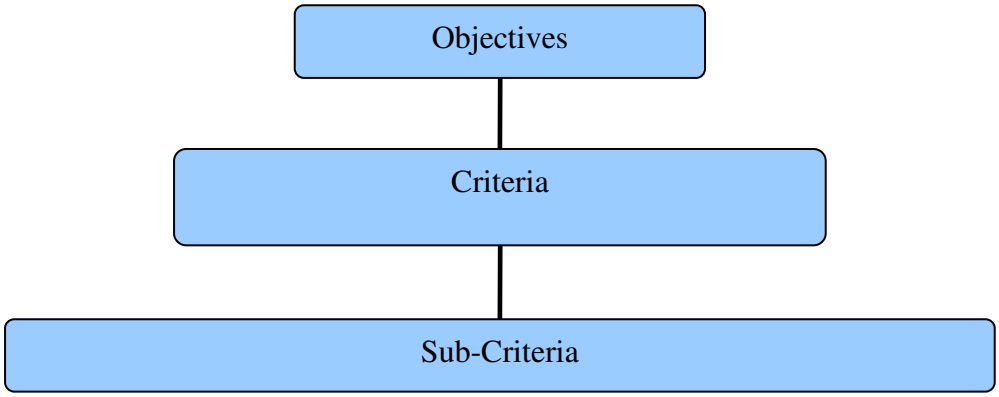


Figure 2: Hierarchy of Objectives and Criteria

The three objectives are 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 which underpin it. These sub-criteria are the subject of the next phase of work.

CARBOWASTE will provide data that will enable evaluation of options. Member states will input country and/or region specific factors, including socio-political.

## 2.2 Application

Figure 3 summarises the CARBOWASTE option evaluation process for i-graphite management. Following option identification, the option screening phase eliminates some options prior to detailed assessment. The application of the structure of objectives, criteria and sub-criteria within the MCDA process occurs within the assessment phase. On completion of the option assessment phase, the preferred option is selected by member states, taking into account any external factors e.g. political, which are outside the CARBOWASTE project scope.

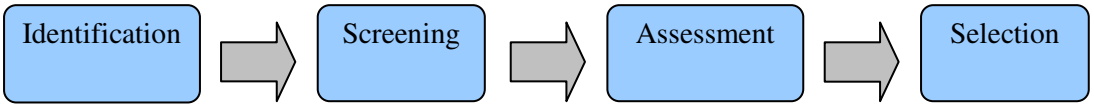


Figure 3: Option evaluation

### 2.2.1 Option Identification

A process of option identification is necessary at the outset in order to generate a set of options for the disposition of graphite. Illustrative options are discussed in this report.

### 2.2.2 Option Screening

Options are then screened using a set of constraints (see Figure 4 below). These constraints are expressed as conditions which must be passed for the option to proceed further in the analysis. 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.

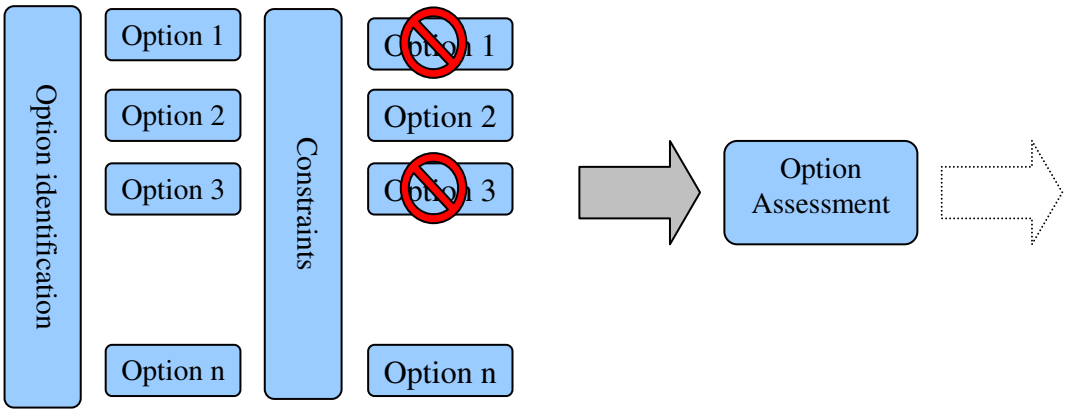


Figure 4: Option Screening

### 2.2.3 Option Assessment

The MCDA process of option assessment utilises a ranking mechanism to derive ordering of options, with the highest scoring option being the most preferred. The details of scoring 'scales' will be reported in the next phase of work as these will be defined for each of the sub-criteria.

At each level, weightings to scores can be applied which reflect the relative importance ascribed by decision-makers to different objectives, criteria and sub-criteria.

This approach can be applied at two levels within CARBOWASTE. It is expected to be applied for strategy selection, and can also be applied at a more detailed level for technology selection for each of the key stages in the route map.

In order to facilitate such studies, it is necessary to have clearly defined end points for each of the stages (retrieval, treatment, recycle and disposal) in the route map. Definition of stage end-points within the route map is discussed within this report.

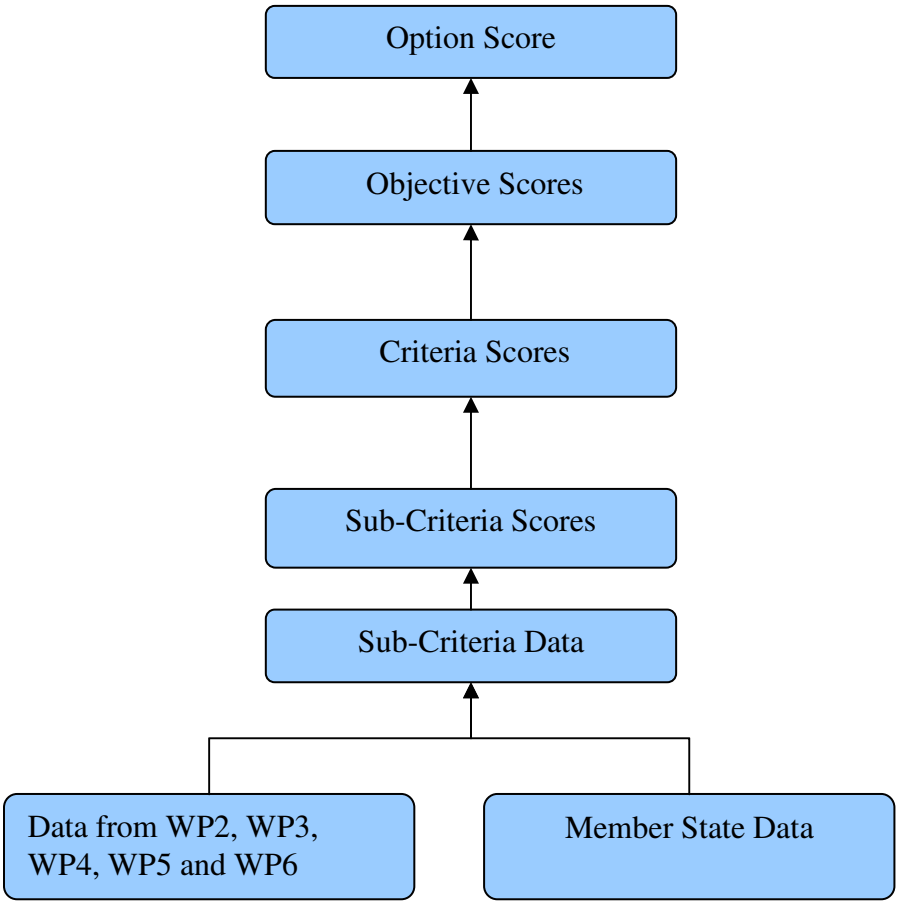


Figure 5: Option Assessment

# 3 Processing Stages and End Points

There are distinct stages in the processing of i-graphite. Definition of end points between the stages can assist with the definition of options for assessment within the MCDA. The three processing stages are:

- Retrieval and Segregation
- Treatment
- Disposal

It is also essential to clearly define these stages if evaluation of technology options is to be performed using MCDA since a meaningful comparison can only be done by considering the same start and end points for each processing stage. Processing stages are illustrated in detail in Appendix 2, and in outline in Figure 6.

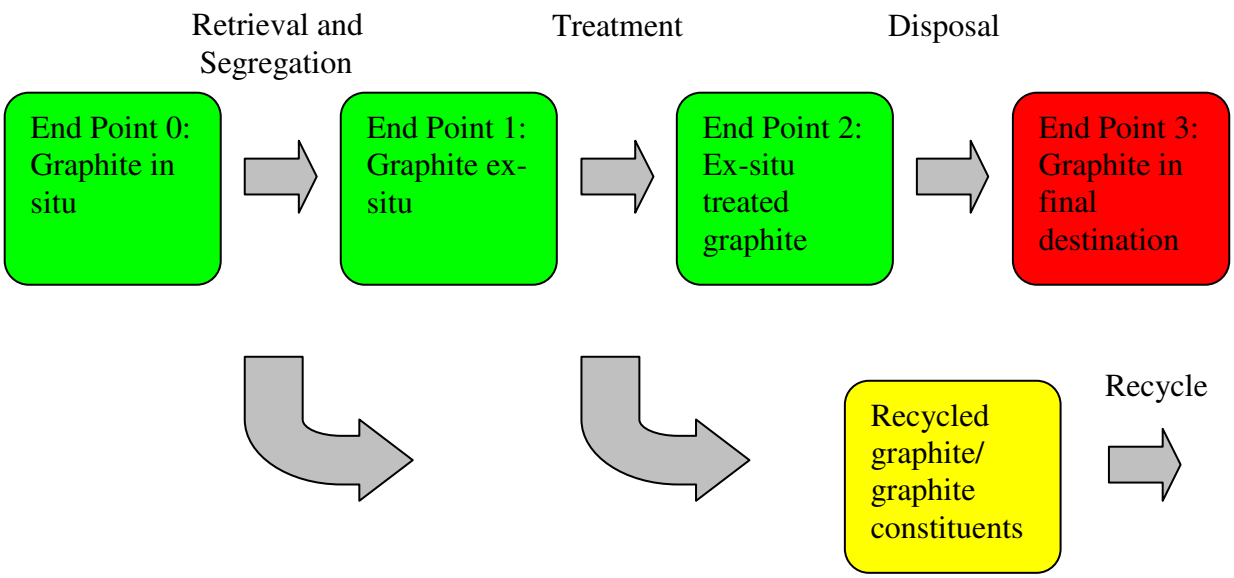


Figure 6: End Points

## 3.1 Retrieval and Segregation: End Point 0 to 1

The processing stages commence with the i-graphite in the reactor core, or in storage facilities. This is *END POINT 0: Graphite in-situ*. After a delay period of 0, 25, 50 or 75 years (these periods have been selected in the CARBOWASTE project to reflect the most likely retrieval scenarios), the graphite may be subjected to some form of in-situ treatment. It is noted that treatment processes at this, and subsequent processing stages, produce secondary wastes which will lead to additional waste, unless it can be recycled.

Retrieval and segregation of the graphite then commences; retrievals may be manual (if there has been sufficient radioactive decay to permit access), or may use remote handling devices, or some combination of the two. The graphite may be retrieved intact or in fragments.

In some cases the graphite is immediately transported to the next processing stage, but it is possible that some member states would elect for some form of interim storage at this stage.

Reactor cores contain a wide range of non-graphite components such as thermocouples, securing wires and metallic connecting pins. These may need to be segregated from the graphite either at the point of retrieval or subsequently during the retrieval process.

Ex-situ graphite, potentially segregated from non-graphite components, and following an optional interim storage period forms *END POINT 1: Graphite Ex-situ*

## 3.2 Treatment: End Point 1 to 2

The treatment phase commences with the graphite ex-situ, potentially following a period in an interim store. The graphite, if subject to ex-situ treatment, is then transferred to the treatment facility. This may be at a location remote from the original reactor/graphite waste store site. As with in-situ treatment there are a range of treatment techniques which may be deployed. The range of potential treatment technologies is likely to be much wider than those deployed in-situ.

Following treatment, as for the initial retrieval stage, there may be a period of interim storage prior to the next processing stage.

Ex-situ graphite, following treatment and, potentially, an interim storage period forms *END POINT 2: Ex-situ treated Graphite*.

## 3.3 Disposal: End Point 2 to 3

The third, and final, stage encompasses the conditioning and disposal of the graphite. Conditioning includes processing the wasteform into a product that meets the waste acceptance criteria (WAC) for the receiving facility.

The final end point for the graphite is *End Point 3: Graphite in final destination.*

## 3.4 Recycle and Re-use

The retrieval, treatment and disposal stages each manage graphite, or graphite constituents, which could potentially be recycled or re-used. This includes:

- Graphite bricks and tiles
- Graphite constituents e.g. $^{14}C$
- Materials for potential re-use/recycle

## 3.5 Summary

In summary, the end points identified are:

End Point 0 Graphite in situ; this is the start point for Work Package 2 (Retrievals and Segregation) and possibly a starting stream for Work Package 5 (Recycle).

End Point 1 Graphite ex situ; this is the end point for Work Package 2 (Retrievals and Segregation), the start point for Work Package 4 (Treatment). This may also be a starting stream for Work Package 5 (Recycle).

End Point 2 Ex-situ treated graphite; this is the end point for Work Package 4 (Treatment) and the start point for Work Package 6 (Disposal).

End Point 3 Graphite in final destination; this is the end point for Work Package 6 (Disposal).

## 3.6 Example Strategic Options

The four strategic options in Table 1 are examined and end points defined. This will act as an illustration of the various end-point definitions. These illustrative options were used to facilitate discussion of retrieval and segregation strategies at the WP2 workshop[8] in July 2009.

| Option | Retrieval Medium | Delay | In-Situ Treatment | Disposal Conditioning | Disposal |
|---|---|---|---|---|---|
| 1 | Air | 75 Years | No treatment | Condition (grout) | Deep disposal |
| 2 | Water | <25 Years | In-situ leaching | Condition (grout) | Near surface disposal |
| 3 | Air | <25 Years | No treatment | Grout | Intermediate Depth Disposal |
| 4 | Air/Inert | 50 Years | Size reduction | Gasification | Capture and Disposal of $CO/CO_2$ |

Table 1: Illustrative Strategy Options for i-graphite Waste Management

End points for these four illustrative options are shown in Table 2 below.

| Option No. | End Point No. | | | |
|---|---|---|---|---|
| | 0 | 1 | 2 | 3 |
| 1 | Graphite in-situ in reactor | Graphite ex-situ in form of intact tiles/bricks, having been retrieved in air after delay period of 75 years | Graphite after decontamination and segregation into LLW and ILW | LLW and ILW Disposal Site WAC met, graphite conditioned to immobilise and disposed |
| 2 | Graphite in-situ in reactor | Graphite ex-situ in form of intact tiles/bricks, having been retrieved under water; short delay period | No change from End Point 1 | LLW Disposal Site WAC met, graphite conditioned to immobilise, graphite and secondary wastes co-disposed |
| 3 | Graphite in-situ in reactor | Graphite ex-situ in form of intact tiles/bricks, having been retrieved in air, after delay period of <25 years | No change from End Point 1 | ILW Disposal Site WAC met, graphite conditioned to immobilise and disposed |
| 4 | Graphite in-situ in reactor | Graphite ex-situ having been size reduced and retrieved in air or inert atmosphere, after delay period of <25 years | Graphite gasified and effluent subject to isotope separation process to capture and recover long-lived radioactive species | $CO/CO_2$ disposal site conditions met |

Table 2: Key End Points for Illustrative i-graphite Waste Management Options

Key differences between options at the four key stage End Points are evident from the above table. It is concluded that the End Points, as defined, adequately characterise the four diverse illustrative options.

# 4 Objectives and Criteria

Earlier work for CARBOWASTE[4] 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.

## 4.1 Criterion 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 2.

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.

## 4.2 Criterion 2: Worker Safety

Criterion 1 above 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.

## 4.3 Criterion 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.

## 4.4 Criterion 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 time scales can be very long for the complete project (from End Point 0: in-situ to End Point 3: disposed), an appropriate discount rate must be selected and applied.

### 4.5 Criterion 5: Technology Predictability

Technology selection will have impacts in several criteria. Emissions and effluents will influence Criterion 1, the nature of the technology (e.g. hands-on vs. remote) will affect Criterion 2, capital and operating costs will influence Criterion 4. 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.

### 4.6 Criterion 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.

### 4.7 Criterion 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 difficulties 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.

## 5 Audit of Criteria

It is important that the criteria are comprehensive, and allow a full assessment of the process options to take place. This section outlines a series of audit checks that were performed as part of the development of criteria. These checks have compared the criteria to relevant international legislation, principles and guidelines to ensure that the criteria reflect the full set of concerns for decision making without duplication. The audit was performed against the following sources:

- The IAEA nuclear energy basic principles[5]. These principles are intended to “provide a holistic approach to the use of nuclear energy”.
- The European Commission have established a High-Level European Group on Nuclear Safety and Waste Management (ENSREG). This group have produced guidelines[6] for the content and objectives of national programmes for the management and the safety of radioactive waste and spent fuel. These guidelines set out principles for spent fuel and radioactive waste management.
- EU environment impact assessment directive 85/337/EEC[7] requires an Environmental Impact Assessment for many projects, including those aimed at storage and disposal of nuclear waste.

Results are summarised in Table 3 below and presented in detail in Appendix 1.

| Criteria | CARBOWASTE Scope Document | IAEA Nuclear Energy Basic Principles | ENSREG Principles | Environmental Impact Assessment |
|---|---|---|---|---|
| Criterion 1: Environment and Public Safety | Safety<br>Environmental | Principle 3: Protection of people and the environment | Protection of human health<br>Protection of the environment<br>Protection beyond national borders<br>Safety of facilities | Direct and indirect effects on human beings, fauna and flora. |
| Criterion 2: Worker Safety | Safety | Principle 3: Protection of people and the environment | Protection of human health<br>Safety of facilities | Direct and indirect effects on human beings, fauna and flora. |
| Criterion 3: Security | Safety | Principle 4: Security<br><br>Principle 5: Non-Proliferation | Safety of facilities | Direct and indirect effects on human beings, fauna and flora. |
| Criterion 4: Economic | Economic | Principle 1: Benefits<br><br>Principle 6: Long term commitment | | |
| Criterion 5: Technology Predictability | Eco-engineering considerations | Principle 7: Resource efficiency | Control of radioactive waste generation | - the use of natural resources,<br>- the production of waste,<br>- pollution and nuisances, |
| Criterion 6: Stability of Employment | Socio-political | Principle 6: Long term commitment | | |
| Criterion 7: Burden on Future Generations | Sustainable | Principle 6: Long term commitment | Protection of future generations<br>Burdens on future generations | Long-term effects to be considered |

Table 3: Assessment of MCDA Criteria

In summary, no principles were found that required additions to the criteria although, in some cases, information was found that will be useful in establishing constraints, and in constructing the more detailed sub-criteria.

# 6 Conclusions

The report identifies objectives, criteria and end-points for the assessment of options for the management of irradiated graphite (i-graphite).

**Three objectives are defined:**

1. Safety and Environmental
2. Economic
3. Social

**Seven criteria are defined in support of these three objectives:**

1. Environment and Public Safety
2. Worker Safety
3. Security
4. Economic Costs and Benefits
5. Technology Predictability
6. Stability of Employment
7. Burden on Future Generations

**Four end points are defined:**

1. Graphite in-situ
2. Graphite ex-situ
3. Ex-situ treated graphite
4. Graphite in final destination

**The principal conclusions of this report are:**

- Objectives and criteria have been identified which are consistent with the requirements of the CARBOWASTE project scope, the MCDA process, relevant EU Directives and IAEA Principles; and
- End points for the various stages in i-graphite retrieval, treatment and disposal have been defined.

# 7 References

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7. DIRECTIVE 85/337/EEC (AS AMENDED BY DIRECTIVE 97/11/EC) INFORMAL CONSOLIDATION OF DIRECTIVE 85/337/EEC on the assessment of the effects of certain public and private projects on the environment as amended by Council Directive 97/11/EC, EU, March 1997.
8. Minutes of WP2 Workshop in Gateshead, UK on 14-16 July 2009
9. Our Common Future, Brundtland Commission Report to the United Nations, 20/3/1987.

# Appendix 1: Review of Criteria against Published Principles

This appendix considers:

1. The IAEA nuclear energy basic principles
2. ENSREG principles in spent fuel and radioactive waste management
3. EU environment impact assessment directive 85/337/EEC

and notes how each of the principles in these sources is reflected by the MCDA process, and particularly within the criteria.

## IAEA Nuclear Energy Basic Principles

PRINCIPLE 1 — BENEFITS
*The use of nuclear energy should provide benefits that outweigh the associated costs and risks.*

The benefits of nuclear power are the electricity produced with relatively low greenhouse gas emissions. Among the costs are the carbonaceous wastes formed from operating the reactors that produce the electricity. CARBOWASTE focuses only on the disposal of the i-graphite and so cannot fully assess the costs and benefits of the nuclear power cycle. Nevertheless, it is apparent that that this principle requires consideration of both costs and risks associated with the management of i-graphite. Costs include both economic costs as well as environmental and security related costs. These are reflected in the objectives. It is also apparent that the costs and risks must be considered over the whole life cycle of the processing and disposal of the i-graphite. This is part of the MCDA overview which requires an assessment from present state to final disposal.

PRINCIPLE 2 — TRANSPARENCY
*The use of nuclear energy should be based on open and transparent communication of all its facets.*

The decision making process being developed for CARBOWASTE is aimed at selecting the best treatment route for i-graphite. In defining an explicit process common to all participating member states, the transparency of the decision making is enhanced. Moreover, stakeholder engagement is integral to the MCDA decision making process.

PRINCIPLE 3 — PROTECTION OF PEOPLE AND THE ENVIRONMENT
*The use of nuclear energy should be such that people and the environment are protected in compliance with the IAEA safety standards and other internationally recognized standards.*

Safety and environmental issues are explicitly represented as objectives in the decision making process.

PRINCIPLE 4 — SECURITY
*The use of nuclear energy should take due account of the risk of the malicious use of nuclear and other radioactive material.*

Security is explicitly represented as an objective in the decision making process.

PRINCIPLE 5 — NON-PROLIFERATION
*The use of nuclear energy should take due account of the risk of the proliferation of nuclear weapons.*

CARBOWASTE does not address fuels and fissile materials directly. The prime issue for CARBOWASTE in addressing non-proliferation is the prevention of theft of materials for use in a weapons programme. This issue is considered as part of the Security Objective.

PRINCIPLE 6 — LONG TERM COMMITMENT
*The use of nuclear energy should be based on a long term commitment.*

The assessment of the options for disposal of i-graphite are required to take place over the whole lifecycle of the disposal option. There is also an explicit objective for the burden on future generations.

PRINCIPLE 7 — RESOURCE EFFICIENCY
*The use of nuclear energy should be efficient in using resources.*

The use of natural resources is considered as part of the environment objectives.

PRINCIPLE 8 — CONTINUAL IMPROVEMENT
*The use of nuclear energy should be such that it pursues advances in technology and engineering to continually improve safety, security, economics, proliferation resistance, and protection of the environment.*

Assessment of technology is performed as part of the economic prosperity objective. Safety, security (including proliferation resistance), economics and protection of the environment are considered as individual objectives.

Application of the decision making process should result in the best option being chosen. Consistency across member states will also allow the dissemination of best practice to other member states.

## ENSREG Principles in Spent Fuel and Radioactive Waste Management

| **Protection of human health** |
|---|

*Spent fuel and radioactive waste shall be managed in such a way as to secure an acceptable level of protection of human health.*

Safety of both the public and workers is explicitly represented as objectives in the decision making process.

**Protection of the environment**

*Spent fuel and radioactive waste shall be managed in such a way as to provide an acceptable level of protection of the environment.*

Environmental issues are explicitly represented as an objective in the decision making process.

*The fundamental principles in environment protection such as precaution principle, polluter-pays principle should by applied to the spent fuel and radioactive waste management.*

The polluter-pays principle underpins all European environmental legislation, and consideration of the precaution(ary) principle is a requirement of international law, and hence these are mandatory requirements for all options.

**Protection beyond national borders**

*Spent fuel and radioactive waste shall be managed in such a way as to assure that possible effects on human health and the environment beyond national borders will be taken into account.*

This principle is incorporated within the objectives for safety and the environment.

**Protection of future generations**

*Spent fuel and radioactive waste shall be managed in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today.*

There is an explicit objective for the burden on future generations. Consideration of direct impacts also takes place as part of the safety and environment objectives.

**Burdens on future generations**

*Spent fuel and radioactive waste shall be managed in such a way that no undue burdens will be imposed on future generations.*

There is an explicit objective for the burden on future generations.

**National legal framework**

*Spent fuel and radioactive waste shall be managed within an appropriate national legal framework including clear allocation of responsibilities and provision for independent regulatory functions.*

Conformance with national and international law is considered mandatory and so is an essential requirement which will remove illegal options prior to assessment against the objectives.

**Control of radioactive waste generation**

*Generation of radioactive waste shall be kept to the minimum practicable.*

Each option is assessed against its entire lifecycle, including the formation of secondary waste. Generation of waste will therefore be penalised within the environmental category (use of raw materials) and in economics (cost associated with packaging and disposal of secondary waste).

**Radioactive waste generation and management interdependencies**

*Interdependencies among all steps in spent fuel and radioactive waste generation and management shall be appropriately taken into account.*

Each option is assessed against its entire lifecycle, and the preferred option will be selected on this basis. This process ensures that all interdependencies are appropriately considered.

**Safety of facilities**

*The safety of facilities for spent fuel and radioactive waste management shall be appropriately assured during their lifetime.*

Safety of both the public and workers are explicitly represented as objectives.

**Information and involvement of the public**

*Appropriate means should be established to inform parties in the vicinity, the public and other interested parties, and the information media about the safety aspects (including health and environmental aspects) of facilities and activities and about regulatory processes on spent fuel and radioactive waste management;*

*Parties in the vicinity, the public and other interested parties, as appropriate, shall be consulted in an open and inclusive process in this context.*

Stakeholder engagement is established as an integral part of the CARBOWASTE MCDA process.

**The environmental impact assessment directive 85/337/EEC**

Requires that certain projects are assessed for their impact on the environment. Appendix 4 of the legislation specifies the scope of the assessment. Bold face has been added for emphasis within this paper and is not present in the original.

*1. Description of the project, including in particular:*
*- a description of the physical characteristics of the whole project and the* ***land-use requirements*** *during the construction and operational phases,*
*- a description of the main characteristics of the production processes, for instance,* ***nature and quantity of the materials used****,*
*- an estimate, by type and quantity, of expected* ***residues and emissions*** *(water, air and soil pollution, noise, vibration, light, heat, radiation, etc.) resulting from the operation of the proposed project.*

Each of these issues is addressed within Environment and Public Safety Objective.

*2. An outline of the main alternatives studied by the developer and an indication of the main reasons for this choice, taking into account the environmental effects.*

Options must be enumerated prior to assessment within the MCDA approach.

*3. A description of the aspects of the environment likely to be significantly affected by the proposed project, including, in particular, population, fauna, flora, soil, water, air, climatic factors, material assets, including the architectural and archaeological heritage, landscape and the inter-relationship between the above factors.*

These are considered as part of the Environment and Public Safety Objective.

*4. A description ( ... cover[ing] the direct effects and any indirect, secondary, cumulative, short, medium and long-term, permanent and temporary, positive and negative effects of the project.) of the likely significant effects of the proposed project on the environment resulting from:*
*- the existence of the project,*
*- the use of natural resources,*
*- the emission of pollutants, the creation of nuisances and the elimination of waste,*
*- and the description by the developer of the forecasting methods used to assess the effects on the environment.*

Use of natural resources and emissions are considered as part of the Environment and public Safety Objective. Some of the long-term effects are considered under the Burden on Future Generations Objective.

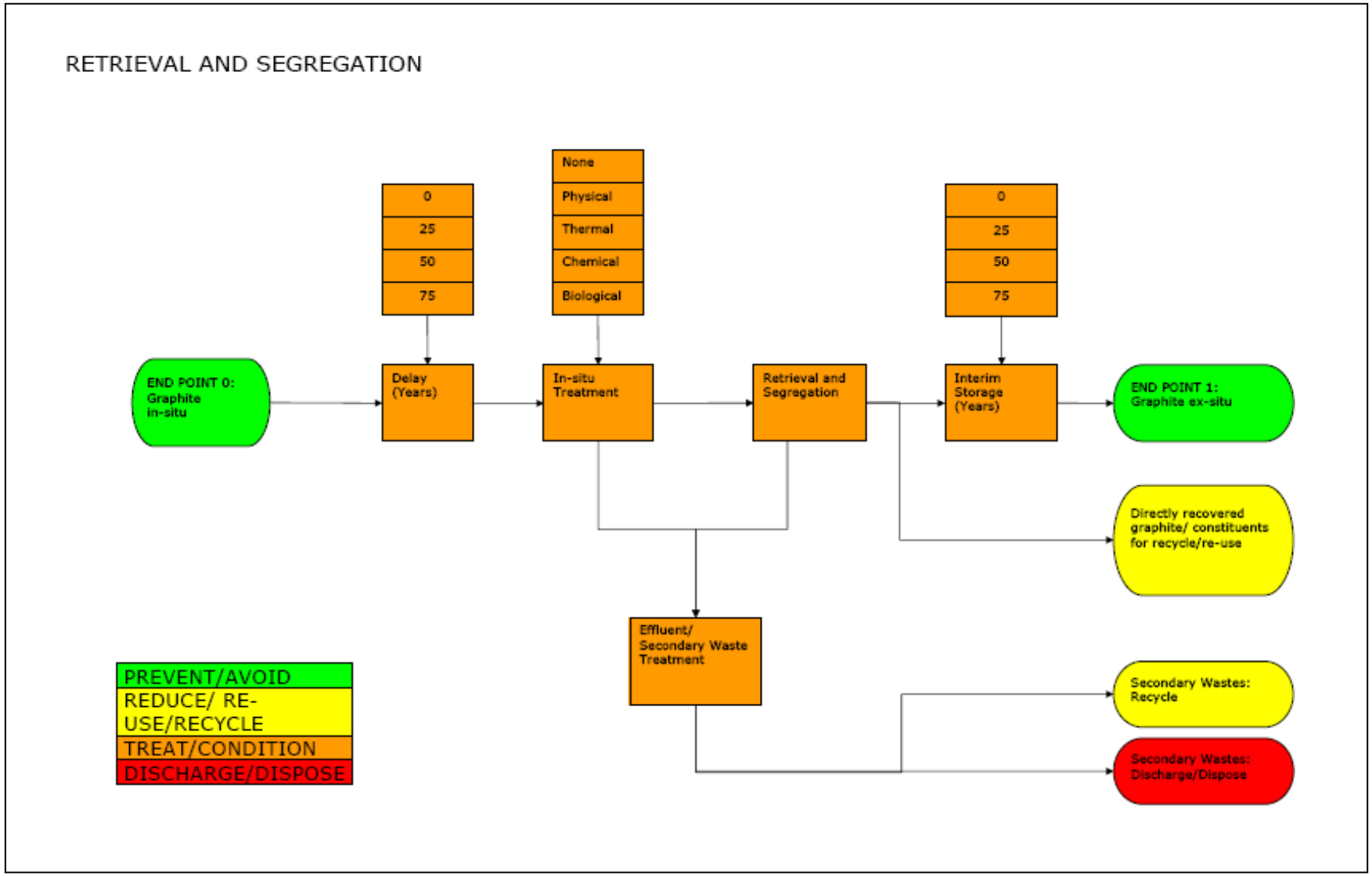
*5. A description of the measures envisaged to prevent, reduce and where possible offset any significant adverse effects on the environment.*

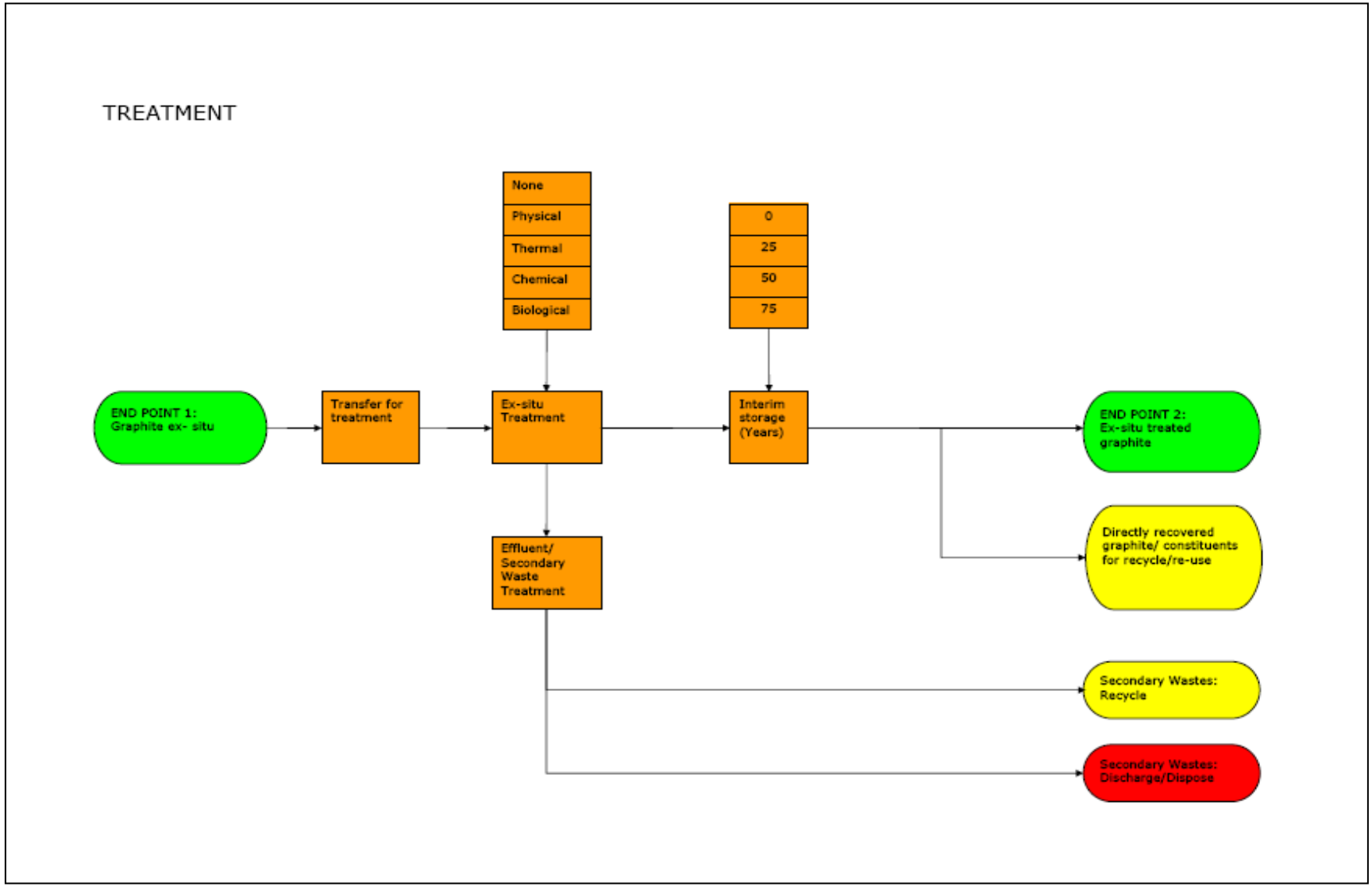
This forms part of the option description required before the option can be assessed.

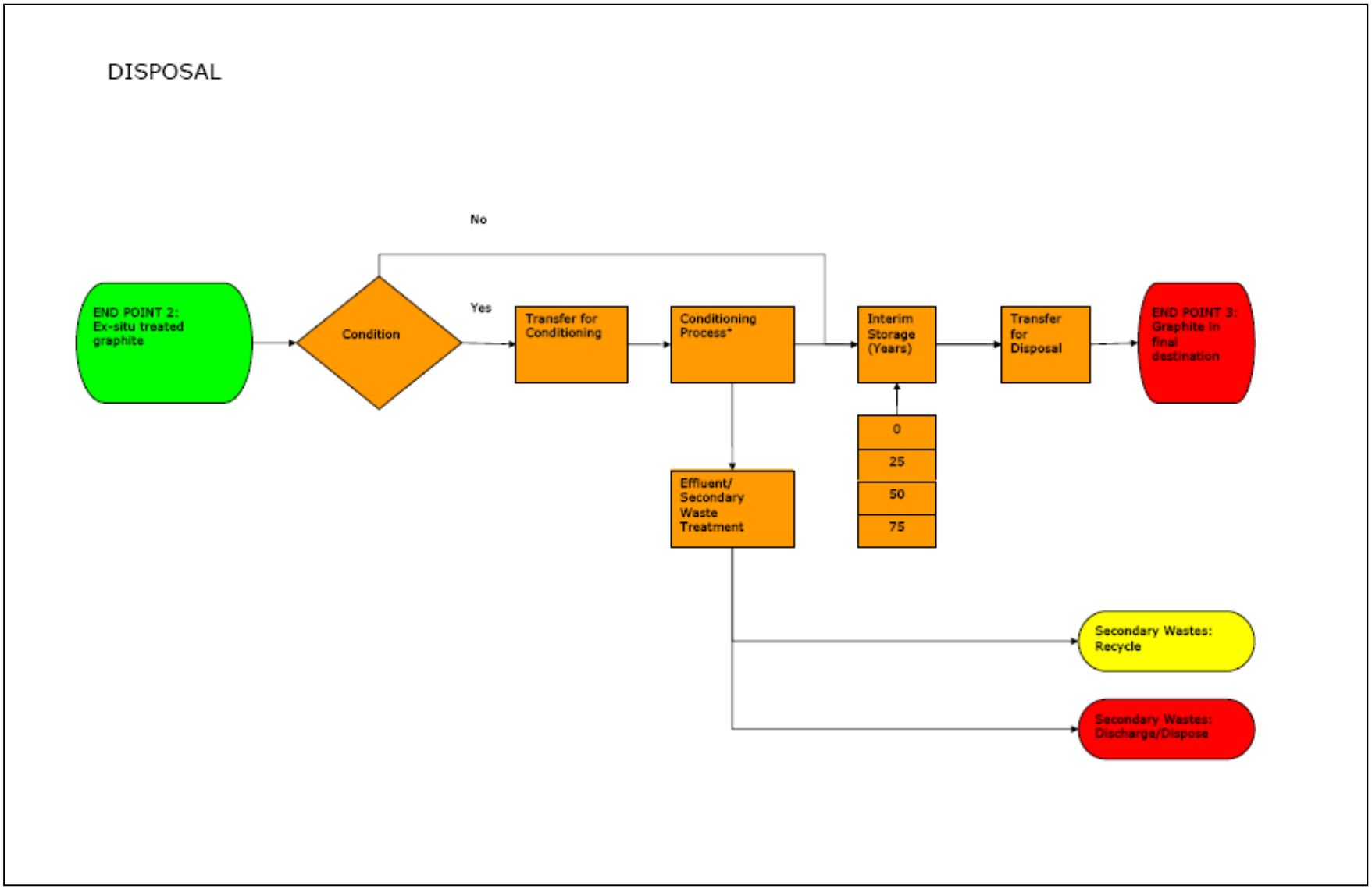
*6. A non-technical summary of the information provided under the above headings. An indication of any difficulties (technical deficiencies or lack of know-how) encountered by the developer in compiling the required information.*

It is expected that the scores for the various categories will act as a non-technical summary of key problems associated with an option. The MCDA approach encourages stakeholder participation in the decision making process, and non-technical explanations may be required to support this.

# Appendix 2: Process Flowcharts


RETRIEVAL AND SEGREGATION
0
25
50
75
None
Physical
Thermal
Chemical
Biological
0
25
50
75
END POINT 0: Graphite in-situ
Delay (Years)
In-situ Treatment
Retrieval and Segregation
Interim Storage (Years)
END POINT 1: Graphite ex-situ
Directly recovered graphite/ constituents for recycle/re-use
Effluent/ Secondary Waste Treatment
Secondary Wastes: Recycle
Secondary Wastes: Discharge/Dispose
PREVENT/AVOID
REDUCE/ RE-USE/RECYCLE
TREAT/CONDITION
DISCHARGE/DISPOSE


TREATMENT
None
Physical
Thermal
Chemical
Biological
0
25
50
75
END POINT 1: Graphite ex- situ
Transfer for treatment
Ex-situ Treatment
Interim storage (Years)
END POINT 2: Ex-situ treated graphite
Directly recovered graphite/ constituents for recycle/re-use
Effluent/ Secondary Waste Treatment
Secondary Wastes: Recycle
Secondary Wastes: Discharge/Dispose


DISPOSAL
No
END POINT 2: Ex-situ treated graphite
Condition
Yes
Transfer for Conditioning
Conditioning Process*
Interim Storage (Years)
Transfer for Disposal
END POINT 3: Graphite in final destination
0
25
50
75
Effluent/ Secondary Waste Treatment
Secondary Wastes: Recycle
Secondary Wastes: Discharge/Dispose