Nuclear Engineering and Technology 56 (2024) 4820–4825

Contents lists available at ScienceDirect

Nuclear Engineering and Technology

journal homepage: www.elsevier.com/locate/net

Original Article

Application of the Analytic Hierarchy Process (AHP) method to identify the most suitable approach for managing irradiated graphite

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ARTICLE INFO

Keywords:
Irradiated graphite
^{14}C
Analytic Hierarchy Process
CARBOWASTE project
I-graphite management
Waste disposal

ABSTRACT

Scientific literature studies irradiated graphite treatment. Research also covers graphite conditioning and its long-term behavior under disposal conditions. The European Commission's CARBOWASTE project, titled "Treatment and disposal of irradiated graphite and other carbonaceous waste", is a key reference for state-of-the-art studies on alternative solutions. It identified 24 strategic options for managing irradiated graphite throughout its complete life cycle. The methodology proposed in this paper entails the application of the Analytic Hierarchy Process (AHP) method to rank the 24 options, placing particular emphasis on the weighting of seven criteria for selecting management options for the irradiated graphite. The highest weights were assigned by experts to 'environment and public safety' (28.05 %) and 'worker safety' (26.16 %). The objective is to develop a standardized approach enabling waste management companies to identify the most appropriate management option, considering structural and legislative constraints in their operating country. Examining the study findings, option 19 "In-situ entombment" stands out as the best choice in both the CARBOWASTE project and the proposed methodology. Thus, this methodology could assist hypothetical entities in examining management options for irradiated graphite, with the aim of identifying the optimal solution for graphite waste disposal.

1. Introduction

Graphite has been widely used as a moderator in reactors in the United Kingdom and Russia, predominantly (Fig. 1), leading to a significant challenge in managing the large amounts of irradiated graphite (i-graphite) generated from decommissioned reactors (over 250,000 tonnes) [1]. The primary concern stems from the presence of long-half-life radionuclides like ^{14}C and ^{36}Cl [2], which complicates waste management. Factors affecting this variability include the type of graphite used, its role within the facility, and irradiation values. I-graphite requires careful disposal due to properties such as stored Wigner energy, graphite dust explosiveness, and potential radioactive waste release [3]. While several scholarly articles have addressed radioactive waste management involving graphite [4–6], a comprehensive understanding remains rare. Few interventions have been made on large quantities of i-graphite (two reactors in USA, Fort St. Vrain and Graphite Research Reactor, and two reactors in UK, Windscale Advanced Gas-cooled Reactor and Graphite Low Energy Experimental Pile, for a total of about 1600 tonnes), and ongoing studies are currently under review to identify potential new decontamination methods and disposal techniques to address the growing need for managing i-graphite.

In the recent Italian classification of radioactive waste [7], based on the International Atomic Energy Agency (IAEA) framework [8], i-graphite is categorized as intermediate-level waste (ILW). This designation entails disposal in a medium-depth underground facility following temporary storage at a designated facility for 50–100 years. Future disposal methods for irradiated graphite may not require permanent emplacement in intermediate-depth or geological-type facilities due to factors such as varying activation levels in the reactor core, concentration of long-lived radionuclides in specific zones, the graphite structure's ability to retain radionuclides through leaching for over 300 years, low heat generation after decay, and the potential for treatment to separate significant amounts of long-lived radionuclides like ^{14}C, ^{36}Cl,

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https://doi.org/10.1016/j.net.2024.06.045
Received 28 February 2024; Received in revised form 8 May 2024; Accepted 25 June 2024
Available online 27 June 2024

Nuclear Engineering and Technology 56 (2024) 4820–4825

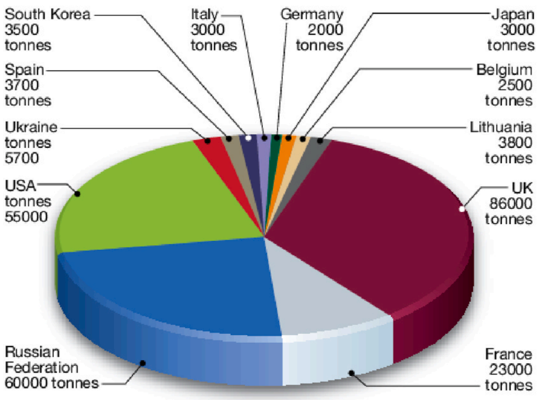

Fig. 1. Assessment of the global inventory of irradiated graphite waste (tonnes) [1].

^{59}Ni, and ^{63}Ni with the aim of downgrading the waste.

The European Commission's project "Treatment and disposal of irradiated graphite and other carbonaceous waste" (CARBOWASTE), initiated in 2008 under the 7th Framework Programme and concluded in 2013, is a significant reference in studies on alternative solutions for managing irradiated graphite [9]. This project identified 24 strategic options for managing irradiated graphite throughout its life cycle. The aim was not to prescribe a singular national waste management strategy concerning i-graphite, but rather to construct a comprehensive set of methodologies, which could be systematically examined and assessed to identify optimal choices based on individual national strategies, limitations, and regulatory frameworks [10].

Additionally, the IAEA Coordinated Research Project (CRP) "Treatment of irradiated graphite to meet acceptance criteria for waste disposal" aims to comprehensively review the state of the art on this subject [1]. Regarding final disposal, the CRP has investigated three main options: geological disposal, near-surface or surface disposal, and deep subsurface injection after appropriate treatment. While geological disposal may be the least restrictive in terms of waste acceptance criteria, it could also be the most expensive. Near-surface or surface disposal is the most commonly studied solution, while deep subsurface injection faces significant regulatory constraints and currently lacks support from national agencies responsible for managing radioactive waste.

The IAEA has initiated the GRAPA (Irradiated GRAphite Processing Approaches) project to assist Member States in effectively managing graphite, from recovery to industrial implementation of various technologies. This project stems from successful demonstrations indicating that graphite from long-operating commercial reactors can be recovered, treated, and disposed of using different procedures [11]. While the IAEA doesn't prescribe waste management policies, the management of i-graphite poses challenges due to ongoing studies on treatment methods, conditioning, and final disposal. Countries with graphite reactors typically opt for disposal in geological repositories, although acceptance criteria for such waste remain unclear. In instances where decommissioning of graphite reactors has occurred, i-graphite is frequently temporarily stored, as observed in the cases of the Fort St. Vrain and Brookhaven reactors in the USA, without completing the full management cycle [1]. The research objective is to apply the AHP method to the 24 options for managing i-graphite, selected within the framework of the CARBOWASTE project, with the aim of ranking these options.

2. The CARBOWASTE project

The CARBOWASTE project aimed to develop comprehensive guidelines for environmentally sustainable technologies in the recovery, treatment, and disposal of irradiated graphite. Collaboration among CARBOWASTE work packages resulted in consensus on 24 potential options for managing irradiated graphite, as summarized in Table 1.

One of the project objectives was to develop a method for evaluating the defined options. In Ref. [12], the 24 options were assessed to establish a ranking highlighting their performance. Quantitative assessments were conducted in terms of the impact of each option on a set of criteria and sub-criteria, as agreed upon by representatives of the CARBOWASTE project. Seven criteria were defined based on three high-level objectives: safety and environmental, economic, and social.

To proceed with a numerical evaluation, it became necessary to further divide the criteria into sub-criteria (Table 2), enabling the assignment of numerical values for comparison. The criteria used for the quantifier assessment are elucidated in Ref. [12].

A series of flowcharts were created for each option, outlining the processes involved in irradiated graphite management. Additionally, spreadsheets were developed for each phase of the process, including in-reactor storage, recovery, treatment, etc. These spreadsheets analyze the impact of each phase on specific criteria and assign numerical values accordingly. Each of the 24 flowsheet options was further detailed into a quantified flow diagram, tracking the movement of radionuclides through various steps. Subsequently, these flow diagrams were expanded to include calculations for assessing different criteria related to each option. The resulting metrics provide a comprehensive evaluation of flowsheet performance for waste management selection. The summarized results from these flowcharts are presented in Ref. [12]. The numerical values have different units, such as energy use (GJ) versus transportation (number of truck trips), making direct comparison challenging. Therefore, a Multi-Criteria Decision Analysis (MCDA) process was implemented to compare options in a similar manner, allowing for the assignment of a normalized score to the impact of each option on every criterion. The main results of this analysis were as follows:

a) option 10, involving temporary storage of graphite before encapsulation with the final destination being a surface repository, incurs higher associated costs due to the dual storage mode;

Table 1
Options for the management of i-graphite (CARBOWASTE Project) [12].

Option N°	Description
1	Encapsulation and deep repository
2	Size reduce graphite for minimised waste package volume; local immobilisation
3	Minimum processing
4	Deferred start with remote retrieval
5	Deferred start with manual retrieval
6	Minimum processing with deferred start
7	Alternative retrieval and graphite form in package
8	Alternative retrieval and repository
9	Interim storage and repository
10	Alternative retrieval, encapsulation and intermediate storage
11	In-situ treatment and near-surface repository
12	Ex-situ treatment and near-surface repository
13	Gasification and isotopic dilution with conventional fossil fuel CO_2
14	Gasification and isotopic dilution with conventional fossil fuel CO_2 as a result of sequestration
15	Gasification and isotopic dilution by dispersal as CO_2 in the sea
16	^{14}C re-use
17	^{14}C re-use with no isotope separation
18	Graphite re-use for nuclear application only
19	In-situ entombment
20	Waste volume reduction and emission to atmosphere
21	Make use of graphite as inert filler, removing the need for some encapsulation
22	Immobilise in medium impermeable to ^{14}C
23	Chemically bind ^{14}C
24	Interim storage of raw waste and repository

Table 2
Subdivision of objectives into primary criteria and sub-criteria.

Objectives	Criteria	Sub-criteria	Units
Safety and environmental	Environment and public safety	1. Radiological impact - man	Man Sv
		2. Radiological impact - environment	Man Sv
		3. Resource usage	GJ
		4. Non radiological discharge	m^3
		5. Local intrusion	Decibel (noise) Hectares (land) Truck journeys (transport)
		6. Hazard potential	Man Sv
	Worker safety	7. Radiological worker safety	mSv
		8. Conventional worker safety	Injuries
	Security	9. Security misappropriation	Man Sv
Economic	Economic cost and benefit	10. Economic costs	M€
		11. Economic benefits (reuse& spinoff)	M€
	Technology predictability	12. Technology predictability: concept	TRL (1–9) M€
		13. Technology predictability: operational	M€ years
Social	Stability of employment	14. Stability of employment	jobs
	Burden on future generations	15. Burden on future generations	Decades until material no longer requires management

b) option 19 demonstrates low resource utilization, minimal transportation demands, and low costs. However, its principal drawbacks include inadequate security measures and high levels of radioactive discharges;
c) gasification options (13, 14, 15, and 20) and reuse options (18 and 21) have lower costs as a fraction of ^{14}C is redirected elsewhere (resulting in smaller quantities of graphite requiring disposal);
d) options with significant discharges (13 and 15) exhibit poor performance on environmental criteria. However, these options mitigate hazards, reduce resource consumption and transportation needs, and may be more cost-effective than alternative options;
e) the options with the poorest scores are those involving large and repeated construction activities, such as multiple treatment facilities or indefinite storage.

The CARBOWASTE project analyzed options for managing irradiated graphite creating a model for comparison using arbitrary weight assignments at three levels. Given diverse national strategies and regulations, a single preferred option for all countries is unfeasible. The decision not to rank options stemmed from the challenge of assigning definitive weights, as priorities vary among scientists, engineers, governments, regulators, and the public [9]. To make the choice as objective as possible, multiple alternative weightings were considered, assuming three different stakeholders associating varying levels of importance with each sub-criterion [11]. Stakeholder A employs extreme weight assignments, yielding two result sets. In one, a broad weight assignment is used, making high-weight criteria 100 times more influential than low-weight ones (high = 100, medium = 50, low = 1). In another scenario, narrow weight assignment is applied, with high = 75, medium = 50, low = 25. Stakeholders B and C use narrow weightings. B prioritizes radiological impacts, worker safety, hazard potential, security, and burden on future generations. C prioritizes radiological impacts, resource use, hazard potential, economic costs, and operational predictability.

The iterative process involves eliminating low-scoring options to identify preferred ones, refining scores for remaining choices. Removing worst options may change the optimal choice in MCDA, as weighted scores from all options influence each other. This shift occurs due to the allocation of weighted scores derived from all options, where eliminating a poorly performing option can affect a well-performing one in certain criteria, given the comparative evaluation of performance [14]. This method identified option 10 as consistently least favorable, while option 19 consistently ranked highest, followed closely by options 18, 20, and 3. Stakeholder B (Allocation B – narrow weightings) also favored options 7 and 1. Interestingly, diverse weighting allocations had minimal impact on relative rankings across stakeholders A, B, and C, indicating robustness in the analysis.

3. AHP method

The Analytic Hierarchy Process (AHP) is a decision-making technique developed by Thomas L. Saaty in the 1970s. The technique holds significance in addressing complex problems that influence human perceptions and judgments. Its utility becomes particularly pronounced when decision components prove challenging to quantify or compare, or when diverse areas of expertise hinder effective communication within a collaborative work environment. It is a widely recognized method for prioritizing alternatives in decision-making problems involving multiple criteria [15]. It decomposes problems into hierarchical levels, quantifies influences through paired comparisons, and calculates weights iteratively. The AHP method unfolds in three distinct steps: a) pairwise comparisons; b) evaluation of the consistency of pairwise judgments; c) calculation of relative weights. At the core of Saaty's method lies an ordinal pairwise comparison of all criteria and alternative. In essence, it specifically deals with preference statements, enabling the comparison of qualitative judgments into numerical values. For each pair of criteria, decision-makers assess the degree to which one criterion is more important than the other, using a semantic 9-point scale (a value of 1 indicates equal importance between criterion A and criterion B, while a value of 9 signifies that criterion A is vastly more important than B).

The described methodology assigns weights to criteria based on experts' significance attributed to objectives or alternatives. It evaluates alignment between weight vector components and initial judgments via pair-wise comparisons, resulting in a comparison matrix. Utilizing the eigenvector approach, a weight vector is computed for further evaluation. The methodology includes verifying matrix consistency by calculating eigenvalues, ensuring coherence and reliability. AHP accommodates inconsistency while quantifying it within judgment sets. The consistency of the judgmental matrix can be assessed using a metric known as the Consistency Ratio (CR), expressed as:

$$CR = \frac{CI}{RI} \tag{1}$$

where CI represents the Consistency Index and RI denotes the Random Index. Saaty has established average consistencies (RI values) based on randomly generated matrices for reference [16] (Table 3). Saaty contends that pairwise comparisons are considered sufficiently consistent when the Consistency Ratio (CR) value is below 0.1. Should the value surpass this threshold, the judgment may lack reliability and ought to be reconsidered.

The AHP method is valuable in providing policy makers with technical insights for categorizing various i-graphite management options, even though political decisions are sometimes made irrespective of technical elements, given that other considerations come into play. The validity of the method has been substantiated by a comprehensive range

Table 3
Average consistencies of random matrices (RI values).

	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

of examples documented in academic literature. In the nuclear sector, AHP has been proposed for site selection for radioactive waste repositories [17–19].

4. Proposed methodology

The objective of the proposed methodology extends beyond mere identification of the optimal disposal option. Instead, its aim is to empower each radioactive waste management company to discern the most fitting approach to managing i-graphite. This determination should align with the structural and legislative constraints unique to each State, recognizing variations that exist between different jurisdictions. The methodology focuses on the dual objective of establishing a unique ranking among the 24 options for managing irradiated graphite proposed by the CARBOWASTE project and placing greater emphasis on the weighting method to ensure increased confidence in the assessment of results. The ranking was generated by adhering to the outlined procedure below:

Step 1) for each of the 24 options, the values of each sub-criterion, found in Ref. [11], were compared to the corresponding sub-criterion of option 1, as follows:

$$\frac{value\ of sub - criterion\ x\ option\ y}{value\ of\ sub - criterion\ x\ option\ 1} \tag{2}$$

Sub-criteria 1, 2, and 6, sharing the same unit of measurement, were initially summed together before comparison.

Step 2) once these comparisons were established, the arithmetic mean of items within the same criterion was computed, resulting in a 7-item vector for each disposal option;
Step 3) the geometric mean of each vector was then calculated to derive a score. Using these scores, a ranking was formulated, wherein higher results indicate poorer performance.

While acknowledging that identifying the most suitable methodology to express the weightings is a challenging task, given the simultaneous technical-scientific, economic, social, and ethical implications, an attempt to achieve a more objective evaluation of the 24 options was made using the AHP method. The investigation involved a sample of 20 experts with diverse expertise in various disciplinary fields (6 engineers with different specializations, 4 economists, 2 sociologists, 4 environmental issues experts, 4 safety and security experts) aiming to approach, as much as possible, an objective judgment. The experts were selected from academic backgrounds (Guglielmo Marconi University and Sapienza University of Rome) as well as among researchers from ENEA and professionals from a radioactive waste management company. The expert panel was curated to integrate viewpoints from a variety of fields relevant to the criteria delineated in Table 2. The invitations extended to them included information regarding the research objectives and the AHP methodology. Each expert completed a matrix (Table 4) via pairwise comparisons of criteria contained in Table 2, resulting in a vector of priorities for each criterion, expressed by the weight shown in Table 4. For each matrix, the indices *(CI, RCI, CR)* reported in Table 5 were computed, as defined in Section 3. This methodology culminated in a “weighted ranking" incorporating the weights determined in the second step of the analysis. Specifically, before calculating the geometric mean, the values were weighted by multiplying them with the weighting factors derived from the priority vector obtained through expert consultation. The Technology Readiness Level (TRL) posed a unique consideration, as higher scores denote greater technological maturity, contrary to other indices. To align TRL consistently with other evaluations, the reciprocal of its value was calculated before ranking formulation. For options 16 and 21, where TRL was zero (indicating untested technologies), a decision was made to assign the unit value.

The vector of priorities is composed by calculating the geometric mean of each item from the priority vectors expressed by each of the 20 experts (Table 6).

Upon completion of the procedure, the weighted ranking is then compiled (Table 7).

5. Discussion

The purpose of the proposed methodology is not to identify the optimal option for managing i-graphite but to develop a standardized approach that enables each waste management company to identify the most suitable management option to meet its structural and legislative constraints in the country of operation. The CARBOWASTE project, as described in Ref. [13], suggests that before conducting MCDA, options

Table 5
Index values.

N° of components	CI	RCI	CR	Judgement
7	0.12	1.32	0.09	Acceptable

Table 4
Example of matrix completed by an expert.

	Environment and public safety	Worker safety	Security	Economic cost and benefit	Technology predictability	Stability of employment	Burden on future generations	Geometric mean	Weight
Environment and public safety	1	1/2	3	6	7	6	3	2.73	0.25
Worker safety	2	1	4	7	9	8	5	4.12	0.38
Security	1/3	1/4	1	3	5	5	4	1.58	0.15
Economic cost and benefit	1/6	1/7	1/3	1	2	3	1/7	0.49	0.05
Technology predictability	1/7	1/9	1/5	1/2	1	1/2	1/4	0.30	0.03
Stability of employment	1/6	1/8	1/5	1/3	2	1	1/9	0.32	0.03
Burden on future generations	1/3	1/5	1/4	7	4	9	1	1.23	0.11
Total	4.14	2.33	8.98	24.83	30.00	32.50	13.50	10.76	1.00

Table 6
Vector of priorities.

Ranking	Criterion	Priority
1°	Environment and public safety	28.05 %
2°	Worker safety	26.16 %
3°	Security	14.58 %
4°	Burden on future generations	11.20 %
5°	Economic cost and benefit	5.20 %
6°	Technology predictability	3.79 %
7°	Stability of employment	2.95 %

Table 7
Ranking of the 24 options after applying AHP method.

Ranking	Option N°	Description	Score
1°	19	In-situ entombment	0.67
2°	6	Minimum processing with deferred start	0.74
3°	3	Minimum processing	0.80
4°	9	Interim storage and repository	0.84
5°	4	Deferred start with remote retrieval	0.86
6°	8	Alternative retrieval and repository	0.91
7°	7	Alternative retrieval and graphite form in package	0.94
8°	1	Encapsulation and deep repository	0.95
9°	2	Size reduce graphite for minimised waste package volume; local immobilisation	0.96
10°	11	In-situ treatment and near-surface repository	0.96
11°	12	Ex-situ treatment and near-surface repository	0.98
12°	20	Waste volume reduction and emission to atmosphere	1.08
13°	5	Deferred start with manual retrieval	1.10
14°	18	Graphite re-use for nuclear application only	1.21
15°	16	^{14}C re-use	1.25
16°	17	^{14}C re-use with no isotope separation	1.30
17°	15	Gasification and isotopic dilution by dispersal as CO_2 in the sea	1.31
18°	21	Make use of graphite as inert filler, removing the need for some encapsulation	1.41
19°	24	Interim storage of raw waste and repository	1.64
20°	14	Gasification and isotopic dilution with conventional fossil fuel CO_2 as a result of sequestration	2.02
21°	22	Immobilise in medium impermeable to^{14}C	2.46
22°	23	Chemicallybind^{14}C	2.47
23°	13	Gasification and isotopic dilution with conventional fossil fuel CO_2	2.96
24°	10	Alternative retrieval, encapsulation and intermediate storage	71.13

should undergo screening based on the users' constraints. These constraints are specified as conditions that must be met for the option to advance further in the analysis, the application of the AHP method allows for the determination of a ranking that captures a generally valid overview, not subject to changes influenced by the progressive exclusion of one or more options, entailing the adjustment of the ranking as options with lower scores are excluded, as observed in Ref. [13]. Multiple alternative methods can be used for evaluating the best option. Since the evaluations consider subjective weightings based on different criteria, seeking a "perfect" method may not be fruitful. However, the availability of alternative methods can prove advantageous, as they can either offer confirmation of the validity of the analysis or provide further insight, depending on specific boundary conditions. Following the approach outlined in the paper, the following steps could be pursued by a hypothetical entity aiming to investigate which option for managing i-graphite to adopt to find the optimal solution for i-graphite waste disposal:

1) AHP analysis concerning the 7 criteria, contained in Table 2, to identify the weights to use in the weighting phase;
2) drafting of the weighted ranking;
3) elimination of impracticable options based on legislative constraints and structural limitations;
4) revision of the ranking with the remaining options and final selection based on further investigation.

Option 19 achieves the best outcome both in the CARBOWASTE project and with the application of the methodology proposed in the paper. It performs favorably, primarily attributed to its lack of repository and exhibits minimal impact on resource utilization, truck journeys, worker safety (involving a small workforce), economic costs, technical risk, changes in employment, and imposes a low burden on future generations. Indeed, only two operational processes are envisaged (graphite storage inside the reactor for 25 years and subsequent entombment). Furthermore, the magnitude of security misappropriation is significantly amplified, as i-graphite is in a substantially more accessible state within an entombed reactor in contrast to a repository. Nevertheless, the commendable performance across other criteria propels this option to attain the highest overall weighted score in the current stage of the MCDA assessment, considering the allocated weightings. Options 6 and 3, focusing on process minimization, achieve excellent scores and rank closely behind option 19. The CARBOWASTE project also corroborates this trend, as these options yield the best results in Allocation B prior to the elimination of less performing options [13]. Option 10 is undoubtedly the least favorable option for managing irradiated graphite in both methodologies. This option yields the poorest results across all criteria, except for " technology predictability" and "stability of employment," in which it instead achieves moderate results.

6. Conclusions

The failure to address i-graphite waste cannot be solely attributed to a lack of available studies and technologies. The main challenges lie in the absence of suitable storage facilities and inadequate regulations that hinder the safe disposal of this radioactive waste. The proposed methodology, based on the AHP method, assigns weights to the classification criteria of the 24 options for the treatment of i-graphite identified in the CARBOWASTE project. The highest weights were assigned by experts to 'environment and public safety' (28.05 %) and 'worker safety' (26.16 %), as evidenced by the vector of priorities leading to the ranking of the 24 options. The AHP method is valuable for furnishing policymakers with technical insights to classify various graphite management options. This is pertinent even though political decisions may occasionally be made regardless of technical considerations, as other factors come into play. The authors believe that the use of the AHP method could provide a trustworthy technical-scientific basis to support the decision regarding the selection of the best option, even though the method exhibits a certain degree of subjectivity in the selection of experts.

The multitude of variables influencing the selection of the optimal strategy clearly favors the adoption of customized solutions. Despite potentially impeding standardized approaches, these tailored solutions serve as a catalyst for accumulating experience, enhancing understanding, and guiding the future of graphite-utilizing nuclear facilities. Considering the foregoing, it is desirable that the efforts of the involved States and the scientific community focus on the following four points: 1) greater coordination between the State and the scientific community, aimed at establishing regulatory frameworks and/or streamlining existing procedures; 2) investments in infrastructure to fulfill this task, particularly in treatment facilities and national surface and geological repositories (for the latter, given the high cost and technical challenges involved, it may be advisable to explore international shared solutions); 3) standardization processes for nuclear facilities and the production of used graphite, facilitating the dissemination of common know-how across countries, thus reducing costs and the risk of knowledge loss due to delayed operations; 4) continuous updating in anticipation of a broader future review to identify any potential issues not currently understood due to lack of on-site experience.

The Italian context presents a challenging scenario for managing i-graphite, with only one feasible option, "in situ entombment," out of 24 due to the absence of a repository, ranking at the top after the application of the AHP method. However, implementing this option requires a temporary repository for low and intermediate activity waste from decommissioning. Moreover, as entombment lacks legislative consideration as a decommissioning strategy, Italy currently lacks feasible disposal options for its approximately 3000 tonnes of i-graphite. Fortunately, recent advancements in siting the National Repository in Italy offer hope, (the Ministry of the Environment and Energy Security (MASE) released, on December 23, 2023, via its official website a list of 51 areas included in the proposed National Map of Suitable Areas [20]) potentially enabling consideration of alternative options such as 10, 11 and 12, although option 10 is deemed the worst choice in both the CARBOWASTE project and the proposed methodology.

CRediT authorship contribution statement

Giambattista Guidi: Conceptualization, Data curation, Formal analysis, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing. **Giacomo Goffo:** Conceptualization, Data curation, Formal analysis, Methodology, Validation, Writing – review & editing. **Anna Carmela Violante:** Conceptualization, Data curation, Formal analysis, Methodology, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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