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SEVENTH FRAMEWORK PROGRAMME

CARBOWASTE

Treatment and Disposal of Irradiated Graphite and Other Carbonaceous Waste

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- Dissemination of High and Low Level Objectives - to Consortium -

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Document title
Dissemination of High and Low Level Objectives to Consortium

Executive summary

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

Four end points are defined:

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

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

15 Lower Level Objectives (Generic Sub-Criteria) are defined:

1. Radiological Impact - Man
2. Radiological Impact - Environment
3. Resource Usage
4. Non-Radiological Discharges
5. Local Intrusion
6. Hazard Potential
7. Worker Safety (Radiological)
8. Worker Safety (Non-Radiological)
9. Security - Misappropriation
10. Cost
11. Spin-off
12. Concept Predictability
13. Operational Predictability
14. Stability of Employment – Employment Factor
15. Burden on Future Generations – Burden Factor

Each of these is underpinned by a Performance Criterion (Measures).

Technology Sub-Criteria are also introduced; these extend the generic criteria and are to be used for technology, rather than strategy selection.

The principal conclusions of this report are:

- End points for the various stages in i-graphite retrieval, treatment and disposal have been defined;
- 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
- Sub-Criteria and Performance Measures have been identified which support these Objectives and Criteria

Revisions						
Rev.	Date	Short description	Author	Internal Review	Task Leader	WP Leader
00	dd/mm/yyyy	Issue	Name, Organisation	Name, Organisation *Signature*	Name, Organisation *Signature*	Name, Organisation *Signature*
01	29/03/2010	1st issue	Ross, D N NNL	Whitton, J NNL	Banford, A NNL	Banford, A NNL

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
EQS	Environmental Quality Standard
ERICA	Environmental Risk from Ionising Contaminants
EU	European Union
GWh	Giga-Watt Hours
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
i-graphite	Irradiated Graphite
ILW	Intermediate Level Waste
LLW	Low Level Waste
MCDA	Multi-Criteria Decision Analysis
mSv	Millisievert
NNL	The National Nuclear Laboratory
TBq	Terabecquerel
te	Tonne
TRL	Technology Readiness Level
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)."*

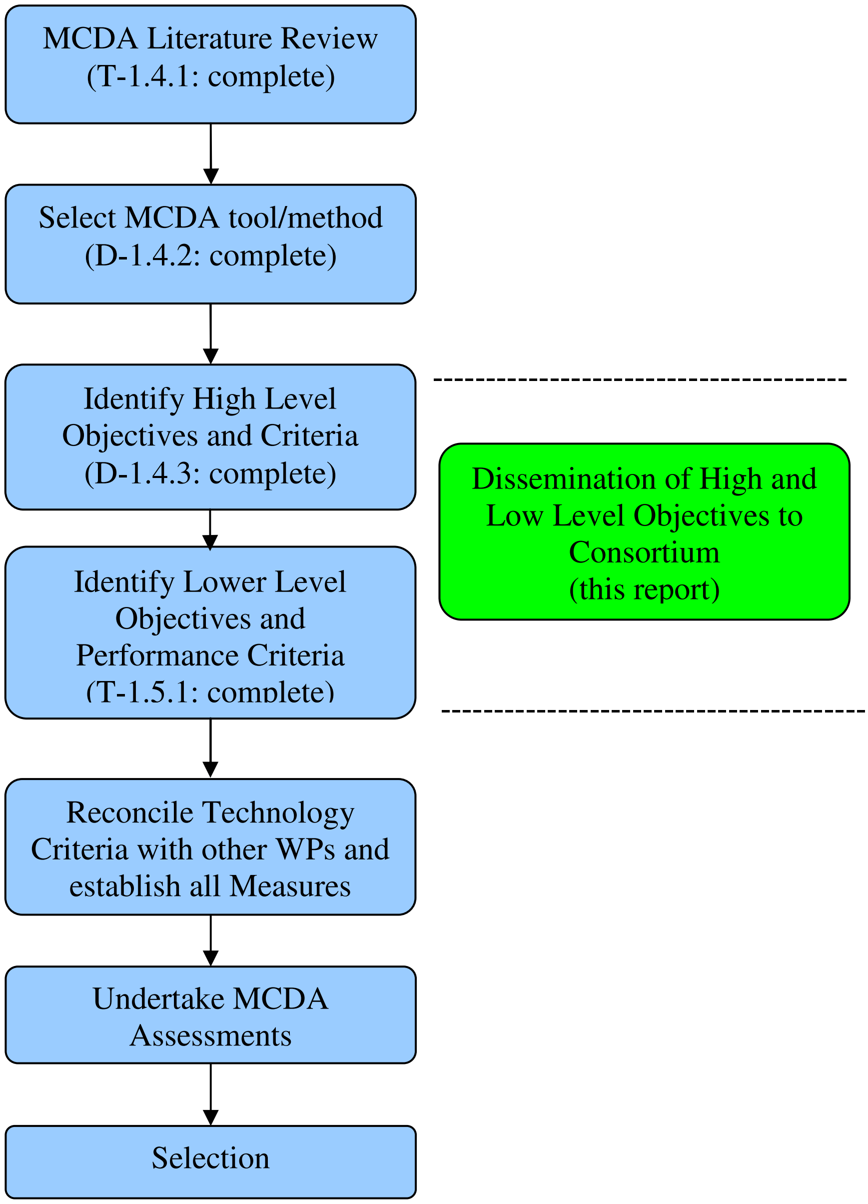

Figure 1: Tasks underpinning development and implementation of the CARBOWASTE MCDA Process

The achievement of this overall aim is supported by a Multiple Criteria Decision Analysis (MCDA) process. Development of the MCDA process for CARBOWASTE strategy selection is delivered through a series of tasks, as shown in

Figure 1 above.

1.2 Terminology

For consistency with previously reported work under CARBOWASTE[2, 3], lower-level objectives are referred to in this report as 'sub-criteria'; performance criteria are referred to as 'performance measures'.

1.3 Purpose

This report defines end points for all key stages of i-graphite retrieval, segregation, treatment and disposal. It also identifies objectives and criteria for the ranking of strategy options for treating i-graphite using MCDA. Generic sub-criteria and performance measures to facilitate the evaluation of strategy options for treating irradiated graphite (i-graphite) are defined. Technology Sub-Criteria are also introduced; these sub-criteria extend the strategy sub-criteria and allow comparison of the operational performance characteristics of technology options in more depth. Other work packages will supplement these technology sub-criteria with sub-criteria relevant to the specific work package.

Each sub-criterion is expressed on a numerical scale. Each of these numeric values is called a performance measure. Data requirements to calculate each generic Performance Measure are also provided in this report. Technology Sub-Criteria Performance Measures will be developed in the next phase of work.

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[4];
- Builds on previous work[5,6] in the MCDA area under the CARBOWASTE project;
- Is consistent with IAEA principles[7], EU Guidelines[8] and Directives[9]
- Takes account of feedback[10] raised at the WP2 Workshop in Gateshead, UK on 14-16 July 2009;
- Contributes to the effective integration of CARBOWASTE work packages; and
- Consolidates the earlier work[2,3,5,6] in establishing an MCDA compartment of the CARBOWASTE toolbox; remaining work will focus on ensuring that the compartment will be implemented effectively

2 Option Screening and Assessment

Figure 2 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.

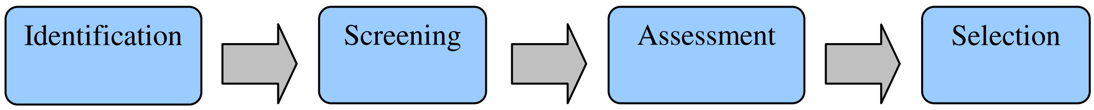

Figure 2: Option evaluation

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 Option Screening

Options are then screened using a set of constraints (see Figure 3 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.

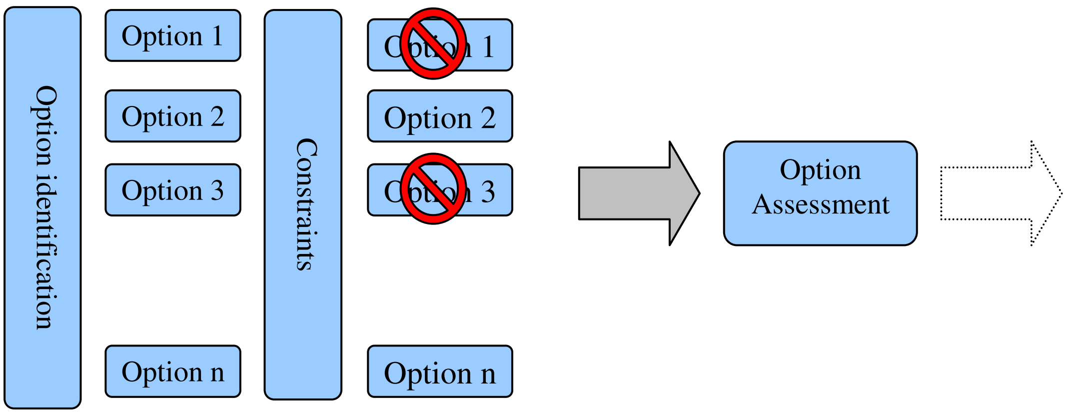

Figure 3: Option Screening

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. Scoring 'scales' will be implemented for the Performance Measures described in this report.

At each level, score weightings can be applied which reflect the relative importance attributed 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.

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 requires consideration of the same start and end points for each processing stage. Processing stages are illustrated in detail in Appendix 1, and in outline in Figure 4 below.

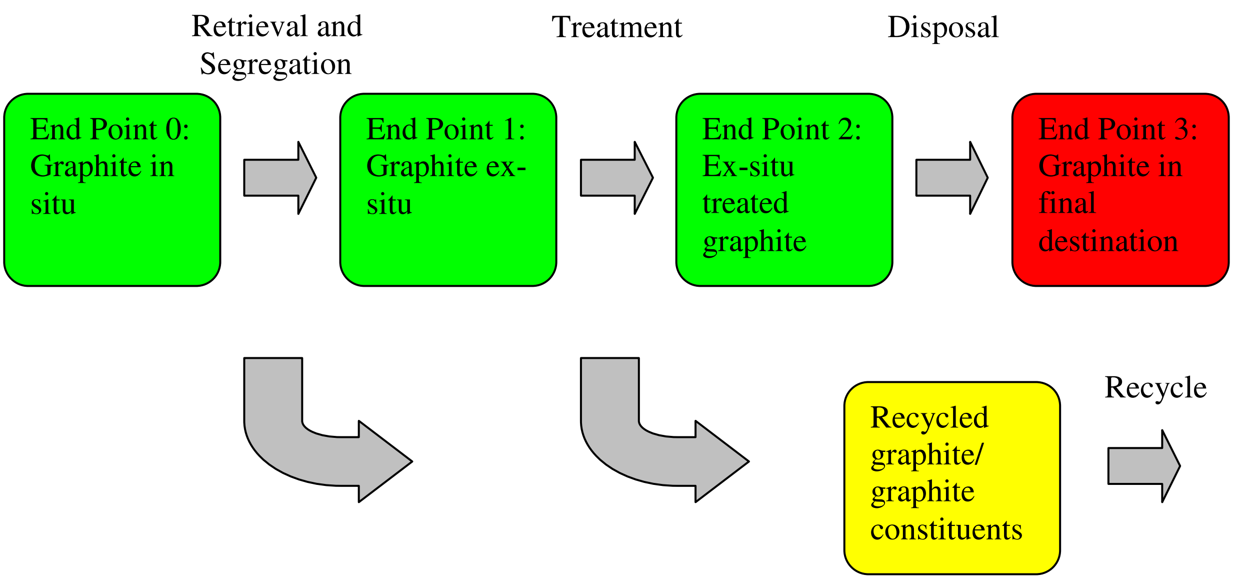

Figure 4: End Points

3.1 Retrieval and Segregation: End Point 0 to 1

The processing stages commence with 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[10] 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, Criteria and Measures

4.1 Hierarchy

The hierarchy of objectives, criteria and performance measures to be applied within the CARBOWASTE project is illustrated in Figure 5 below and discussed in detail in the subsequent sections. At the highest level are the principal objectives which need to be met to achieve the CARBOWASTE project aim. These are underpinned by criteria and sub-criteria which develop these objectives in more detail allowing meaningful comparison of both strategy and technology options at an appropriate level of detail to discriminate between options. Data to populate the measures will be derived from other Work Packages and, for member-specific issues, from Member State data

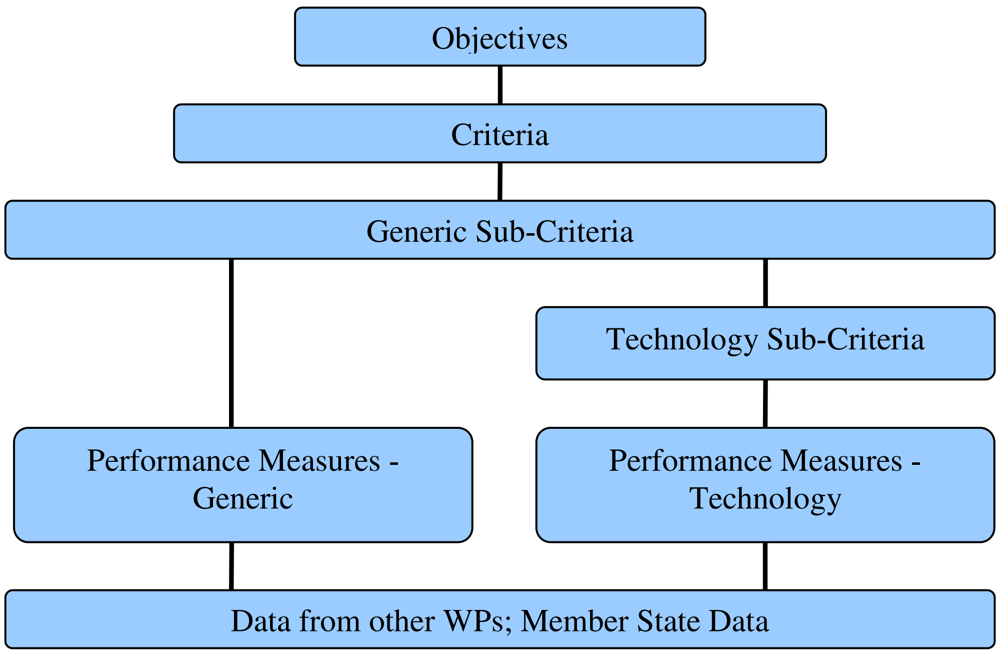

Figure 5: Hierarchy of Objectives and Criteria

4.2 Objectives

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[11] 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 5.

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.

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

4.3 Criteria

Earlier work for CARBOWASTE[6] 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.

4.3.1 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 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.

4.3.2 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.

4.3.3 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.

4.3.4 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 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.

4.3.5 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.

4.3.6 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.

4.3.7 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 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.

4.4 Generic Sub-Criteria

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[2] 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.

These sub-criteria are described under two headings – ‘Generic’ and ‘Technology’. Generic Sub-Criteria are to be used when evaluating high level ‘strategy’ options for retrieval, treatment and disposal of i-graphite, whereas Technology Sub-Criteria are designed for use in more detailed technical evaluation of specific technologies within each of the retrieval, treatment or disposal phases. Technology Sub-Criteria may be used on their own to evaluate technologies predominantly on a technical basis, or they may be used to support Generic Sub-Criteria in providing a more detailed evaluation of technical aspects.

4.4.1 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 (in the UK 1 million years is considered an appropriate time horizon, though CARBOWASTE participants can select time horizons appropriate to their waste streams).

The ICRP[12] 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 recommended as the performance measure for this sub-criterion.

4.4.2 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) programme[13] 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.

4.4.3 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.

4.4.4 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.

4.4.5 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. Because this measure is largely qualitative, some form of normalisation is required. This can most readily be done by providing guidance on Local Intrusion 'scores' for a range of construction projects of differing sizes.

4.4.6 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[14] 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[15].

4.4.7 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.

4.4.8 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.

4.4.9 Security - Misappropriation

The Hazard Potential sub-criterion discussed above encourages passive storage of material to achieve hazard reduction, in accordance with established[15] 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.

4.4.10 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.

4.4.11 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.

4.4.12 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.

4.4.13 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. More detailed Technology Sub-Criteria are presented in the next section, to facilitate the comparison of competing technologies; these will not be used for strategy selection.

4.4.14 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.

4.4.15 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.

4.5 Technology Sub-Criteria

The key eight technology considerations are outlined below, these supplement the strategy sub-criteria when assessing technology selection. Measures to evaluate these more detailed considerations will be the subject of the next phase of work.

4.5.1 Versatility

The ability to accommodate a range of process feeds e.g. from different reactors, is an important attribute for a processing option because it reflects the benefits of as much as possible of the total feedstock being processed by a single processing route.

4.5.2 Flexibility

Variations in process parameters/conditions such as temperature, pressure, humidity, dust etc. are common in radioactive decommissioning environments. These and other process parameters can have a detrimental effect on product quality. This in turn can have an adverse effect on the next processing stage. Flexible technology solutions are able to adapt to such variations with minimal effect on product quality.

4.5.3 Simplicity

Processing technologies that require minimal operator intervention, or are automated, are preferred over those which require a high degree of operator control. From an engineering perspective, simplicity of operation contributes to achieving the desired processing efficiency.

4.5.4 Robustness

Mal-operations and system faults can occur even with the most straightforward manual operations or mature technologies. Processing technology needs to be inherently reliable and robust to deviations from normal conditions in the sense that there should be minimal resulting effect on environment, safety and product quality.

4.5.5 Efficiency

The most efficient processes require minimal rework and wastage to achieve product quality. The generation of secondary wastes such as filters and packaging should also be avoided or minimised.

4.5.6 Predictability

It is important to be able to predict, with certainty, the outcome of a decommissioning process because the opportunity to re-configure in-situ is often extremely limited. Being able to model, and optimise, the process accurately before installation has significant advantages.

4.5.7 Compactness

There are benefits from process equipment having a small footprint, given the limited availability of suitable space within, and adjacent to, reactor cores. Being able to deploy a modular approach to decommissioning nuclear reactor cores can also provide significant benefits. Once the decommissioning task on one site is complete, equipment can be transported to another site for use.

4.5.8 Product Quality

Processing technology should achieve the stated output quality e.g. treatment methods achieving a defined decontamination factor, package conditioning for disposal meeting the conditions for acceptance or recycled material meeting a product (or product feed) specification.

4.6 Measures and Data Requirements

The hierarchy of Sub-Criteria, Measures, Measurement Units, Data Requirements and Data Units is summarised in Appendix 2. A brief description of the measurement rationale is included in the following sub-sections.

4.6.1 Radiological Impact – Man

The measure of the radiological impact on man is the European collective dose in man-Sieverts when evaluated over a long period of time (defined by CARBOWASTE participants, and can be as long as 10^6 years). Data requirements are the activity in Terabecquerel (TBq) versus time for radioactive discharges from the facility, together with a representative collective dose factor in man-Sieverts/TBq.

4.6.2 Radiological Impact – Environment

Discharges are assessed and expressed in terms of their concentration. This may require the use of dispersion modelling or a conservative “end-of-pipe” figure. The risk quotient is then calculated for each radioisotope by dividing the concentration of that radioisotope by the environmental media concentration limit for the given radionuclide for the most limiting reference organism.

The sum over all radioisotopes gives the total risk quotient. When used within ERICA as a screening quantity this value is examined. If less than 1, there is a very low probability that the absorbed dose rate to any organism exceeds the screening dose rate, and the situation may be considered to be of negligible radiological concern. For CARBOWASTE, it is recommended that the total risk quotient is used as the performance measure.

4.6.3 Resource Usage

For each tonne of the resources used (steel, concrete etc.), the energy required in Giga-Watt hours (GWh) to produce the resources is calculated for the facility lifecycle. The overall resource usage is then derived by calculating the sum of principal contributions. A judgement will need to be made on limiting the assessment to those resources which are most energy-intensive and/or are used in large quantities.

4.6.4 Non-Radiological Discharges

Non radiological discharges will be assessed by comparison to Environmental Quality Standards (EQS). The discharge of each material (in mass units) will be divided by the EQS for the material to give the amount of water needed to dilute the material to the EQS. The sum of these dilution factors over all species is treated as a performance measure for the impact of non-radiological discharges.

4.6.5 Local Intrusion

Whilst it is possible to make semi-quantitative assessments of certain intrusive impacts e.g. noise, light and vibration, qualitative evaluation will be necessary for impacts such as wildlife disturbance. The measure assigns a value between 0 (no impact) and 1 (significant impact) to each of the following categories (definition of the "most exposed" member of the public will be addressed in the next phase of work):

- Off-site noise to "most exposed" member of the public;
- Off-site visual impact to "most exposed" member of the public;
- Impact of construction traffic and off-site transport of process feeds/products/wastes on "most exposed" member of the public;
- Land use (compare both hectares used and time for which they are used);
- Impact of noise on wildlife (both on and off-site);
- Impact of artificial light on wildlife (both on and off-site);
- Impact of excavation on wildlife (both on and off-site); and
- Impact of vibration (e.g. due to piling) on wildlife (both on and off-site).

The sum of the categories is a measure of local intrusion. Judgement is to be based on assessments of the activities needed to deliver the project, the physical size of any construction and of wildlife present on the proposed construction site.

4.6.6 Hazard Potential

Assessment is performed by multiplying the maximum mass of material in each form (gases, liquids, powders, solids and monolithic solids) in each process stage by the number of years the process stage will continue to operate and by a risk factor which considers the probability of an incident, and a modifier for accidents considered essentially irreversible. This is a variation of the Hazard Potential concept[14] developed as part of the NDA prioritisation process in the UK. A flow diagram of the assessed process is needed to underpin the assessment. Since the duration of each process stage is considered (unlike in the NDA hazard potential approach) the result is therefore an *integrated* Hazard Potential.

4.6.7 Radiological Worker Safety

Collective Dose in Man Sieverts is used as the measure of worker radiological safety. The number of workers, the period in years for which they are required, and the predicted dose per operator in millisieverts (mSv) are combined to derive the measurement value.

4.6.8 Non-Radiological Worker Safety

An estimate of the fatal injury rate per 100,000 workers per year is made by comparison to published figures for industry sectors relevant to CARBOWASTE participants. The number of operators, the number of years the operators are required, and the environment (services, manufacturing or construction sectors) operators are exposed to are used to estimate a fatal injury rate for the decommissioning process(es).

4.6.9 Security - Misappropriation

Misappropriation is calculated in a similar manner to the Hazard Potential. Assessment is made of:

- Barriers that must be breached;
- Ease of transporting material away;
- Amount of material that can be misappropriated; and
- Time that the material is 'vulnerable'.

From the above factors, a misappropriation factor is derived. The calculation method is currently being developed.

4.6.10 Cost

Discounted lifecycle costs over a long period of time will be measured, as agreed for the environmental assessment. Due to the use of discounting for future expenditure, this measure will be less sensitive to future actions than the environmental effects. An appropriate discount rate, selected by the member state will be applied.

4.6.11 Spin-Off

The measure of spin-off is an estimate of the discounted value (Net Present Value) of spin-off opportunities. The monetary value, after discounting, will be used as the performance measure.

4.6.12 Concept Predictability

The Technology Readiness Level (TRL)[16] is to be used as the measure for this criterion.

CARBOWASTE processing options under evaluation are likely to be based on more than one key technology, each having a distinct TRL value. The calculation method for deriving an overall TRL value is under development.

4.6.13 Operational Predictability

The Operational Predictability Level is to be derived in the form a subjective score from the assessment of:

- Process Flow Diagram;
- Throughput sensitivity to feed variations;
- Feed probability distribution;
- Equipment/System Reliability Data; and
- Equipment/System interface (familiarity and ease of use).

4.6.14 Stability of Employment – Employment Factor

Determination of the Employment Factor is achieved through subjective assessment of:

- Employment profile for project lifecycle;
- Employment history in project region (numbers, skills, stability); and
- Transferable skills derived from project.

Further development of this measure will be undertaken in the next phase of work.

4.6.15 Burden on Future Generations – Burden Factor

A measure of the burden level is assessed subjectively from consideration of the following factors:

- Lifecycle project cost profile vs. time;
- Discharge profile for radioactive species vs. time;
- Discharge profile for toxic species vs. time;
- A future cost 'inflation' parameter (penalty); and
- A future discharge parameter (penalty).

Further development of this measure will be undertaken in the next phase of work.

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[7]. 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[8] 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[9] 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 3.

Criteria	CARBOWASTE Scope Document	IAEA Nuclear Energy Basic Principles	ENSREG Principles	Environmental Impact Assessment
Criterion 1: Environment and Public Safety	Safety Environmental	Principle 3: Protection of people and the environment	Protection of human health Protection of the environment Protection beyond national borders 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 Safety of facilities	Direct and indirect effects on human beings, fauna and flora.
Criterion 3: Security	Safety	Principle 4: Security Principle 5: Non-Proliferation	Safety of facilities	Direct and indirect effects on human beings, fauna and flora.
Criterion 4: Economic	Economic	Principle 1: Benefits 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, - the production of waste, - 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 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, sub-criteria, performance measures and end-points for the assessment of options for the management of irradiated graphite (i-graphite).

Four end points are defined:

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

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

15 Lower Level Objectives (Generic Sub-Criteria) are defined:

1. Radiological Impact - Man
2. Radiological Impact - Environment
3. Resource Usage
4. Non-Radiological Discharges
5. Local Intrusion
6. Hazard Potential
7. Worker Safety (Radiological)
8. Worker Safety (Non-Radiological)
9. Security - Misappropriation
10. Cost
11. Spin-off
12. Concept Predictability
13. Operational Predictability
14. Stability of Employment – Employment Factor
15. Burden on Future Generations – Burden Factor

Each of these is underpinned by a Performance Criterion (Measure).

Technology Sub-Criteria are also introduced; these extend the generic criteria and are to be used for technology, rather than strategy selection.

The principal conclusions of this report are:

- End points for the various stages in i-graphite retrieval, treatment and disposal have been defined;
- 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
- Sub-Criteria and Performance Measures have been identified which support these Objectives and Criteria

7 References

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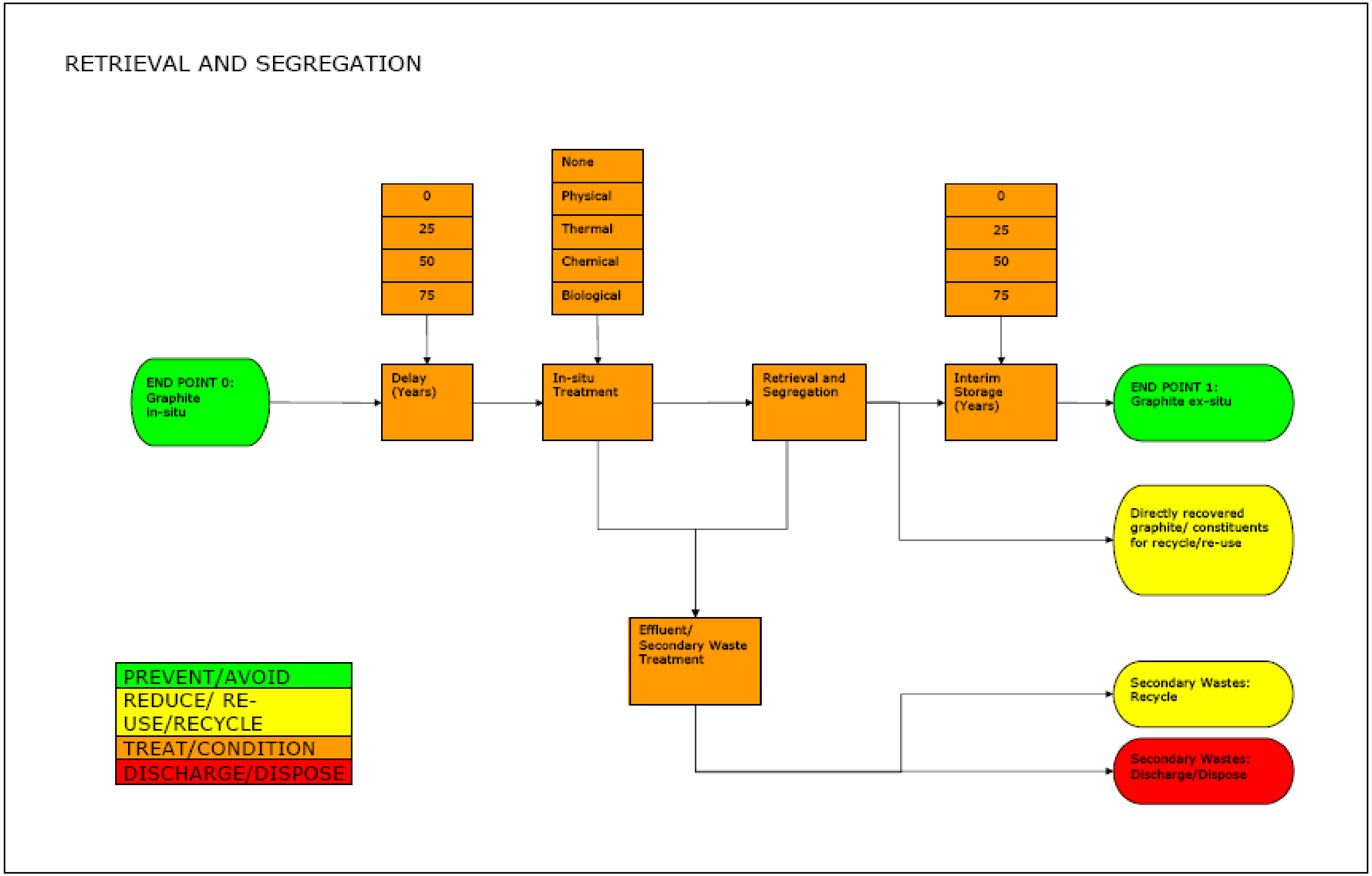
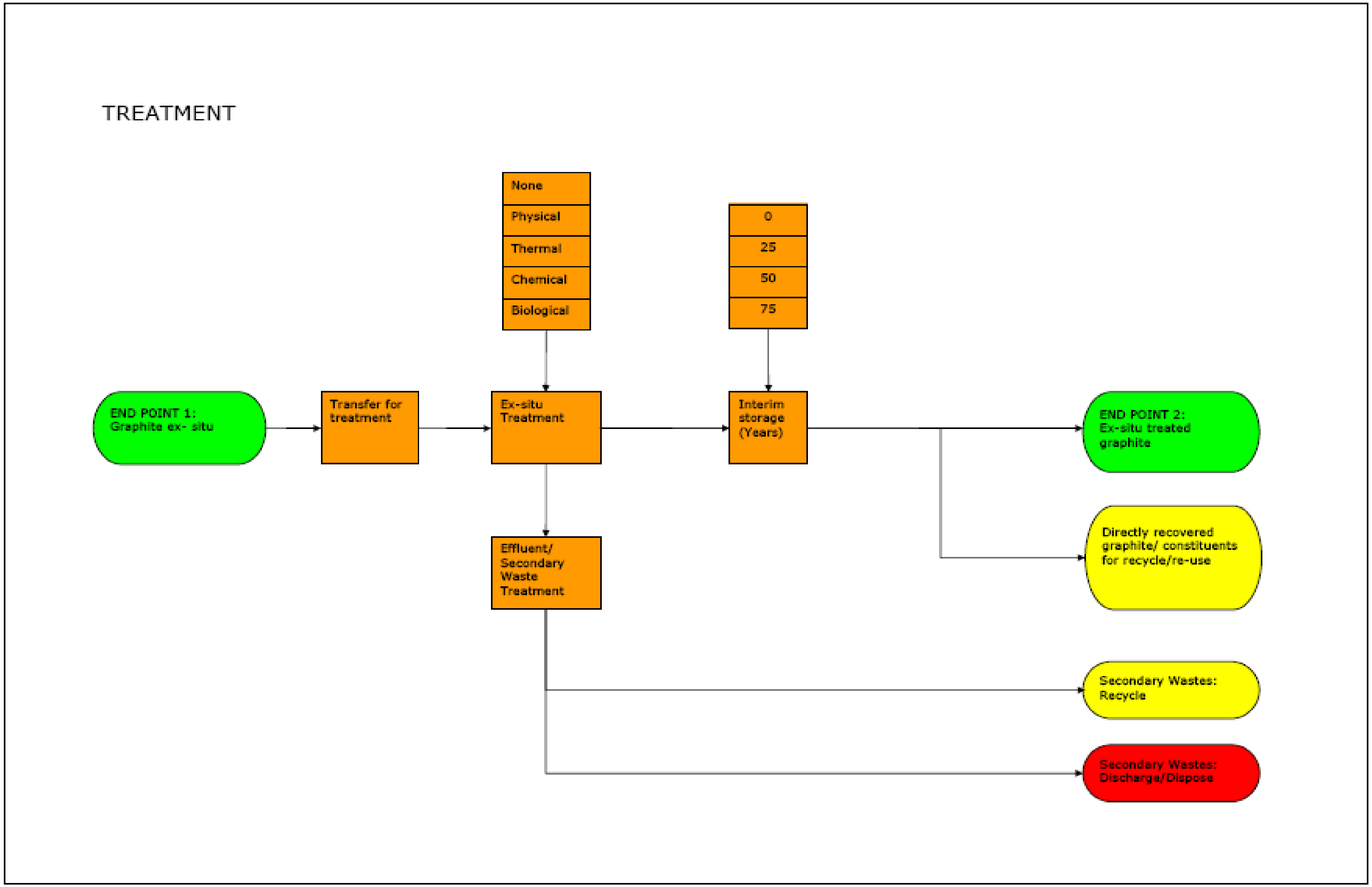
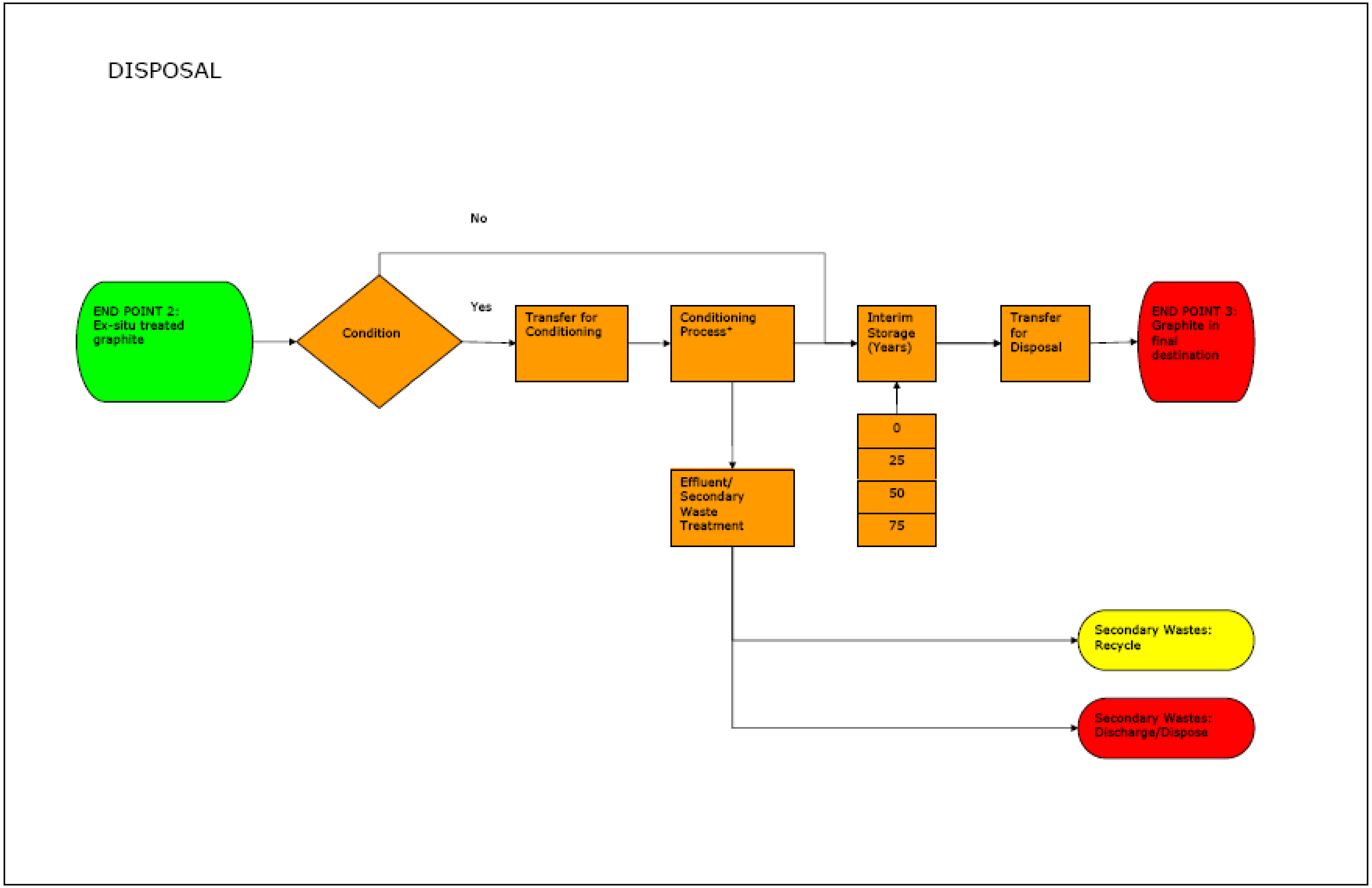
Appendix 1: Process Flowcharts




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
Yes
END POINT 2:
Ex-situ treated graphite
Condition
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

Appendix 2: Sub-Criteria, Measures and Data Requirements

Sub-Criteria	Measure	Measure Units	Data Requirement	Data Units
Rad Impact - Man;	Collective Dose over 10^6 years	Man Sieverts	Time Varying Discharge Profile	End of pipe Tbq vs. time
			Aerial and Liquid Collective Dose Factors for each site	Man Sieverts/TBq
Rad Impact - Environment	Tier 1 ERICA score	Dimensionless	Edge of mixing zone activity concentration for discharged species	TBq/m^3
Resource Usage	Energy	GWh	Lifecycle resource usage	tonne
			Energy required to manufacture unit of resource	GWh/tonne
Non-rad discharges	Sum of dilution required to meet EQS for all toxic species	m^3	Time Varying Discharge Profile	te discharged
			Environmental Quality Standards	te/m^3
Local Intrusion	Impact value between 0 (no impact) and 1 (significant impact) normalised to known projects	Subjective Score	Lifecycle Environmental Impact Assessment of facility	None
(Integrated) Hazard Potential	Hazard Potential	None	Duration of each processing stage	Years
			Active Process Materials Inventory	TBq
			Process Materials Inventory	te
			(Control and Form) Risk Factors	Numerical
Worker Safety (Radiological)	Collective Dose	Man Sieverts	Number of Operators	Numerical
			Number of Years Operators Required	Numerical

Sub-Criteria	Measure	Measure Units	Data Requirement	Data Units
			Predicted Dose/Operator	mSv
Worker Safety (Non-Radiological)	Fatal Injuries	Numerical	Number of Operators	Numerical
			Number of Years Operators Required	Numerical
			Industrial Sector applicable to working environment	Information only
			Industrial Sector Death Rates	Number/100,000 workers/year
Security - Misappropriation	Misappropriation Factor	Numerical Value	Number of barriers to overcome Amount of each radioisotope vulnerable Duration of vulnerability	Numerical
Cost	Discounted Lifecycle Cost	Monetary Values	Lifecycle Cost (assumes no income from Graphite disposal)	Monetary Value
			Discount Rate	Annual Percentage
Spin-Off	Discounted Lifecycle Value	Monetary Values	Lifecycle Net Present Value (NPV)	Monetary Value
			Discount Rate	Annual Percentage
Concept Predictability	Technology Maturity Level	Numerical	Technology Readiness Level	Numerical Value
			Process Flow Diagram	Information only
Operational Predictability	Operational Predictability Level	Subjective Score	Process Flow Diagram	Information only
			Throughput sensitivity to feed	Information only

Sub-Criteria	Measure	Measure Units	Data Requirement	Data Units
			variations	
			Feed probability distribution	Information only
			Equipment/System Reliability Data	Information only
			Equipment/System interface (familiarity and ease of use)	Information only
Employment Level	Employment Factor	Subjective Score	Employment profile for project lifecycle	Information only
			Employment history in project region (numbers, skills, stability)	Information only
			Transferable skills derived from project	Information only
Burden Level	Burden Factor	Subjective Score	Costs profile vs. time	Monetary Value
			Discharge profile for rad. species vs. time	TBq/m3 vs. time
			Discharge profile for toxic species vs. time	Mass concentration vs. time
			Future cost parameter (penalty)	Numerical
			Future discharge parameter (penalty)	Numerical

Appendix 3: 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.

<u>The environmental impact assessment directive 85/337/EEC</u>

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.