METHODOLOGIES OF COST ASSESSMENT FOR RADIOACTIVE WASTE AND SPENT FUEL MANAGEMENT. AN OVERVIEW OF THE PRACTICES ADOPTED IN THE EU

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Abstract

Radioactive waste is mainly a result of the production of electricity in nuclear power plants or the use of radioactive materials for medical, research, industrial and agricultural purposes. Due to the radiological properties of radioactive waste and the potential hazard it poses, it is important to ensure safe management of radioactive waste. EU Council Directive 2011/70/Euratom establishes a Community framework for the responsible and safe management of spent fuel and radioactive waste to avoid imposing undue burdens on future generations. This Directive requires among other things that Member States:

- have a national policy;
- draw up and implement National Programmes for the management, including the disposal, of all spent nuclear fuel and radioactive waste generated on their territory;
- provide cost assessments for spent fuel and radioactive waste management in their National Programmes, including assumptions used and profile over time;
- have in place financing mechanisms to ensure that adequate funds are available.

This study assesses the methodologies in use for cost assessment, the financing schemes in place and the relationship between them. It is based on the data available and the results of surveying Member States. It identifies common trends, good practices and challenges for all Member States. It then defines possible tools that can contribute to building common ground among Member States in the analysis of the cost assessment in the field of radioactive waste and spent fuel management. This includes a comprehensive structure of activities and cost items, and relevant Cost Assessment Indicators (CAIs)

Executive Summary

Context

The 2011/70/Euratom Council Directive outlines the general long-term objectives of the European Union in the area of spent fuel and radioactive waste management. One of the main goals of the Directive is to avoid the burden of radioactive waste and spent fuel management being transferred to future generations. The Directive requires Member States to develop proper organisational frameworks, including defining National Programmes, presenting the cost of these over time, detailing the financing schemes in place and systems of appropriate control, including regulatory inspections and reporting obligations. Article 4 establishes the principle of responsibility for waste management by specifying that “each Member State shall have ultimate responsibility for management of the spent fuel and radioactive waste generated in it.”

While the 2011 Directive establishes rules for Member States to follow, it also provides them appropriate flexibility in implementation. This is a necessity as Member States have their own specificities, e.g. generating different types of waste and in different quantities.

The analysis and the comparison of Member States’ cost estimates is challenging because of these specificities, the many methods used in arriving at the estimates, and differences in the underlying basis of analysis and hypotheses used.

Objectives and approach to the study

The aim of this study is to present an in-depth qualitative and quantitative analysis of the methodologies for cost assessment and financing mechanisms in use in the European Union in the management of spent fuel and radioactive waste. The main specific objectives of this study were to:

- Identify common trends, best practices and challenges for Member States;
- Foster knowledge sharing among Member States;
- Identify a set of tools that can contribute to building common ground between Member States.

To provide the basis for this, four main tasks were carried out:

- Costs: determining how the costs are evaluated by assessing the methodologies in use, including the underlying bases and hypotheses;
- Financing methods: reviewing the current financing schemes and how they link to the cost assessments, bearing in mind that another study carried out on behalf of the Commission has looked at this in-depth[1];
- Commonalities: identifying common trends, challenges and good practices across Member States;
- Tools and indicators: defining a set of tools, including a comprehensive structure of activities and cost items, as well as relevant Cost Assessment Indicators (CAIs),

[1] Study on the risk profile of funds allocated to finance the back-end activities of the nuclear fuel cycle in the EU.

which can contribute to building common ground between Member States in the analysis of the cost assessment of radioactive waste and spent fuel management.

The first two tasks, on costs and financing methods, were carried out through documentary analysis. The main sources for these were National Programmes and National Reports produced by Member States (the latter in their 2015 version) under the 2011/70/Euratom Council Directive. This was complemented with additional desk research.

The costs task focused on how the scope of the cost calculation has been defined and the robustness of the methodologies and hypotheses used, since these assessments should be updated periodically to update hypotheses, scope and methodologies.

The financing methods task analysed the nature of the funding schemes and the consistency of the related cost assessment. This question is of crucial importance in ensuring the burden is not transferred to future generations since many of the cash disbursements related to waste management and decommissioning activities occur only years after generation of the waste.

A research protocol was used for each of these tasks consisting of data collection, data analysis and assessment. This was overseen and reviewed by experts, and submitted to the European Commission for validation.

The tasks on finding commonalities and developing tools and indicators were synthesis phases. The goal of the task on commonalities was to identify common trends, common challenges and good practices across Member States in the cost assessment of radioactive waste and spent fuel management.

The task on tools and indicators provided a common description of activities and cost categories for radioactive waste and spent fuel related processes, including the identification of Cost Assessment Indicators.

In order to address these tasks:

1. Relevant information was extracted from key documents identified in the first two tasks (analysis tasks on cost information and funding schemes);[2]
2. Information gaps were identified and addressed with additional desk research;
3. Preliminary findings were presented at an expert workshop organised by the European Commission in October 2018;
4. A survey was prepared and distributed to the EU Member States to collect further information on the methodologies and tools to develop (taxonomy and Cost Assessment Indicators) in the two synthesis tasks;
5. Subject matter experts complemented the desk research and survey results with input from their experience and knowledge.

[2] Due to the structure and organisation of the study, and the availability of data during the different stages of the assignment, the information used may not be the latest available. The core of the data collection was carried out during the period when only the 2015 Council Directive 2011/70/EURATOM reporting was available for all Member States. As mentioned above, this information was complemented with additional information collected by the team at the time of the data collection, as well as expert opinion; however, new information may have emerged in the last year which it was not possible to integrate without jeopardising the timeline of this study.

While a wide range of radioactive waste and spent fuel cost assessment approaches, methods, practices and expertise are in use in the EU Member States, there are also similarities and common trends. These offer an opportunity for mutual learning and exchange of experiences that, together, might disseminate state-of-the-art solutions to all the Member States.

This work has enabled the authors to identify five topics which appear to offer fruitful avenues for discussion across the Member States, notwithstanding the differences in scale of the nuclear programmes, technological approaches and governance of the nuclear industries in each Member State.

Topic areas for further discussion

The five areas identified as offering potential for useful exchanges of experience and identification of good practice are:

- Governance of cost assessment processes – good practices in cost calculation, review and frequency;
- Methodologies for cost calculation – good practices for proper cost calculation;
- Key parameters in cost calculation – good practices in taking into account uncertainties, contingencies and the several additional parameters needed to build cost estimations;
- High-level taxonomy – how to build a reference list of activities and cost items relating to radioactive waste and spent fuel management;
- Cost Assessment Indicators (CAI) – what meaningful cost assessments indicators could be developed for radioactive waste and spent fuel management.

Governance of cost assessment processes

The governance of cost assessment of radioactive waste and spent fuel includes the following steps: cost calculation, which is usually performed by operators, and a review of the cost calculation, which in most Member States is performed by the relevant ministries and/or regulatory bodies. The trends identified in the governance processes for cost assessment in the Member States are:

Cost calculation process

Cost calculation processes in the Member States are different. In most Member States[3], the operators perform the cost calculation, while six Member States have mixed approaches where several different types of actor participate in different parts of the cost calculation process. One of the notable cases of the mixed approach is France, where several bodies are responsible for different aspects of the cost calculation.[4]

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[3] Based on survey responses from 14 Member States.

[4] The licensees are required to send a report to the Ministers in charge of Energy and Economy every three years describing their evaluation of the long-term costs, methods applied to compute reserves as well as the choices made in the composition and management of the assets covering reserves. The licensees update this report every year, but not all inputs are reassessed yearly. The main licensees also publish their financial statements yearly. The evaluation of the cost of the Cigéo waste disposal project has been published by ministerial order of 15th January 2016. This ministerial order specifies that this evaluation will need to be regularly (but not annually)

In most Member States, cost calculations are made every year. Finland and France have mixed approaches, where different aspects of the cost calculation are calculated at different times.

Review of the cost calculation

The purpose of the review is to assess the robustness of the cost calculation methodology and the validity of the cost calculation. The review processes differ across the Member States. In most Member States, ministries and regulatory bodies perform the cost calculation review. As in the case of the cost calculation process, most Member States perform a review of the cost calculation every year.

Governance of cost calculation processes - good practices

- Cost calculations and cost calculation reviews are performed by different organisations (e.g. operators perform cost assessments and government bodies – ministry, national agency – perform the reviews).
- Synchronisation of recurrence of the cost calculation reviews (e.g. if cost calculations are performed annually, the review should also take place annually).

Methodologies for cost calculation

Deterministic, probabilistic, benchmarking and a mix of methods are all in use for calculating the costs for radioactive waste and spent fuel management. All Member States use deterministic methods; of these, seven also make use of probabilistic cost calculation methodologies and seven use benchmarking as a tool for cost calculation.

Deterministic methods are considered to be the simplest and are the most common methods used for radioactive waste (RAW) and spent fuel (SF) cost assessment and for establishing contingency budgets. These methods offer a point estimate for cost assessment at a given date.

In probabilistic methods, uncertainties are explicitly modelled using appropriate statistical distributions. These types of model calculate a range of estimates rather than a point estimate.

Benchmarking is the practice of comparing business processes and performance metrics to industry best practice and best practices from other companies.

DCF (discounted cash flow) is used as a standard valuation method to estimate the actual value of an investment based on its future cash flows.

updated and at least at the key steps in the development of the project (creation authorisation, commissioning, end of pilot industrial phase, periodic safety reviews). Furthermore, the National Plan (Plan National de Gestion des Matières et des Déchets Radioactifs – PNGMDR) is updated every three years, as required by law. This National Plan includes an assessment of the national programme costs, the underlying basis and hypothesis for that assessment and the financing schemes in force. This cost assessment takes operators' cost assessments into account.

Methodologies - good practices

- There is a constant need to ensure the reliability and effectiveness of the chosen methodology.
- Methodologies need to be regularly back-tested.
- Independent assessment of the methodology is a good practice in back-testing.

Key parameters in cost calculation

Elements that have a major impact on the cost assessment process and results are the key parameters used. Hypotheses (on the main cost items), contingencies and expected inflation rates are amongst the key parameters.

Hypotheses

Hypotheses include, among others, the lifetime of installations, inventories of existing spent fuel and radioactive waste, quantities of spent fuel and radioactive waste generated over time. For instance, there would be significant difference in the costs over time of radioactive waste and spent fuel if a nuclear power plant had a lifetime of 30 years but this was extended to 50 years, because more radioactive waste and spent fuel will be generated. Extended operation would at the same time defer the generation of decommissioning wastes, and extend the period available for setting aside funds to cover the cost of decommissioning. The years of additional electricity production will also reduce the cost of waste management and decommissioning per unit of electricity produced.

Uncertainties

The study shows that a wide range of sources of uncertainty are considered in the cost calculation: society, economics, implementation, organisation, technology, calculation and others. They can affect cost calculation in different ways: societal uncertainty can take the form of local community opposition to construction/operation of a storage/disposal facility for radioactive waste; technological uncertainty (future innovative technologies, for example) can lead to uncertainties in costs and project planning. Most Member States consider many categories of uncertainties in their cost calculation.

Contingencies

As in the case of uncertainties, most Member States apply contingencies in cost calculation, but in various ways. The most common answer on contingencies in cost calculations provided by the Member States in the survey was 10-20%, but answers were in the range of 5-50% for specific cost categories.

Inflation rate

The inflation rate is a parameter that directly affects future costs. Most Member States use the general economy inflation rate. However, the nuclear sector inflation rate might differ from that for the economy as a whole, for reasons such as the uniqueness of the technologies and at times high levels of uncertainty (e.g. societal, economic, etc.)

Discount rate

This is a key parameter, since it establishes the connection between the cost calculation and the necessary funds for radioactive waste and spent fuel management. The future costs of radioactive waste and spent fuel management are supposed to be covered by the dedicated funds. The money in the funds is typically invested in low risk government bonds.[5] Therefore, the discount rate needs to be taken into account.

> **Key parameters - good practices**
>
> **Contingencies**
>
> - Include contingencies in the cost calculation;
> - Link contingencies and uncertainties;
> - Take into account that different types of uncertainty (e.g. societal or technological) can lead to different types of contingency.
>
> **Uncertainties**
>
> - Include a variety of relevant uncertainties in cost calculation.
>
> **Inflation rate**
>
> - Consider the need to use a specific inflation rate for the nuclear industry, as opposed to general inflation rate for the whole economy.
>
> **Discount rate**
>
> - Link the calculation of the discount rate to:
>   - the inflation rate used in the Member State; and
>   - the ROI (return on investment) of the investments made with the money in the fund (for example, an inflation rate higher than fund's ROI might need an adjustment for the fund to be able to cover the future costs).

Potential future developments

High-level taxonomy

The radioactive waste and spent fuel management environment is very heterogeneous and, consequently, so are the terminology used and the type of information shared by countries worldwide. To promote better understanding and potentially foster peer learning, there is a case for developing an equivalent of the International Structure for Decommissioning Costing (ISDC) in the area of radioactive waste and spent fuel management.

This study presents a first attempt at developing such an equivalent through a high-level taxonomy comprising four levels:

[5] Portfolio of Swedish nuclear waste fund, p. 10 http://www.karnavfallsfonden.se/download/18.46d462c3159fb761aca1f4f/1523619691724/Fakta%20om%20K%C3%A4rnavfallsfonden%202017%20engelska.pdf

- Level I differentiates between the categories/classes of waste and of spent fuel;
- Level II specifies the management processes according to a structure of broad cost items;
- Level III introduces an additional level of granularity through segregation by possible management stages;
- Level IV might be added with key cost categories based on the ISDC cost categories and additional recurring cost categories used by Member States.

Take-away

The proposed high-level taxonomy was presented to all Member States through a survey, where they were asked whether the levels proposed represent a useful reference for building a high-level taxonomy, and if they wanted to suggest an alternative approach.

The results of the survey submitted to EU Member States suggested that this high-level taxonomy could be a good basis for embarking on further discussions with Member States and relevant international organisations (in particular IAEA and OECD-NEA).

Cost Assessment Indicators (CAI)

There are many approaches to developing Cost Assessment Indicators in use around the world, including those used by the Member States. This study identified two concrete approaches that could facilitate peer learning between Member States:

- A top-down approach: this approach further builds on the suggested taxonomy developed in this study. However, as the high-level taxonomy is still only a proposal and Member States today use only some of the categories in their reporting, it is an approach that cannot yet be put forward systematically. The aim is to be able to build towards it over time, e.g. in areas such as storage costs, repository costs, processing costs, etc. (per waste stream identified in the taxonomy, as relevant).
- A bottom-up approach: this approach might be considered more accessible to Member States, as they are already using some of the indicators. This could be considered an intermediate approach or an alternative, if the top-down approach is not yet feasible, albeit the results of the consultation survey would suggest otherwise. Some examples of areas it could cover (per waste stream, as relevant) are allowances for unspecified items, operational costs, compensation to authorities.

Take-away

As in the case of the high-level taxonomy, all Member States were asked their views on a top-down approach to developing Cost Assessment Indicators, based on the availability of data in their country, and whether they had alternative approaches to suggest.

Of those Member States responding, the majority said that the suggested top-down Cost Assessment Indicators would be a feasible option. This suggests that a majority of Member States could use such Cost Assessment Indicators to assess their cots in future.

Sommaire

Les déchets radioactifs résultent principalement de la production d'électricité dans les centrales nucléaires ou de l'utilisation de substances radioactives à des fins médicales, industrielles, agricoles et de recherche. En raison des propriétés radiologiques des déchets radioactifs et du danger potentiel qu'ils représentent, il est essentiel de garantir une gestion sûre de ces déchets. La directive 2011/70/Euratom du Conseil européen établit un cadre communautaire pour une gestion responsable et sûre du combustible usé et des déchets radioactifs afin d'éviter d'imposer aux générations futures des contraintes excessives. Cette directive exige entre autres que les États membres:

- mènent une politique nationale ;
- élaborent et mettent en œuvre des programmes nationaux pour la gestion, y compris le stockage, de l'ensemble du combustible nucléaire usé et des déchets radioactifs produits sur leur territoire ;
- fournissent une évaluation des coûts de la gestion du combustible usé et des déchets radioactifs dans leurs programmes nationaux, y compris les hypothèses utilisées et un calendrier ;
- mettent en place des mécanismes de financement pour garantir la disponibilité de fonds suffisants.

Cette étude évalue les méthodes utilisées pour l'évaluation des coûts, les mécanismes de financement mis en place et la relation qui les unit. Elle se fonde sur les données disponibles et les résultats des enquêtes menées auprès des États membres. Elle identifie les tendances, les bonnes pratiques et les défis communs des États membres. Par ailleurs, elle définit les outils possibles pouvant contribuer à bâtir un terrain d'entente entre les États membres dans le cadre de l'analyse de l'évaluation des coûts en matière de gestion du combustible usé et des déchets radioactifs. Cela comprend une structure complète des activités et des postes de coûts, ainsi que des indicateurs pertinents d'évaluation des coûts (IEC).

Résumé

Contexte

La directive 2011/70/Euratom du Conseil européen décrit les objectifs généraux à long terme de l'Union européenne en termes de gestion du combustible usé et des déchets radioactifs. L'un des principaux objectifs de la directive est d'éviter que la contrainte de la gestion du combustible usé et des déchets radioactifs ne soit transférée aux générations futures. La directive exige des États membres qu'ils élaborent des cadres organisationnels adéquats, notamment en élaborant des programmes nationaux, en présentant les coûts de ces programmes dans le temps, en détaillant les mécanismes de financement mis en place ainsi que les systèmes de mesures de contrôle appropriées, y compris les inspections réglementaires et l'établissement de rapports. L'article 4 consacre le principe de la responsabilité de la gestion des déchets en précisant que « chaque État membre est responsable, en dernier ressort, de la gestion du combustible usé et des déchets radioactifs qui ont été produits sur son territoire. »

Si la directive de 2011 fixe les règles à respecter par les États membres, elle leur offre également une certaine flexibilité de mise en œuvre. Il s'agit là d'une nécessité, car les États membres ont tous leurs propres spécificités, p. ex. la production de différents types de déchets en différentes quantités.

L'analyse et la comparaison des évaluations des coûts des États membres représentent dès lors un véritable défi en raison de ces spécificités, des nombreuses méthodes utilisées pour réaliser ces évaluations et des différences dans le fondement de l'analyse et des hypothèses utilisées.

Objectifs et approche de l'étude

Le but de cette étude est de présenter une analyse qualitative et quantitative approfondie des méthodes d'évaluation des coûts et des mécanismes de financement en usage au sein de l'Union européenne dans le cadre de la gestion du combustible usé et des déchets radioactifs. Les principaux objectifs spécifiques de cette étude étaient les suivants :

- Identifier les tendances, les bonnes pratiques et les défis communs des États membres ;
- Encourager le partage de connaissances entre les États membres ;
- Identifier un ensemble d'outils pouvant contribuer à bâtir un terrain d'entente entre les États membres.

Pour y parvenir, quatre tâches principales ont été accomplies :

- Coûts : déterminer comment les coûts sont estimés en évaluant les méthodes utilisées, y compris les fondements et les hypothèses ;

- Modes de financement : examiner les mécanismes de financement actuels et le lien qu'ils entretiennent avec les évaluations des coûts, sachant qu'une autre étude menée pour le compte de la Commission a examiné cette question plus en détail[6] ;
- Points de convergence : identifier les tendances, les bonnes pratiques et les défis communs des États membres ;
- Outils et indicateurs : définir un ensemble d'outils, y compris une structure complète des activités et des postes de coûts, ainsi que des indicateurs pertinents d'évaluation des coûts (IEC) pouvant contribuer à bâtir un terrain d'entente entre les États membres dans l'analyse de l'évaluation des coûts en matière de gestion du combustible usé et des déchets radioactifs.

Les deux premières tâches, relatives aux coûts et aux modes de financement, ont été accomplies par le biais d'une analyse documentaire fondée principalement sur les programmes et les rapports nationaux fournis par les États membres (ces derniers dans leur version de 2015) en vertu de la directive 2011/70/Euratom du Conseil. Cette analyse a été complétée par une recherche documentaire supplémentaire.

La tâche relative aux coûts s'est concentrée sur la manière dont le champ d'application du calcul des coûts a été défini et sur la fiabilité des méthodes et des hypothèses utilisées, étant donné que ces évaluations doivent périodiquement être mises à jour pour actualiser les hypothèses, le champ d'application et les méthodes.

La tâche portant sur les modes de financement s'est axée sur l'analyse de la nature des mécanismes de financement et de la cohérence de l'évaluation des coûts associés. Ce point est fondamental pour veiller à ce que la contrainte ne soit pas transmise aux générations futures, étant donné qu'une grande partie des décaissements liés aux activités de gestion des déchets et de démantèlement n'interviennent que des années après la production des déchets.

Un protocole de recherche a été suivi pour chacune de ces tâches. Celui-ci consistait en la collecte, l'analyse et la vérification de données et a été supervisé et examiné par des experts avant d'être soumis à la Commission européenne pour validation.

Les tâches consistant à trouver des points de convergence et à développer des outils et des indicateurs constituaient des phases de synthèse. La tâche relative aux points de convergence visait à identifier les tendances, les bonnes pratiques et les défis communs des États membres en matière d'évaluation des coûts de la gestion des déchets radioactifs et du combustible usé.

La tâche portant sur les outils et les indicateurs fournissait une description commune des activités et des catégories de coûts pour les processus associés aux déchets radioactifs et au combustible usé, y compris l'identification des indicateurs d'évaluation des coûts.

[6] Étude sur le profil de risque des fonds alloués au financement des activités en aval du cycle du combustible nucléaire au sein de l'UE.

Afin d'atteindre ces objectifs :

1. Des informations pertinentes ont été extraites de documents clés identifiés au cours des deux premières tâches (analyse des coûts et des mécanismes de financement) ;[7]

2. Les lacunes en matière d'information ont été identifiées et corrigées à l'aide de recherches documentaires supplémentaires ;

3. Des résultats préliminaires ont été présentés lors d'un atelier d'experts organisé par la Commission européenne en octobre 2018 ;

4. Une enquête a été réalisée et distribuée aux États membres de l'UE afin de recueillir de plus amples informations sur les méthodes et les outils à développer (taxonomie et indicateurs d'évaluation des coûts) dans les deux tâches de synthèse ;

5. Des spécialistes ont complété la recherche documentaire et les résultats de l'enquête en apportant leur expérience et leurs connaissances.

Bien qu'un large éventail d'approches, de méthodes, de pratiques et de savoir-faire en matière d'évaluation des coûts des déchets radioactifs et du combustible usé sont en usage au sein des États membres de l'UE, il existe également des similitudes et des tendances communes. Celles-ci offrent une occasion d'apprentissage mutuel et d'échanges d'expériences qui, conjointement, pourraient apporter des solutions de pointe à tous les États membres.

Ce travail a permis aux auteurs d'identifier cinq domaines qui semblent offrir des pistes de discussion constructives entre les États membres, indépendamment des différences d'échelle des programmes nucléaires, des approches technologiques et de la gestion de l'industrie nucléaire dans chaque État membre.

Sujets à approfondir

Les cinq domaines considérés comme offrant un potentiel d'échanges d'expériences utiles et une identification des bonnes pratiques sont les suivants :

- Gestion des processus d'évaluation des coûts – bonnes pratiques en matière de calcul des coûts, d'examen et de fréquence ;
- Méthodes de calcul des coûts – bonnes pratiques pour un calcul correct des coûts ;
- Paramètres clés du calcul des coûts – bonnes pratiques pour la prise en compte des incertitudes, des imprévus et d'autres paramètres nécessaires à l'évaluation des coûts ;
- Taxonomie de haut niveau – comment dresser une liste de référence des activités et des postes de coûts associés à la gestion des déchets radioactifs et du combustible usé ;

[7] En raison de la structure et de l'organisation de l'étude, ainsi que de la disponibilité des données durant les différentes étapes du projet, les informations utilisées ne sont peut-être pas les dernières disponibles. L'essentiel de la collecte de données a été effectué pendant la période où seule la directive 2011/70/EURATOM du Conseil de 2015 était disponible pour tous les États membres. Comme indiqué précédemment, ces informations ont été complétées par d'autres informations recueillies par l'équipe au moment de la collecte des données ainsi que par des avis d'experts. Toutefois, il est possible que de nouvelles informations soient parues l'année dernière, mais n'aient pas pu être intégrées à l'étude sans en compromettre le calendrier.

- Indicateurs d'évaluation des coûts (IEC) - quels indicateurs significatifs d'évaluation des coûts peuvent être développés dans le cadre de la gestion des déchets radioactifs et du combustible usé.

Gestion des processus d'évaluation des coûts

La gestion de l'évaluation des coûts des déchets radioactifs et du combustible usé comprend les étapes suivantes : un calcul des coûts, généralement effectué par les exploitants, et un examen du calcul des coûts, réalisé dans la plupart des États membres par les ministères et/ou les organismes de réglementation compétents. Les tendances identifiées dans les processus de gestion de l'évaluation des coûts au sein des États membres sont les suivantes :

Processus de calcul des coûts

Les processus de calcul des coûts varient selon les États membres. Dans la plupart des États membres[8], ce sont les exploitants qui effectuent le calcul des coûts, tandis que six États membres adoptent des approches mixtes où plusieurs types d'acteurs participent aux différentes phases du processus de calcul des coûts. La France constitue un bel exemple de cette approche mixte, car plusieurs organismes sont responsables de différents aspects du calcul des coûts.[9]

Dans la plupart des États membres, le calcul des coûts est effectué chaque année. La Finlande et la France appliquent des approches mixtes, où plusieurs aspects du calcul des coûts sont abordés à des moments différents.

Examen du calcul des coûts

L'objectif de cet examen est d'évaluer la fiabilité de la méthode de calcul des coûts et la validité du calcul des coûts. Les procédures d'examen varient d'un État membre à l'autre. Dans la plupart d'entre eux, ce sont les ministères et les organismes de réglementation qui y procèdent. Comme dans le cas du processus de calcul des coûts, la plupart des États membres réalisent un examen du calcul des coûts chaque année.

[8] Sur la base des réponses à l'enquête de 14 États membres.

[9] Les licenciés sont tenus d'envoyer tous les trois ans un rapport aux ministres de l'Économie et de l'Énergie décrivant leur évaluation des coûts à long terme, les méthodes utilisées pour le calcul des provisions ainsi que leurs choix en matière de composition et de gestion des actifs couvrant les provisions. Les licenciés actualisent ce rapport chaque année, mais toutes les données ne sont pas réévaluées sur base annuelle. Les licenciés principaux publient également leurs états financiers chaque année. L'évaluation des coûts du projet de stockage des déchets de Cigéo a été publiée par l'arrêté ministériel du 15 janvier 2016. Celui-ci précise que cette évaluation devra régulièrement (mais pas annuellement) être mise à jour, au moins aux étapes clés du développement du projet (autorisation de création, mise en service, fin de la phase industrielle pilote, bilans périodiques de sûreté). Par ailleurs, le Plan national (Plan National de Gestion des Matières et des Déchets Radioactifs – PNGMDR) est actualisé tous les trois ans, comme l'exige la loi. Ce plan national comprend une évaluation des coûts du programme national, le fondement et les hypothèses nécessaires à cette évaluation, ainsi que les mécanismes de financement en vigueur. Cette évaluation des coûts tient compte de celle des exploitants.

Gestion des processus de calcul des coûts - bonnes pratiques

- Les calculs des coûts et leurs examens sont effectués par différentes organisations (p. ex., les exploitants se chargent de l'évaluation des coûts et les organismes gouvernementaux – ministères, agences nationales – des examens).
- Synchronisation de la récurrence des examens des calculs des coûts (p. ex. si les calculs des coûts sont effectués chaque année, les examens doivent également avoir lieu sur base annuelle).

Méthodes de calcul des coûts

Des méthodes déterministes, probabilistes, d'étalonnage et de plusieurs types sont utilisées dans le calcul des coûts de la gestion des déchets radioactifs et du combustible usé. Tous les États membres emploient des méthodes déterministes ; sept d'entre eux emploient également des méthodes probabilistes de calcul des coûts, tandis que sept autres ont recours à l'étalonnage comme outil de calcul des coûts.

Les méthodes déterministes sont considérées comme les plus simples et sont les plus couramment utilisées pour évaluer les coûts des déchets radioactifs et du combustible usé et pour établir les budgets de réserve. Ces méthodes offrent une estimation ponctuelle de l'évaluation des coûts à une date donnée.

Dans les méthodes probabilistes, les incertitudes sont explicitement modélisées grâce à des distributions statistiques adéquates. Ces types de modèles calculent plutôt une fourchette d'estimations qu'une estimation ponctuelle.

Quant à l'étalonnage, il consiste à comparer les processus opérationnels et les mesures de performance aux bonnes pratiques de l'industrie et d'autres entreprises.

Le DCF (flux de trésorerie actualisé) est utilisé comme méthode d'évaluation standard pour estimer la valeur réelle d'un investissement sur la base des flux de trésorerie futurs.

Méthodes - bonnes pratiques

- Il est constamment nécessaire de garantir la fiabilité et l'efficacité de la méthode choisie.
- Les méthodes doivent régulièrement faire l'objet de contrôles a posteriori.
- Une évaluation indépendante de la méthode constitue une bonne pratique de contrôle a posteriori.

Paramètres clés du calcul des coûts

Les paramètres clés utilisés ont un impact majeur sur le processus d'évaluation des coûts et les résultats. Parmi ces derniers figurent les hypothèses (sur les principaux postes de coûts), les imprévus et les taux d'inflation prévus.

Hypothèses

Les hypothèses comprennent, entre autres, la durée de vie des installations, les inventaires du combustible usé et des déchets radioactifs existants, ainsi que les quantités de combustible usé et de déchets radioactifs produits au fil du temps. Par exemple, il existerait une différence importante dans les coûts des déchets radioactifs et du combustible usé au fil du temps si la durée de vie d'une centrale nucléaire était portée de 30 à 50 ans, car davantage de déchets radioactifs et de combustible usé seront produits. L'exploitation prolongée reporterait en même temps la production des déchets de démantèlement et prolongerait la période disponible pour constituer une réserve de fonds en vue de couvrir le coût du démantèlement. Les années de production d'électricité supplémentaire permettront également de réduire le coût de la gestion des déchets et du démantèlement par unité d'électricité produite.

Incertitudes

L'étude montre qu'un large éventail de sources d'incertitude est pris en compte dans le calcul des coûts : société, économie, mise en œuvre, organisation, technologie, calcul et autres. Celles-ci peuvent affecter le calcul des coûts de différentes manières : l'incertitude sociétale peut se présenter sous la forme d'une collectivité locale s'opposant à la construction/exploitation d'une installation de stockage/d'entreposage des déchets radioactifs, tandis que l'incertitude technologique (de futures technologies innovantes, par exemple) peut induire des incertitudes dans les coûts et la planification du projet. La plupart des États membres tiennent compte de nombreuses catégories d'incertitudes dans leur calcul des coûts.

Imprévus

Comme pour les incertitudes, la plupart des États membres tiennent compte des éventuels imprévus dans le calcul des coûts, mais de différentes manières. La réponse la plus courante concernant les imprévus dans les calculs des coûts indiqués par les États membres dans l'enquête était 10-20 %, mais les réponses étaient de l'ordre de 5-50 % pour les catégories de coûts spécifiques.

Taux d'inflation

Le taux d'inflation est un paramètre qui affecte directement les coûts futurs. La plupart des États membres utilisent le taux d'inflation de l'économie générale. Toutefois, le taux d'inflation du secteur nucléaire peut différer de celui de l'économie générale notamment en raison du caractère unique des technologies et des niveaux d'incertitude parfois élevés (sociétale, économique, etc.).

Taux d'actualisation

Il s'agit d'un paramètre clé puisqu'il assure la connexion entre le calcul des coûts et les fonds nécessaires à la gestion des déchets radioactifs et du combustible usé. Les coûts futurs de la gestion des déchets radioactifs et du combustible usé sont censés être couverts par les fonds qui y sont dédiés. L'argent de ces fonds est généralement investi dans des obligations d'État à faible risque.[10] C'est la raison pour laquelle il convient de tenir compte du taux d'actualisation.

Paramètres clés - bonnes pratiques

Imprévus

- Inclure les imprévus dans le calcul des coûts ;
- Établir un lien entre les imprévus et les incertitudes ;
- Garder à l'esprit que différents types d'incertitudes (sociétal ou technologique, p. ex.) peuvent mener à différents types d'imprévus.

Incertitudes

- Inclure une série d'incertitudes pertinentes dans le calcul des coûts.

Taux d'inflation

- Étudier la nécessité d'utiliser un taux d'inflation spécifique à l'industrie nucléaire par opposition au taux d'inflation général pour l'ensemble de l'économie.

Taux d'actualisation

- Établir un lien entre le calcul du taux d'actualisation et :
    - le taux d'inflation utilisé dans l'État membre ; et
    - le RSI (retour sur investissement) des investissements réalisés avec l'argent du fonds (un taux d'inflation supérieur au RSI du fonds peut par exemple requérir un ajustement pour que le fonds puisse couvrir des coûts futurs).

Éventuels développements futurs

Taxonomie de haut niveau

L'environnement de gestion des déchets radioactifs et du combustible usé est extrêmement hétérogène et il en va par conséquent de même pour la terminologie utilisée et le type d'informations partagées par les pays à l'international. Afin de favoriser une meilleure compréhension et un éventuel apprentissage par les pairs, il y a lieu de développer un équivalent de la Structure internationale pour la tarification du déclassement (ISDC) dans le domaine de la gestion des déchets radioactifs et du combustible usé.

Cette étude présente une première tentative d'élaborer un tel équivalent par le biais d'une taxonomie de haut niveau comprenant quatre niveaux :

- Le niveau I distingue les catégories/classes de déchets et de combustible usé ;
- Le niveau II précise les processus de gestion en fonction d'une structure de vastes postes de coûts ;
- Le niveau III introduit un niveau de granularité supplémentaire grâce à la répartition en étapes de gestion possibles ;

[10] Portfolio du fonds suédois des déchets nucléaires, p. 10 http://www.karnavfallsfonden.se/download/18.46d462c3159fb761aca1f4f/1523619691724/Fakta%20om%20K%C3%A4rnavfallsfonden%202017%20engelska.pdf

- Le niveau IV pourrait être ajouté avec des catégories de coûts principales basées sur les catégories de coûts de l'ISDC et des catégories de coûts récurrentes utilisées par les États membres.

À retenir

La taxonomie de haut niveau proposée a été présentée à tous les États membres par le biais d'une enquête au cours de laquelle il leur a été demandé si les niveaux proposés représentaient une référence utile pour l'élaboration d'une taxonomie de haut niveau et s'ils souhaitaient proposer une autre approche.

Les résultats de l'enquête soumise aux États membres ont indiqué que cette taxonomie de haut niveau pourrait constituer une bonne base pour entamer de nouvelles discussions avec les États membres et des organisations internationales compétentes (en particulier l'AIEA et l'OCDE-AEN).

Indicateurs d'évaluation des coûts (IEC)

Il existe plusieurs manières de développer des indicateurs d'évaluation des coûts en usage dans le monde entier, y compris ceux utilisés par les États membres. Cette étude a identifié deux approches concrètes qui pourraient faciliter l'apprentissage par les pairs entre les États membres :

- Une approche descendante : cette approche s'appuie sur la taxonomie présentée dans cette étude. Toutefois, étant donné que la taxonomie de haut niveau n'en est encore qu'au stade de proposition et que les États membres n'utilisent aujourd'hui que certaines catégories dans leurs rapports, il s'agit d'une approche qui ne peut pas encore être proposée systématiquement. L'objectif est de pouvoir s'en rapprocher au fil du temps, p. ex. dans des domaines tels que les coûts de stockage, les coûts de dépôt, les coûts de traitement, etc. (par flux de déchets identifié dans la taxonomie, le cas échéant).
- Une approche ascendante : cette approche pourrait être considérée comme plus accessible aux États membres, car ils utilisent déjà certains indicateurs. Elle pourrait être considérée comme une approche intermédiaire ou une solution alternative si l'approche descendante n'est pas encore possible, bien que les résultats de l'enquête de consultation suggèrent le contraire. Parmi les exemples de domaines qu'elle pourrait couvrir (par flux de déchets, le cas échéant), on peut citer les indemnités pour des éléments non spécifiés, les coûts opérationnels et l'indemnisation des autorités.

À retenir

Comme pour la taxonomie de haut niveau, tous les États membres ont été invités à donner leur avis sur une approche descendante dans le cadre du développement des indicateurs d'évaluation des coûts en fonction de la disponibilité des données dans leur pays, et à indiquer s'ils désiraient proposer d'autres approches.

La majorité des États ayant répondu ont déclaré que l'approche descendante des indicateurs d'évaluation des coûts était une option envisageable. Cela signifie qu'une majorité d'États membres pourraient utiliser ces indicateurs d'évaluation des coûts pour évaluer leurs coûts à l'avenir.

Acronyms and abbreviations

Acronyms /Abbreviations	
General	
DSRS	Design Safety Review Services
HLW	High Level Waste
IAEA	International Atomic Energy Agency
IFRS	International Financial Reporting Standards
ILW	Intermediate Level Waste
ISDC	International Structure for Decommissioning Costing
LILW	Low Intermediate Level Waste
LL	Long-lived waste
LLW	Low Level Waste
MS	Member State
NPP	Nuclear Power Plant
OECD	Organisation for Economic Cooperation and Development
RAW	Radioactive Waste
SF	Spent Fuel
SL	Short Lived waste
ToR	Terms of Reference
VLLW	Very Low Level Waste
Country acronyms	
AT	Austria
BE	Belgium
BG	Bulgaria
CY	Cyprus
CZ	Czechia
DE	Germany
DK	Denmark
EE	Estonia
EL	Greece

Acronyms /Abbreviations	
ES	Spain
FI	Finland
FR	France
HR	Croatia
HU	Hungary
IE	Ireland
IT	Italy
MT	Malta
NL	Netherlands
LT	Lithuania
LU	Luxembourg
LV	Latvia
PL	Poland
PT	Portugal
RO	Romania
SE	Sweden
SI	Slovenia
SK	Slovakia
UK	United Kingdom

Glossary of key concepts[11]

Concept	Definition used in this study
Clearance	Either: a) Removal of radioactive material or radioactive objects within authorized practices from any further regulatory control by the regulatory body. b) The net effect of the biological processes by which radionuclides are removed from a tissue, organ or area of the body.
Conditioning	Those operations that produce a waste package suitable for handling, transport, storage and/or disposal. Conditioning may include the conversion of the waste to a solid waste form, enclosure of the waste in containers and, if necessary, provision of an over pack.
Contingency	The Association for the Advancement of Cost Engineering (AACE) defines contingency as “An amount added to an estimate to allow for items, conditions or events for which the state, occurrence, or effect is uncertain and that experience shows will likely result, in aggregate, in additional costs. Typically estimated using statistical analysis or judgment based on past asset or project experience” A construction contingency is an amount of money set aside to cover any unexpected costs that can arise throughout a construction project. This money is on reserve and is not allocated to any specific area of work. Essentially, the contingency acts as insurance against other, unforeseen costs.
Decommissioning	Administrative and technical actions taken to allow the removal of some or all of the regulatory controls from a facility (except for a repository or for certain nuclear facilities used for the disposal of residues from the mining and processing of radioactive material, which are “closed” and not “decommissioned”).
Disposal	Emplacement of waste in an appropriate facility without the intention of retrieval.
Processing waste	Any operation that changes the characteristics of waste, including pre-treatment, treatment and conditioning.
Repository	A nuclear facility where waste is emplaced for disposal. Repositories are either:

[11] Nuclear Energy Agency, “International Structure for Decommissioning Costing (ISDC) of Nuclear Installations" - https://www.oecd-nea.org/rwm/reports/2012/ISDC-nuclear-installations.pdf

Concept	Definition used in this study
	a) Geological repository. A facility for radioactive waste disposal located underground (usually several hundred metres or more below the surface) in a stable geological formation to provide long-term isolation of radionuclides from the biosphere. b) Near-surface repository. A facility for radioactive waste disposal located at or within a few tens of metres of the Earth's surface.
Retrievability	The ability of a facility to reverse the package emplacement system and more specifically to recover waste or spent fuel packages.
Spent fuel	Nuclear fuel that has been irradiated in and permanently removed from a reactor core.
Storage	The holding of spent fuel or of radioactive waste in a facility that provides for its containment, with the intention of retrieval. Storage is by definition an interim measure, and the term interim storage would therefore be appropriate only to refer to short-term temporary storage when contrasting this with the longer-term fate of the waste. Storage as defined above should not be described as interim storage.
Transportation	The deliberate physical movement of radioactive material (other than that forming part of the means of propulsion) from one place to another.
Treatment	Operations intended to benefit safety and/or economy by changing the characteristics of the waste. Three basic treatment objectives are volume reduction, removal of radionuclides from the waste and change of composition. Treatment may result in an appropriate waste form.
Uncertainties	Uncertainty is defined as a context for risks as events having a negative impact on a project's outcomes, or opportunities, as events that have beneficial impact on project performance. This definition stresses dual nature of uncertainty in potentially having both positive and negative influence o on the project's outcomes. Uncertainty can arise from sources both internal and external to the project. In the case of project management, risk is an uncertain event or condition that, if it occurs has a positive or negative effect on at least one project objective, such as time, cost, scope or quality Uncertainties have a defined range of possible outcomes described by functions reflecting the probability for each outcome. Uncertainty functions can describe discrete events or continuous ranges of outcomes.
Waste	Material for which no further use is foreseen.

Concept	Definition used in this study
Waste, Exempt (EW)	Waste that meets the criteria for clearance, exemption or exclusion from regulatory control for radiation protection purposes. This item may involve also reusable materials.
Waste, High-Level (HLW)	Waste with levels of activity concentration high enough to generate significant quantities of heat by the radioactive decay process or waste with large amounts of long-lived radionuclides that need to be considered in the design of a disposal facility for such waste.
Waste, Intermediate-Level (ILW)	Waste that, because of its content, particularly of long-lived radionuclides, requires a greater degree of containment and isolation than that provided by near-surface disposal. However, ILW needs no provision, or only limited provision, for heat dissipation during its storage and disposal. ILW may contain long-lived radionuclides, in particular, alpha-emitting radionuclides that will not decay to a level of activity concentration acceptable for near-surface disposal during the time for which institutional controls can be relied upon. Therefore, waste in this class requires disposal at greater depths, of the order of tens of metres to a few hundred metres.
Waste, Low-Level (LLW)	Waste that is above clearance levels, but with limited amounts of long-lived radionuclides. Such waste requires robust isolation and containment for periods of up to a few hundred years and is suitable for disposal in engineered near-surface facilities. This class covers a very broad range of waste. LLW may include short-lived radionuclides at higher levels of activity concentration, and also long-lived radionuclides, but only at relatively low levels of activity concentration.
Waste, radioactive	For legal and regulatory purposes, waste that contains, or is contaminated with, radionuclides at concentrations or activities greater than clearance levels as established by the regulatory body.
Waste, Very Low-Level (VLLW)	Waste that does not necessarily meet the criteria of EW, but that does not need a high level of containment and isolation and, therefore, is suitable for disposal in near surface, landfill-type facilities with limited regulatory control. Such landfill-type facilities may also contain other hazardous waste. Typical waste in this class includes soil and rubble with low levels of activity concentration. Concentrations of longer-lived radionuclides in VLLW are generally very limited.
Waste, Very Short-Lived (VSLW)	Waste that can be stored for decay over a limited period of up to a few years and subsequently cleared from regulatory control according to arrangements approved by the regulatory body, for uncontrolled disposal, use or discharge. This class includes waste containing primarily radionuclides with very short half-lives often used for research and medical purposes.

Concept	Definition used in this study
Waste characterisation	Determination of the physical, chemical and radiological properties of the waste to establish the need for further adjustment, treatment or conditioning, or its suitability for further handling, processing, storage or disposal.
Waste conditioning	Those operations that produce a waste package suitable for handling, transport, storage and/or disposal. Conditioning may include the conversion of the waste to a solid waste form, enclosure of the waste in containers and, if necessary, provision of an over pack.
Waste treatment	Operations intended to benefit safety and/or economy by changing the characteristics of the waste. Three basic treatment objectives are: a) Volume reduction; b) Removal of radionuclides from the waste; and c) Change of composition.

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1. Introduction

1.1 Purpose of the document

This is the final report for the study "Methodologies of cost assessment for radioactive waste and spent fuel management. An overview on the practices used in the EU" carried out for the European Commission, Directorate-General for Energy.

In the context of the analysis of the methodologies of cost assessment for radioactive waste and spent fuel management, the main objectives of the study were:

- Identify common trends, best practices and challenges for Member States;
- Foster knowledge sharing among Member States;
- Identify a set of tools that can contribute to build a common ground between Member States.

The report presents the work done, including the main activities carried out to progress with the project and the results linked to the following four main tasks:

- Task A – Reviewing for each Member State the methodologies in use for the cost assessment, including underlying bases and hypotheses;
- Task B – Reviewing for each Member State the financing scheme in force and their link with the cost assessment made;
- Task C - Identifying common trends, good practices and challenges for all Member States;
- Task D – Defining a set of tools, including a comprehensive structure of activities and cost items as well as relevant Cost Assessment Indicators (CAIs) that can contribute to build a common ground between Member States in the analysis of the cost assessment in the field of radioactive waste (RAW) and spent fuel (SF) management.

1.2 Structure and content of the report

The report is structured as follows:

- Chapter 2 presents the understanding of the context, scope, objectives and methodology of the study;
- Chapter 3 provides the review and analysis of the cost assessments and financing schemes (Tasks A and B);
- Chapter 4 includes the trends, best practices, and proposes tools and indicators (Tasks C and D);
- Chapter 5 sets out a series of conclusions.

In addition, the following appendices complete the report:

- Appendix 1: Brief overview of IAEA and ISDC cost classifications;
- Appendix 2: Data sources for the illustration of the top-down approach to Cost Assessment Indicators;

- Appendix 3: Detailed bottom-up approach to Cost Assessment Indicators;
- Appendix 4: Overview of the EU nuclear fleet and of radioactive waste inventories in the EU[12].

[12] The national inventory is made up of the data provided in the declarations submitted by the waste generators. Each generator is therefore responsible for the declaration it submits.

2 Context, objectives and methodology of the study

2.1 Context

The first part of this chapter provides background on Directive 2011/70/EURATOM[13], before describing individual Member State radioactive waste classification systems.

2.1.1 Regulatory context

In the context of the EURATOM treaty, numerous questions relating to the management of the nuclear energy sector have been addressed at European level. One issue is the long-term treatment of radioactive waste and spent fuel generated during the operations of nuclear reactors, including non-power related usage. This is an issue of crucial importance given the relevance of nuclear energy in the total energy mix of the EU-28, the quantities of waste generated and the radiological properties that make them particularly challenging to deal with. To address this, a series of European legal texts on the management of nuclear waste have been adopted over the years, notably:

- Council Directive 2006/117/EURATOM[14] on the control of transboundary shipments of radioactive waste and spent fuel,
- Directive 2006/21/EC[15] on the management of waste from extractive industries,
- Council Directive 2011/70/EURATOM on management of spent fuel and radioactive waste (Radioactive Waste Directive).

As one of the "central" texts in the nuclear back-end, the Radioactive Waste Directive outlines the general long-term objectives of the European Union in this area. One of the goals is to avoid the burden of radioactive waste and spent fuel being transferred to future generations by enforcing safe, sustainable and transparent processes. It requires Member States, inter alia, to develop a proper organisational framework[16], entailing the adoption of National Programmes providing information on appropriate control systems (including regulatory inspections and reporting obligations) as well as the schemes for financing storage and disposal of radioactive waste and spent fuel[17]. Article 4 also establishes that "each Member

[13] Council Directive 2011/70/Euratom of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste, OJ L 199, 2 August 2011, p. 48–56; http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32011L0070&qid=1397211079180.

[14] Council Directive 2006/117/Euratom of 20 November 2006 on the supervision and control of shipments of radioactive waste and spent fuel, OJ L 337, 5.12.2006, p. 21–32; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32006L0117.

[15] Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries and amending Directive 2004/35/EC - Statement by the European Parliament, the Council and the Commission, OJ L 102, 11.4.2006, p. 15–34; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32006L0021.

[16] Articles 1.2 and 5.1 of Council Directive 2011/70/EURATOM.

[17] Article 4 and 5(d) of Council Directive 2011/70/EURATOM.

State shall have ultimate responsibility for management of the spent fuel and radioactive waste generated in it".

While the Radioactive Waste Directive institutes rules for Member States to follow, it also provides them appropriate flexibility in implementation. This is a necessity in the area of nuclear waste and spent fuel management, as countries all have their specificities, generating different types of waste in different quantities. For example, Article 15.2 specifies that "the obligations for transposition and implementation of provisions related to spent fuel of this Directive shall not apply to Cyprus, Denmark, Estonia, Ireland, Latvia, Luxembourg and Malta for as long as they decide not to develop any activity related to nuclear fuel".

The sources of complexities in the implementation of the Directive 2011/70 are in particular:

a) The differences between Member States' waste classification systems: even if the reason for such differences is legitimate, as Member States do not necessarily generate the same types of waste, they blur the overall picture of European radioactive waste and spent fuel management practices. Having a thorough understanding of total waste generated, stored and disposed is difficult.

b) The differences in cost structures and associated funding schemes: such differences, albeit also understandable given the fundamental differences in vision, strategies and approaches to the nuclear industry across the EU-28, add a considerable degree of complexity to the analysis of waste management practices.

c) The differences in reporting: a) and b) above logically result in considerable reporting differences.

Thus, for the Directive to generate all its potential value-added, there is a need for further processing and analysis of the data reported by the Member States.

2.1.2 Waste management and its cost

Given that Member States categorise and define waste individually, the nomenclature generally used in this study is that developed by the International Atomic Energy Agency (IAEA)[18]. This classifies radioactive wastes – and the way they should be stored and disposed of – into six different categories, namely:

- Exempt Waste (EW): Waste that meets the criteria for clearance, exemption or exclusion from regulatory control for radiation protection purposes.
- Very Short Lived Waste (VSLW): Waste that can be stored for decay over a limited period of up to a few years and subsequently cleared from regulatory control according to arrangements approved by the regulatory body, for uncontrolled disposal, use or

[18] IAEA, "Classification of Radioactive Waste", https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1419_web.pdf , also in line with the definitions mentioned under the abbreviation table from the Nuclear Energy Agency, "International Structure for Decommissioning Costing (ISDC) of Nuclear Installations" - https://www.oecd-nea.org/rwm/reports/2012/ISDC-nuclear-installations.pdf

discharge. This class includes waste containing primarily radionuclides with very short half-lives often used for research and medical purposes.

- Very Low Level Waste (VLLW): Waste that does not necessarily meet the criteria of EW, but that does not need a high level of containment and isolation and, therefore, is suitable for disposal in near surface landfill type facilities with limited regulatory control. Such landfill type facilities may also contain other hazardous waste. Typical waste in this class includes soil and rubble with low levels of activity concentration. Concentrations of longer lived radionuclides in VLLW are generally very limited.
- Low Level Waste (LLW): Waste that is above clearance levels, but with limited amounts of long lived radionuclides. Such waste requires robust isolation and containment for periods of up to a few hundred years and is suitable for disposal in engineered near surface facilities. This class covers a very broad range of waste. LLW may include short lived radionuclides at higher levels of activity concentration, and also long lived radionuclides, but only at relatively low levels of activity concentration.
- Intermediate Level Waste (ILW): Waste that, because of its content, particularly of long lived radionuclides, requires a greater degree of containment and isolation than that provided by near surface disposal. However, ILW needs no provision, or only limited provision, for heat dissipation during its storage and disposal. ILW may contain long lived radionuclides, in particular, alpha emitting radionuclides that will not decay to a level of activity concentration acceptable for near surface disposal during the time for which institutional controls can be relied upon. Therefore, waste in this class requires disposal at greater depths, of the order of tens of metres to a few hundred metres.
- High Level Waste (HLW): Waste with levels of activity concentration high enough to generate significant quantities of heat by the radioactive decay process or waste with large amounts of long lived radionuclides that need to be considered in the design of a disposal facility for such waste. Disposal in deep, stable geological formations usually several hundred metres or more below the surface is the generally recognised option for disposal of HLW.

To these categories of radioactive waste, it is also appropriate to add a definition of spent fuel:

- Spent Fuel (SF): Nuclear fuel that has been irradiated in and permanently removed from a reactor core[19].

The Radioactive Waste Directive encourages disposal in the management of high level radioactive waste and spent fuel. It not only states that "storage [...] is an interim solution,

[19] Nuclear Energy Agency, "International Structure for Decommissioning Costing (ISDC) of Nuclear Installations" - https://www.oecd-nea.org/rwm/reports/2012/ISDC-nuclear-installations.pdf

[...] not an alternative to disposal"[20] but it also underlines the Union's preference for deep geological disposal as it is considered "the safest and most sustainable option"[21].

Different types of waste follow different waste management routes as Chapter 4 describes in greater detail.

The waste and spent fuel management cost is usually calculated based on a so-called deterministic method, i.e. a method in which conditions are stipulated and locked. The calculation is based on a functional description for each facility, including layout drawings, equipment lists and staffing forecasts. For facilities and systems in operation, this information is detailed and well known, while the level of detail is lower for future facilities.

To meet the requirements on consideration of uncertainty, relevant organisations in Member States may also use a probabilistic calculation method. The method is used to plan and calculate costs for projects and has been developed specifically to identify, analyse and evaluate uncertainties. The successive calculation involves a scheme implying that variations, deviations or other uncertainties that are of a general or overall nature are dealt with separately. The cost impacts of these uncertainties with different outcomes are then added together on the basis of the chosen statistical method in order to produce the total effect expressed as a probability distribution over different cost levels.

Chapter 4 provides further detail on the methodologies and on how they are being applied in the Member States.

2.1.3 Financing waste management

In order to finance the costs related to radioactive waste management, Member States often impose a fixed contribution on power generators based on the electricity produced by the power plants concerned. They use three types of funds, namely:

- Segregated internal funds: directly managed by operators in separate budgets specifically dedicated to decommissioning and waste management purposes, under the control of competent regulatory authorities;
- Non-segregated internal funds: directly managed by operators in one general budget, where power companies are required by law to build up reserves in their balance sheets for back-end operations.
- Segregated external funds: management is external to the operators. The funds can either be external to or within the State budget.

[20] Recital 21 of Council Directive 2011/70/EURATOM.

[21] Recital 23 of Council Directive 2011/70/EURATOM.

In 2014, Member States affirmed that around EUR 133 billion was currently available in the form of asset-backed funds, covering approximately 51% of the needs[22].

They estimated that EUR 263 billion would be needed by 2050 to cover the costs relating to nuclear decommissioning and radioactive waste management. The largest single item was decommissioning (EUR 123 billion). The projection for the final disposal facility was EUR 74 billion. Other waste management activities accounted for EUR 66 billion. However, the multiplicity of categories, the cost assumptions and several uncertainties make it particularly difficult to obtain a clear picture of the overall cost of radioactive and spent fuel management.

2.2 Objectives and scope of the study

2.2.1 Objectives of the assignment

The aim of this study is to present an in-depth qualitative and quantitative analysis of the methodologies of cost assessment and financing mechanisms in use in the European Union in the management of spent fuel and radioactive waste. The main specific objectives of the study are:

- Identify common trends, best practices and challenges for Member States;
- Foster knowledge sharing among Member States;
- Identify a set of tools that can contribute to build a common ground between Member States.

To do that, the study was carried out around four main tasks:

- Task A – Costs: determining how the costs are evaluated by assessing the methodologies in use, including underlying bases and hypotheses;
- Task B – Financing methods: reviewing the financing scheme in force and the link with the cost assessment made (this task is not tackled in depth as another study has been carried out on this matter[23]);
- Task C – Commonalities: identifying common trends, good practices and challenges across Member States;
- Task D – Tools and Indicators: defining a set of tools, including a comprehensive structure of activities and cost items, as well as relevant Cost Assessment Indicators (CAIs), that can contribute to building common ground between Member States in the analysis of the cost assessment of radioactive waste and spent fuel management.

[22] Communication for the Commission, Nuclear Illustrative Programme presented under Article 40 of the Euratom Treaty, SWD(2017) 158 final, 12 May 2017 https://ec.europa.eu/energy/sites/ener/files/documents/nuclear_illustrative_programme_pinc_-_may_2017_en.pdf.

[23] Study on the risk profile of funds allocated to finance the back-end activities of the nuclear fuel cycle in the EU.

Tasks A and B were analysis phases for each Member State.

Task A had two objectives. One was to analyse how the scope of the cost calculation has been defined. The second was to check the robustness of the methodologies and hypotheses used by Member States, primarily by using National Programmes and the 2015 versions of the National Reports produced by Member States under 2011/70/Euratom Council Directive, but also complementing this with additional desk research. These assessments should be updated periodically as hypotheses, scope and methodologies are subject to change.

Task A analyses the consistency of the evolution of the cost assessment in the light of these changes, as well as the quality control procedures put in place to ensure consistency.

The goal of task B was to analyse the availability and consistency of funding schemes in relation to the cost assessment. This question is of crucial importance given that many of the cash disbursements related to waste management and decommissioning activities only take place years after the generation of the waste. This task was not tackled in depth as a dedicated study on the matter had recently been carried out[24].

To address these tasks, each Member State was analysed based on a research protocol. The process of the analysis for each Member State consisted of data collection, data analysis and assessment, overseen and reviewed by experts, and submitted to the European Commission.

Tasks C and D were synthesis phases.

The goal of task C was to identify critical common trends, good practices and common challenges across Member States with respect both to the cost assessment of radioactive waste and spent fuel management.

The goal of task D was to provide a common description of activities and cost categories with respect to radioactive waste and spent fuel related processes, including the identification of Cost Assessment Indicators.

As publicly available information in this field is frequently scarce or is not complete enough to be able to perform the analysis described in A and B, further information was gathered through specific action by the study team has taken through contact with stakeholders and experts.

2.2.2 Scope of the assignment

The scope of the study is all civilian facilities and activities in the EU that generate and manage spent fuel and radioactive waste, as well as activities in the scope of the National Programmes. Planned facilities are also considered.

[24] European Commission, "Study on the risk profile of the funds allocated to finance the back-end activities of the nuclear fuel cycle in the EU", November 2018

The complete life cycle of facilities dedicated to managing spent fuel and radioactive waste is covered, from design to decommissioning. The specific case of disposal facilities includes post-closure costs, as well as retrievability, when this latter option is considered.

The complete process of spent fuel and waste management is considered. This means that for spent fuel management, the study includes storage, reprocessing (when this option is applicable), and disposal. The waste management process goes from pre-treatment to disposal. Remediation and upgrade of existing sites create radioactive waste; these wastes are part of the waste analysis for each country. The additional costs of reprocessing (for spent fuel) and characterisation (for waste) are also considered, whether these activities are carried out inside or outside the EU.

2.3 Methodology

2.3.1 Tasks A and B

In order to address tasks A and B, as indicated above, each Member State was analysed through a research protocol. The process of analysis for each Member State consisted of data collection, data analysis and assessment, and submission to the European Commission. The detailed steps were:

- Data collection and review:
  - Review of documents provided by the European Commission (including the National Programmes and the National Reports – in their 2015 version - provided by each Member State);
  - Review of additional documents identified by the team;
  - Expert opinion – consultation and quality assurance by nuclear experts, who provided recommendations for additional literature.
- Completion of the research protocol and development of the executive summary.
- Analysis and assessment:
  - Assessment of the scope of the National Programmes;
  - Expert review of the research protocol and executive summary.
- Submission of the research protocol and executive summary for each Member State to the European Commission.

Due to the structure and organisation of the study, and the availability of data during the different stages of the assignment, the information used may not be the latest available. The core of the data collection was carried out during the period when only 2015 Council Directive 2011/70/EURATOM reporting was available for all Member States. As mentioned above, this information was complemented with additional information collected by the team at the time of the data collection, as well as expert opinion; however, new information might have become available in the last year of work on the study, which it was not possible to integrate and still meet the study timetable.

Structure of the research protocol and the executive summary

Research protocol

The results of analysis in tasks A and B are summarised in research protocols for each Member State. The research protocol consisted of six steps:

Step 1 – general information, actors and nuclear facilities

The objectives of Step 1 were to understand:

- the main actors in the area of radioactive waste and spent fuel in the Member State
- the main generators of radioactive waste and spent fuel in the Member State

Step 2 – situation of radioactive waste in the Member State

The objective of Step 2 was to gather data on the quantities, sources, ways of treatment and costs of radioactive waste management

Step 3 – situation of spent fuel in the Member State

The objective of Step 3 was to gather data on the quantities, sources, ways of treatment and costs of spent fuel management

Step 4 – cost calculation methodology

The objective of Step 4 was to understand what cost assessment methodology is in use at the Member State

Step 5 – financing scheme and radioactive waste and spent fuel management funds

The objectives of Step 5 were:

- understanding what financing scheme is in place in the Member State
- how the radioactive waste and spent fuel management fund is governed and managed
- if the radioactive waste and spent fuel management fund is sufficient to cover the expected costs over time

Executive summary (Step 6)

The results of the research protocols were summarised in executive summaries for each Member State. The executive summaries contain key information, such as analysis of the scope, key quantitative information on generation and management of radioactive waste and spent fuel in the Member State. In addition, information from the research protocol was summarised in a list of 52 indicators, divided by the steps described above.

Research protocols and executive summaries are not included in this report.

2.3.2 Tasks C and D

In order to address tasks C and D, several research tools were combined:

- Extraction of relevant information from Member State reports (tasks A and B), with a focus on the best practices in cost calculation methodologies and financing schemes;
- Identification of information gaps, which were addressed with additional desk research;
- Expert opinion of NucAdvisor experts;
- Participation in a European Commission expert workshop in October 2018;
- Preparation and distribution of a survey to Member States to collect further information on the methodologies and tools to develop (Taxonomy and Cost Assessment Indicators).

3 Review and analysis of the cost assessments and financing schemes[25]: information available from publicly accessible sources

3.1 Introduction

As explained in chapter 2, the aim of task A was to determine how the costs in the National Programmes are calculated and to assess the methodologies in use, including the underlying basis and hypothesis for the assessment[26]. This task then fed into tasks B (financing methods), C (identification of commonalities) and D (development of tools and indicators) of the report as it provided the information available to the team at the time of the study, and on which it was possible to rely in delving into key practices, methods and tools.

Given the heterogeneity of the nuclear sector in the EU as highlighted in the previous chapter, Member States have been grouped for Task A in three broad categories, as shown in Table 1 below.

Table 1 – Groups of Member States

Classification	Designation	Member States
	Nuclear power plants in operation and in decommissioning	
	Reprocessing plant in operation or under decommissioning	
	Enrichment plant in operation or under decommissioning	France, United Kingdom
Category I	Extensive R&D studies in medical and industrial (both nuclear and non-nuclear) application	Belgium, Germany, Finland, Italy, Netherlands, Romania, Slovenia, Spain, Sweden
	Nuclear power plants in operation and/or decommissioning	Bulgaria, Czechia, Hungary, Lithuania, Slovakia
	R&D studies in both nuclear and non-nuclear application ongoing or terminated	
	Only VVER and/or RBMK designed nuclear power plants in operation and/or in decommissioning	

[25] For an in-depth review of the financing schemes in use to finance the nuclear back-end in the EU, see the EC “Study on the risk profile of funds allocated to finance the back-end activities of the nuclear fuel cycle in the EU”.

[26] It should be noted that the aim of this study is not to audit the correctness and the accuracy of the single cost estimates (figures) provided by Member States.

Classification	Designation	Member States
	Research reactors in operation and/or in decommissioning	
Category II	No nuclear power plant but at least one research reactor in operation or in decommissioning	Austria, Denmark, Greece, Latvia, Poland, Portugal
Category III	No nuclear power programme but limited use of radioactive sources	Croatia, Cyprus, Estonia, Ireland, Luxembourg, Malta

Source: Authors from various sources

To carry out this task, a series of relevant data were identified, linked directly or indirectly to information requirements set out in Directive 2011/70/EURATOM. These data can be grouped in four categories:

- General information on radioactive waste and spent fuel generators;
- Information on radioactive waste management;
- Information on spent fuel management;
- Information on cost calculation methodologies.

Table 2 provides an overview of the different data per category. In line with task A, this information provides an overview of the radioactive waste and spent fuel context in each country, establishing a basis for an appraisal (to the extent possible) of the costs and the methodologies in use.

Table 2 – Relevant data under task A

General information on RAW and SF generators	Information on RAW management	Information on SF management	Cost calculation methodology
- Responsible authorities - Number of nuclear facilities per category (NPPs, research reactors, other) - Other sources of radioactive waste and spent fuel - Ownership type (public, private) - Planned end year of the National Programme - Total expected produced electricity - Decommissioning period - Costs of decommissioning of radioactive waste/SF generators - Costs of radioactive waste management as part of decommissioning	- List of facilities for radioactive waste management - Years of start of operations - Years of end of operations - Total capacity (m3) - Investment costs (siting, design, construction) - Costs of operations - Decommissioning period - Costs of decommissioning of radioactive waste management facilities - Quantities of radioactive waste - Breakdown of radioactive waste quantities according to radioactive waste management categories (pre-treatment, treatment (incl. outside the country of origin), conditioning, storage, etc.) - Overall costs of radioactive waste management - Detailed costs of radioactive waste management according to radioactive waste management categories (pre-treatment, treatment, etc.)	- List of facilities for spent fuel management - Years of start of operations - Years of end of operations - Total capacity (tonnes) - Investment costs (siting design, construction) - Costs of operations - Decommissioning period - Costs of decommissioning - Quantities of spent fuel - Reprocessing costs - Overall costs for spent fuel management - Detailed costs of spent fuel management	- Cost calculation approach (deterministic, probabilistic, etc.) - Costing process (independent reviews, regulatory authority, etc.) - Frequency of cost assessment reviews - Presentation of different hypotheses - Categorisation of costs (labour, investment, expenses, contingencies, etc.) - Costs for management of a unit of radioactive waste - Costs for management of a unit of spent fuel - Overall costs of the whole radioactive waste and spent fuel management programme (NPPs, radioactive waste, spent fuel and facilities) - Breakdown by year of the overall programme (profile over time)

Source: Authors from various sources

This is structured based on the analysis of the four categories of data and their availability:

- General information on radioactive waste and spent fuel
- Information on radioactive waste management
- Information on spent fuel management
- Information on cost calculation methodologies.

Each section includes an analysis of the relevance of the information, an overview of the availability of information, and an assessment of the potential reasons behind information gaps. Providing an overview of the availability of information is important in understanding the foundation of the assessment. Task A was carried out based on the information made available by the Member States to the Commission for the first reporting under the Directive 2011/70/EURATOM[27], as well as other official sources[28] reviewed by the study team.

If the information has not been found, it is not unlikely that this has had an impact on the assessment. However, an assessment may still be possible even if a Member State does not provide information for all the data identified, as not all data are equally crucial. For this reason, the overview of information available includes the identification of the crucial data points per category of data, the availability of information for those data points per category of Member State, the information that is most often missing, and the possible explanation, if any, for this gap. This exercise differentiates between the categories of Member State in order to take into account, to the extent possible, the distinct radioactive waste and spent fuel frameworks.

Moreover, in addition to the information on the National Programme costs, Art. 12(1) of the Directive requires Member States to set up financing schemes for radioactive waste management. Consequently, this chapter also provides an overview of the different financing schemes for radioactive waste and spent fuel management in place in the Member States as well as taking a wider look at the information available.

3.2 Availability of general information on radioactive waste and spent fuel generators

The aim of this section is to provide a general overview on the availability of information per category of Member State, especially in terms of the current and planned sources of radioactive waste and spent fuel.

The percentages in Figure 1 represent full availability of information for specific data. If information is only partially available, this is not considered in the percentage. The first column provides the availability of information on average, taking into account the availability of information in all Member States, while the subsequent columns provide the average availability per category of Member States. The total average is not calculated as the average

[27] The first reporting under the 2011/70/EURATOM Council Directive took place in 2015. Consequently, the data compiled in this manner mainly dates from 2015 or before.

[28] Such as the European Commission, the IAEA, the different NPPs in the Member State, etc.

of the three categories, but as the average of all Member States, to avoid that categories with less Member States are over-represented in the total.

Although all data are useful, those that can be considered crucial for the review and the analysis of the cost assessments are mainly those linked to the detailing of cost categories, as long as they are stand-alone (i.e. total end amounts). Concretely, these are the costs for the management of radioactive waste and spent fuel (including those linked to decommissioning activities). Other data are indeed useful for estimating cost variations in the event of a change in, for example, the decommissioning period, or where the costs are provided on annual basis, so it is possible to estimate total end costs. These are:

- Planned end year of the National Programme;
- Decommissioning periods.

Finally, data such as the number of nuclear facilities per category (NPPs, research reactors, other) or on other sources of radioactive waste and spent fuel are also important for cost assessment. Indeed, knowing the number and types of radioactive waste and spent fuel sources can contribute to an expert assessment on the adequacy of the cost estimations. Nevertheless, costs linked to these data are typically more difficult to extrapolate and, thus, should be considered with caution.

Figure 1 – Overview of availability of general information on RAW and SF generators overall and per category of Member State

		%	% cat I	% cat II	% cat III
	STEP 1 – GENERAL INFORMATION on RAW/SF generators	71%	68%	67%	81%
1	Responsible authorities	100%	100%	100%	100%
2	Number of nuclear facilities per category (NPPs, research reactors, other)	100%	100%	100%	100%
3	Other sources of RAW and SF	82%	69%	100%	100%
4	Ownership type (public, private)	89%	81%	100%	100%
5	Planned end year of the national programme	43%	56%	17%	33%
6	Total expected produced electricity	86%	88%	83%	83%
7	Decommissioning period	68%	75%	33%	83%
8	Costs of decommissioning of RAW/SF generators	46%	38%	33%	83%
9	Costs of RAW management as part of decommissioning	21%	6%	33%	50%

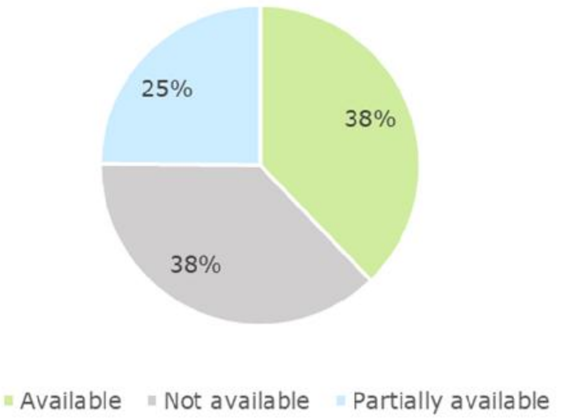
Source: Authors from National Programmes, National Reports or other official sources

The following sub-sections concentrate on the most relevant data points. They highlight, per category of Member State, the availability of information and identify the most frequent gaps.

3.2.1 Category I Member States

As shown in Figure 1, average availability of information for Category I Member States is 68%, three percentage points below the average for the EU-28. By Member State the availability of data ranges from as high as 100% to as low as 33%. In terms of the specific data, the range of availability goes from as high as 100% for the information related to the responsible authorities or the number of nuclear facilities to as low as 6% for the costs of radioactive waste management as part of decommissioning. In principle, the low availability of the latter could be due to the cost being included under the general costs of decommissioning. This could be assumed of countries such as Belgium, Bulgaria, Romania, Slovakia, Spain and Sweden. However, as can be seen in Figure 2, almost two thirds of the category I countries do not provide such information or it is incomplete. In fact, the two areas of data that are most problematic are coincidentally those identified as crucial. Only one Member State in this category provides information on these two data points[29]: France.

Figure 2 –Availability of information on costs of decommissioning radioactive waste/SF generators – Category I



Source: Authors from data in National Programmes, National Reports or other official sources

If information on the costs of decommissioning had been completely available, this would have compensated, to a certain extent, for the non-availability of information on the costs of management of radioactive waste as part of decommissioning. Member States that provided partial information mainly did not provide the decommissioning costs of one or a couple of their facilities (Czechia, Finland, Hungary[30], UK), while one Member State (Italy) did not provide certain costs for the calculation of their decommissioning costs (i.e. the management of radioactive waste and spent fuel).

[29] i.e. Costs of decommissioning of RAW/SF generators, and Costs of RAW management as part of decommissioning.

[30] The Member State has more recent data which has not been possible to integrate to ensure a consistent and timely analysis.

While there is a high level of availability of general information on radioactive waste and spent fuel generators, some key information needed for the review and analysis of the cost assessments is not publicly available. Most of the information available has a low level of stand-alone utility.

3.2.2 Category II Member States

As shown in Figure 1, the availability of information for category II Member States is 67% on average, four percentage points below the average of the EU-28, and one below category I Member States. While the availability per country is not as high on average as in category I Member States, the range is smaller (from 44% to 89%).

In terms of specific data, contrary to category I Member States, the planned end year of the National Programme is the one with the least information available (only one country provides it). However, the two types of data on costs identified as crucial for the assessment (numbers 8 and 9 in Figure 1) are not far behind in terms of limited availability of information. Latvia is the only country that provides information on both; two Member States provide information on one or the other; the rest do not provide even partial information on these data.

The picture is in line with that of category I, as the key information needed for the review and analysis of the cost assessments is scarce and most of the available information has a low level of stand-alone utility.

3.2.3 Category III Member States

Availability of information for Category III Member States is considerably higher than for the other two categories. The Category III average is ten percentage points above the average of all countries. The availability of information is above 50% for all Member States, with two thirds providing 89% of the information.

Like category II, the data point for which the least information is provided is the planned end year of the National Programme. This is likely to be linked to the fact that the origin of their radioactive waste is mainly natural or from industry, so that an end date cannot be estimated. Availability of information on the cost categories is also high. Only two Member States in category III have facilities that need to be decommissioned (Croatia, Estonia), which is why the rate of availability is so high. However, the rate decreases slightly in relation to the data point on costs of radioactive waste and spent fuel management as part of decommissioning as neither of the two Member States provide this information, nor does Ireland.

Overall, availability of data on general information on RAW and SF generators is higher for category III than for the other categories (I and II). However, one of the important data points identified for the review and analysis of the cost assessments and another useful one have a low availability rate, which detracts from the positive overview.

3.3 Availability of information on radioactive waste management

This section provides a view of radioactive waste management per category of Member State, including the facilities, the quantities of waste and the different costs linked to radioactive waste management. This information is necessary to appreciate the range of costs the National Programmes should account for in the future and their timeframe. It provides an overview of the availability of information[31] per category of Member State. It differentiates between crucial and important data.

The crucial data points in carrying out the review and analysis of the cost assessment are linked to categories of costs that can be used on a stand-alone basis. Concretely, these are:

- Investment costs (i.e. siting, design, construction) for radioactive waste management facilities;
- Costs of operation of radioactive waste management facilities;
- Costs of Decommissioning radioactive waste management facilities;
- Overall costs of radioactive waste management.

The second data group that is important (while not crucial) relates to indicators that are useful in estimating cost variations. These are:

- Years of start of operations of the radioactive waste management facilities;
- Years of end of operations;
- Decommissioning period of these facilities;
- Quantities of radioactive waste;
- Breakdown of radioactive waste quantities according to radioactive waste management categories (pre-treatment, treatment (incl. abroad), conditioning, storage, etc.);
- Detailed costs of radioactive waste management by radioactive waste management categories (pre-treatment, treatment, etc.)

These data make it possible to make rough estimates of cost increases or decreases in the event of a variation of lifetime or decommissioning time, or based on quantities and the management phase these quantities have reached. The detailed costs of radioactive waste management by management category could be considered part of the crucial data. However, this data does not provide additional information to that available through the overall costs of radioactive waste management if it is not accompanied by the breakdown of radioactive waste quantities by radioactive waste management category. For that reason, it is not treated as key data.

Finally, data such as the number of facilities for radioactive waste management or the total capacity of these facilities are also important in determining the adequacy and completeness of cost calculations. While information on these points is typically more difficult to extrapolate

[31] As noted previously, the percentages represent the full availability of information for a specific data point. If information is only partially available, this is not considered in the percentage as it does not provide enough material for achievement of the task. The first column provides the availability of information on average, taking into account the availability of information in all Member States, while the subsequent columns provide the average availability per category of Member States. The total average is not calculated as the average of the three categories, but as the average of all Member States, to avoid that categories with less Member States are over-represented in the total.

and, thus, should be treated with caution, information on the capacity of the facilities provides more solid knowledge of their characteristics and helps in making a more accurate estimate and having a point of comparison for extrapolation.

The following sub-sections focus on the most relevant data. They highlight, per category of Member State, the availability of information and identify the most frequent gaps.

Figure 3 – Overview of availability of information on radioactive waste management overall and per category of Member State

		%	% cat I	% cat II	% cat III
	STEP 2 – RAW management	37%	39%	32%	35%
10	List of facilities for RAW management	93%	100%	83%	83%
11	Years of start of operations	39%	44%	50%	17%
12	Years of end of operations	25%	31%	17%	17%
13	Total capacity (m3)	46%	50%	50%	33%
14	Investment costs (siting, design, construction)	11%	13%	0%	17%
15	Costs of operations	18%	19%	0%	33%
16	Decommissioning period	25%	31%	17%	17%
17	Costs of decommissioning of RAW management facilities	14%	19%	0%	17%
18	Quantities of RAW	89%	88%	100%	83%
19	Breakdown of RAW quantities according to management categories (pre-treatment, treatment (incl. abroad), conditioning, storage, etc.)	32%	19%	33%	67%
20	Overall costs of RAW management	39%	50%	33%	17%
21	Detailed costs of RAW management according to RAW management categories (pre-treatment, treatment, etc.)	7%	6%	0%	17%

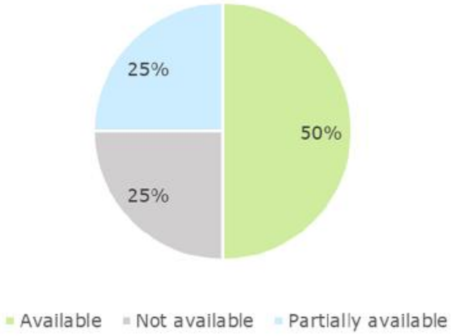
Source: Authors from data in National Programmes, National Reports or other official sources

3.3.1 Category I Member States

As shown in Figure 3, the availability of information for Category I Member States is 39% on average, two percentage points above the average of the EU-28. Only four countries have 50% or more of the analysed information available. The rate of availability by country ranges from as high as 83% to as low as 17%.

Three of the four types of data considered as crucial have a rate below 20%. Overall, the highest availability of information is for the "list of facilities for radioactive waste management" (point 10), which scores 100%. The lowest rate is for "detailed costs of RAW management according to RAW management categories" (point 21) with 6%. This is one of the important (while not crucial) data points. While "overall costs of radioactive waste management" (point 20) achieves a fairly good score, there is generally no information on the breakdown of RAW quantities per category, making it logical that there is little information on point 21[32].

Figure 4 – Overall costs of radioactive waste management – Category I



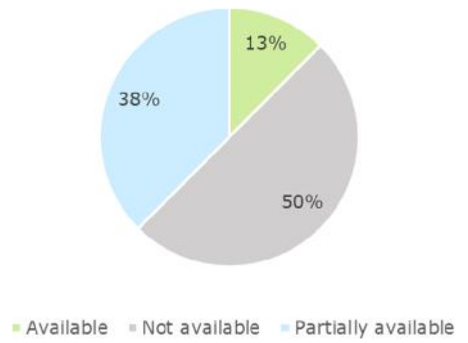
Source: Authors from data in National Programmes, National Reports or other official sources

For the rest of the data identified as crucial, the amount of information only partially available is significant, yet not pivotal. Even if it were considered completely available instead, it would not modify the overall picture as the availability of information would still not reach 50%. The exception would be point 14 "investments costs": for this category, the only investment costs available are usually those for disposal projects, while investment costs for other facilities are generally not available. If the partially available information were to be considered completely available, the data point would attain 50% availability. Three figures below highlight this clearly (Figure 5, Figure 6 and Figure 7)[33].

[32] Data point 20 could have a better rate if the overall costs of radioactive waste management were not provided separately. Often, the only information available is the estimated total cost of spent fuel and radioactive waste management combined, reported to the Commission in Staff Working Document 159. As shown in the figure below, if the partially available information on the overall costs of radioactive waste management had been completely available instead, the hypothesis put forward would have been even stronger, as the availability of information would have been 75%.

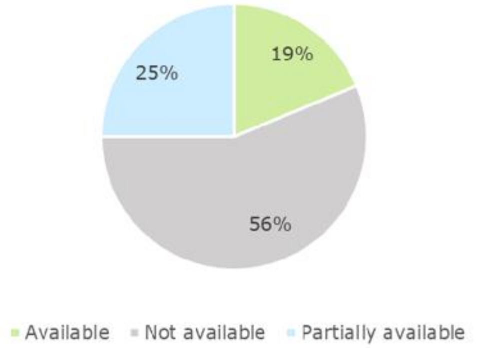
[33] Concretely, as shown in Figure 13, 25% of the information about costs of operation provided by Category I Member States is partially available. The reason behind it is that for four countries this information is available only for certain facilities. Then, more specifically, for one country the costs of operation were only available for three storage facilities for radioactive waste (out of 18 storage facilities) and two disposal facilities for radioactive waste (out of eight disposal facilities). Finally, one country provided information only for disposal facilities, and another had data only on an annual basis for disposal facilities. The same scenario is presented in Figure 14, where 25% of the information about costs of decommissioning of radioactive waste management facilities is partially available. Once again, the information provided by four Member States belonging to category I concerns only some of the facilities present in their territory. Once more, one country provided information only for disposal facilities. Meanwhile, another country had information about the estimated overall cost of releasing sites free of radiological restrictions, but the latest costs of decommissioning for each facility dated back to 2006. One Member State offered information only about the storage and disposal facilities of two operating NPPs, while another gave only the expected decommissioning costs of a storage facility.

Figure 5 – Investment costs (siting, design, construction) – Category I



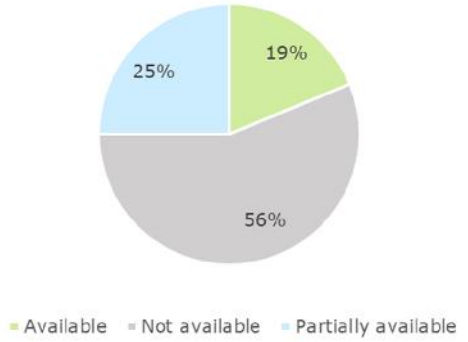
Source: Authors from data in National Programmes, National Reports or other official sources

Figure 6 – Costs of operation – Category I



Source: Authors from data in National Programmes, National Reports or other official sources

Figure 7 – Costs of decommissioning radioactive waste management facilities – Category I



Source: Author from data in National Programmes, National Reports or other official sources

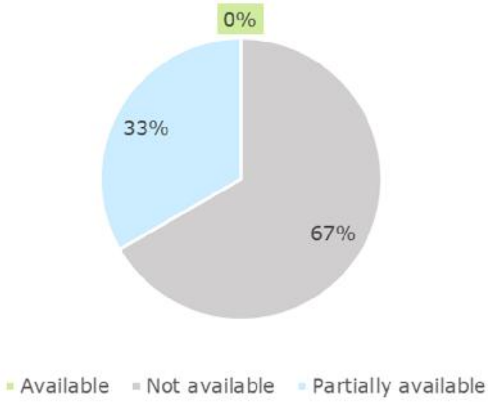
Overall, information on RAW management has a low rate of availability. Specifically, the information identified as key is insufficient.

3.3.2 Category II Member States

As shown in Figure 3, the availability of information for Category II Member States is 32%, five percentage points below the EU-28 average. Only Member State in category II shows 50% availability of information. The figures for the other countries range from 17% to 42%.

As is the case for the countries in category I, the data point with the least information available (0%) is "detailed costs of radioactive waste management" (point 21), with no country providing even partial information. The figure for "overall costs of radioactive waste management" (point 20) is only 33% for the category II countries. Finally, the rates is zero for "investment costs" (point 14), "costs of operation" (point 15) and "costs of decommissioning of RAW management facilities" (point 17). However, some countries provide partial information on these three data points, as shown in the graphs below[34].

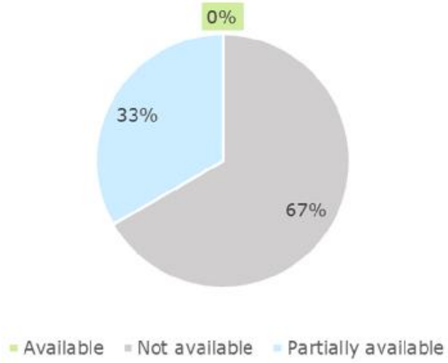
Figure 8 – Investment costs (siting, design, construction) – Category II



Source: Authors from data in National Programmes, National Reports or other official sources

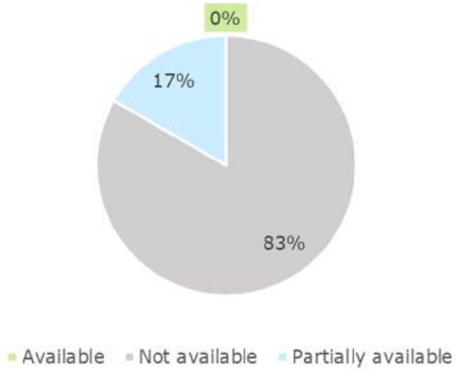
[34] In the case of one Member State, the investment costs are not provided separately, so the information available covers both costs of investment and operations. The investment costs for another Member State are only available for the years 2015-2025 and are calculated for the National Plan. For this cost of operations data point, the information available provided by one country covers both the costs of investment and operations, while the cost breakdown provided by another, does not specify whether this covers all radioactive waste and spent fuel management related activities or not. In the case of the costs for decommissioning RAW management facilities, the information provided by one country is considered partially available as it offers two possible solutions: an establishment for final disposal (for which some costs are given) or a long-term intermediate storage facility (for which no data is provided).

Figure 9 – Costs of operations – Category II



Source: Authors from data in National Programmes, National Reports or other official sources

Figure 10 – Costs of decommissioning radioactive waste management facilities – Category II



Source: Authors' elaboration based on National Programmes, National Reports or other official sources

Even if the partially available information were to be considered completely available, the outcome for this category would not change significantly. Consequently, overall the situation is in line with that of category I, as the key information needed for task A (Review and analysis of the cost assessments) is insufficient and most of the available information has a low level of stand-alone utility.

3.3.3 Category III Member States

Availability of information for Category III Member States is two percentage points below the EU-28 average (35%). Hence, there is a slightly better availability of information compared to Category II countries, but it is not as good as the results obtained from Category I Member States. Moreover, the availability of information is below 50% for all Member States in this category except Ireland (75%). The range for the other countries is from 8% to 42%.

As is the case for Category I and Category II countries, point 21 “detailed costs of radioactive waste management” has the least information available, scoring only 17%. For Category III, the rate for “overall costs of radioactive waste management” (point 20) is even lower than for Category II Member States (at 33%), offering only 17% of availability of information for the Category III countries. Moreover, for this data point only one country provides partially available information. Therefore the overall availability would not improve significantly even if the data were to be considered completely available. Hence, once again, it is difficult to see an explanation for the low availability (17%) for “detailed costs of radioactive waste management” (point 21). The result is the same (17%) for points 11, 12, 14, 16 and 20. The highest percentage of availability of information is for “quantities of RAW” (point 18), which in one of the group of data points that are important (while not crucial), and “list of facilities for radioactive waste management” (point 10), both at 83%.

For Category III countries, the key information needed for the review and analysis of the cost assessments is insufficient and most of the information available has a low level of stand-alone utility.

3.4 Availability of information on spent fuel management

This section offers an overview of the availability of information on spent fuel management per category of Member State. Specifically, it covers the list of facilities that manage the spent fuel, the actual quantities of spent fuel belonging to the Member States, the way it is treated and the related costs. This analysis displays the overall availability of information, which ultimately will be key in determining the completeness and adequacy of the costs and assessing the methodologies in use. Figure 11 summarises the information available[35].

As stated previously, all data may represent relevant information, nonetheless. As in the case of the previous sections, the data points identified as crucial relate to the categories of costs that stand alone, such as:

- Investment costs (siting design, construction);
- Costs of operations;
- Costs of decommissioning;
- Reprocessing costs;
- Overall costs for spent fuel management.

The second group of data that are important (while not crucial) under this category, are the ones useful to estimate cost variations (i.e.: costs contingent upon variations of the

[35] As noted previously, the percentages represent the full availability of information for a specific data point. If information is only partially available, this is not considered in the percentage as it does not provide enough material for achievement of the task. The first column provides the availability of information on average, taking into account the availability of information in all Member States, while the subsequent columns provide the average availability per category of Member States. The total average is not calculated as the average of the three categories, but as the average of all Member States, to avoid that categories with less Member States are over-represented in the total.

decommissioning period or based on quantities) and that ultimately help to estimate total end costs. Those are:

- Years of start of operations;
- Years of end of operations;
- Decommissioning period;
- Detailed costs of spent fuel management;
- Quantities of spent fuel.

The data concerning “detailed costs of SF management” is not classified as crucial because, as it is dependent on knowing the breakdown of spent fuel quantities if this information is not available, it does not provide additional information in comparison to the overall costs of spent fuel management.

Additionally, other data points that are useful for the assessment of the scope, specifically to determine adequacy and completeness of cost calculations, are:

- List of facilities for spent fuel management;
- Total capacity (tonnes).

The following sub-sections concentrate on the most relevant data points. They highlight, per category of Member State, the availability of information, and identify the most frequent gaps.

Figure 11 – Overview of availability of information on spent fuel management overall and per category of Member State

		%	% cat I	% cat II	% cat III
	STEP 3 – SF management	53%	37%	49%	100%
22	List of facilities for SF management	100%	100%	100%	100%
23	Years of start of operations	54%	44%	33%	100%
24	Years of end of operations	50%	31%	50%	100%
25	Total capacity (tonnes)	64%	56%	50%	100%
26	Investment costs (siting design, construction)	39%	19%	33%	100%
27	Costs of operations	36%	13%	33%	100%
28	Decommissioning period	46%	25%	50%	100%
29	Costs of decommissioning	39%	19%	33%	100%
30	Quantities of SF	79%	69%	83%	100%
31	Reprocessing costs	36%	6%	50%	100%
32	Overall costs for SF management	54%	44%	33%	100%
33	Detailed costs of SF management	39%	19%	33%	100%

Source: Authors’ elaboration based on National Programmes, National Reports or other official sources

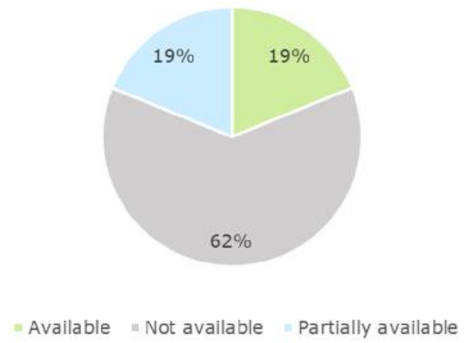
3.4.1 Category I Member States

As shown in Figure 11, availability of information for Category I Member States is 15 percentage points below the average of all countries (37%). Focusing on each Category I country, only three have 50% or more of the required information available, scoring 100%, 58% and 50% respectively. The rates for Category I Member States for go from a low of 17% availability to a high of 100%.

The highest percentage of availability is obtained for “list of facilities for SF management” (point 22), which is classified as useful in the list above, and reaches 100%. Contrarily, for what concerns the availability of information per data point, all five points identified as crucial have a rate below 20%. “Reprocessing costs” (point 31), one of the crucial data collected, reaches a low of 6%, the lowest availability for this category. The fact that a country might not reprocess spent fuel is not a deterrent for the negative score for this point. Indeed, whenever a Member State does not reprocess spent fuel, the data point is considered not applicable, while the information is registered as available.

In the case of the other four crucial data points, at least two countries provide full information and have at least one other Member State which presents partial data. For instance, as the following Figure 12 shows, “investment costs” (point 26) has 19% of information fully available (which represents three countries) and the same amount partially available because costs are only provided for some facilities. Nevertheless, if this information were to be made available, the result would still not reach 50% and would not, thus, tilt the balance to the positive side.

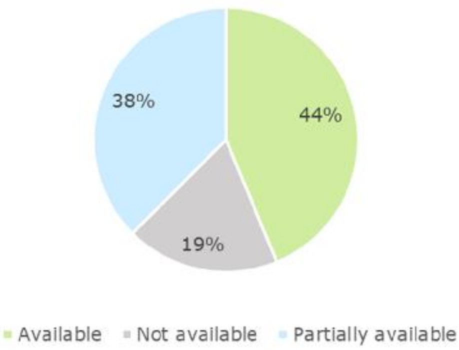
Figure 12 – Investment costs (siting design, construction) – Category I



Source: Authors’ elaboration based on National Programmes, National Reports or other official sources

For “overall costs of SF management” (point 32), which is a crucial data point, the situation is different. As the Figure 13 below shows, even if the availability of information for this point is below 50%, it reaches a substantial 44%. Hence, adding the considerable partially available information (38%), the result would drastically improve, reaching a high of 82% availability.

Figure 13 – Overall costs for spent fuel management – Category I



Source: Authors' elaboration based on National Programme, National report or other official sources

The most common reason why 38% of Category I countries offered only partially available information is that the overall costs of spent fuel management are not provided separately. Often, only the estimated total cost of spent fuel and radioactive waste management reported to is given.

Overall, the key information needed for task A is insufficient. Most of the available information has a low level of utility stand-alone.

3.4.2 Category II Member States

As shown in Figure 11, availability of information for Category II Member States is 49%, three percentage points below the average of all countries, yet 12 percentage points above Category I countries. The range of the availability per country varies from 17% to 100%.

In line with the category I countries, the list of facilities for spent fuel management is the data point with the most available information (100%). The quantities of spent fuel, an important data point while not crucial, follows with 83% availability. Once again, there is limited availability of information for the crucial data points on costs. Only the reprocessing costs achieve a level of 50%, while the rest are at 33% (two countries provide full information). One country per data point provides partial information for the investment cost and overall cost data points for spent fuel management. One Member State provides information only for the siting of new facilities but not of existing locations, and another does not provide the spent fuel costs separately, so that the only figure available in the literature reviewed is the estimated total cost of spent fuel together with radioactive waste. No other country provides even partial information on the crucial data points.

The situation resembles that of category I, meaning that the key information needed for task A is insufficient and most of the information available has a low level of stand-alone utility.

3.4.3 Category III Member States

As Figure 11 shows, the availability of information for Category III Member States is complete, while the average for the EU-28 is marginally above 50%. The reason is straightforward: Member States in this category have no spent fuel or related activities. Hence, the data points are regarded as not applicable and the information is registered as available.

The data points are not applicable because Category III countries have no relevant activities.

3.5 Availability of information on cost calculation methodologies

Article 12(1) (h) of the Directive requires from the Member States in the assessment of the National Programme “an assessment of the National Programme costs and the underlying basis and hypotheses for that assessment, which must include a profile over time.”

In order to understand each Member State’s National Programme approach, this study broke the costing calculation categories into the following items:

- Cost calculation approaches;
- Presentation of different hypotheses and categorisation of costs;
- Cost assessment reviews – institutions and frequency;
- Overall costs of the radioactive management and spent fuel management;
- Breakdown of the overall costs over time;
- Detailed costs for units of radioactive waste and spent fuel.

This section presents the overview and assessment of these six items by the three categories of Member State (as explained in Chapter 2). Figure 14 below presents the general availability of information on cost calculations for the items in this step.

Figure 14 – Overview of availability of information on cost calculation methodologies overall and per category of Member State

		%	% cat I	% cat II	% cat III
	STEP 4 – COST CALCULATION METHODOLOGY	23%	31%	11%	13%
34	Cost calculation approach (deterministic, probabilistic, etc.)	21%	31%	0%	17%
35	Costing process (independent reviews, regulatory authority, etc)	32%	50%	17%	0%
36	Frequency of performing cost assessment reviews	36%	63%	0%	0%
37	Presentation of different Hypothesis	18%	31%	0%	0%
38	Categorisation of costs (labour, investment, expenses, contingencies, etc.)	11%	13%	17%	0%
39	Information on costs for management of a unit of RAW	4%	0%	0%	17%
40	Information on costs for management of a unit of SF	7%	0%	0%	33%
41	Information on overall costs of the whole RAW and SF management programme (NPPs, RAW, SF and facilities)	64%	69%	67%	50%
42	Breakdown per years (profile over time) of the overall costs of the whole RAW & SF management programme	11%	19%	0%	0%

Source: Authors from data in National Programmes, National Reports or other official sources

As can be seen in the figure above, the availability rate of information on the cost calculation methodology is 23% for the EU-28. This can in part be explained by the fact that a large part of the information is probably held at operator level, but is not for public access. For example, in the case of Germany, the cost calculation is carried out by the private power plant operators and not publicly available. For other countries, such as Poland, the cost calculation methodology is not fully developed. Poland is currently establishing its nuclear programme with plans to commission new nuclear power plants in future.

The most detailed information on the cost calculation methodology is available and developed by Category I Member States, which have considerable quantities of the radioactive wastes and spent fuel in their territory. Category II and III Member States have rather less advanced methodologies[36].

[36] Chapter 4 (tasks C and D) of the study presents the theoretical background for cost calculation methodologies. In addition, as part of the study, a survey was conducted on cost calculation processes and methodologies used in different Member States. Fourteen Member States participated in the survey and provided detailed information, which is also presented in Chapter 4.

3.5.1 Category I Member States

Figure 14 presents the availability of information on cost calculation items for Category I Member States. Although the overall availability of information is 31%, it is not equally distributed among different items.

Categorisation of costs

There is no standardised mandatory categorisation of costs for radioactive waste and spent fuel. However, the OECD, IAEA and EU have provided an "International Structure for Decommissioning Costing (ISDC) of Nuclear Installations"[37], which could serve as a reference or a common denominator for the Member States' cost calculation categories for decommissioning costs. The ISDC has identified four major categories of costs:

- Labour costs – payments to employees, payments to social security and health insurance according to national legislation and overheads;
- Investment – capital/equipment/material costs;
- Expenses – consumables, spare parts, taxes etc.;
- Contingencies – a specific provision for unforeseeable elements of costs within the defined project scope.

France and the UK have each developed their own classifications of cost categorisation, as presented in Table 3 below.

Table 3 – Detailed cost categorisation in France and the UK

ISDC	France (EDF)	UK
Labour costs – payments to employees, payments to social security and health insurance according to national legislation and overheads	Central support staff	Labour – man hours
Investment – capital/equipment/material costs	Labour costs	Labour costs
Expenses – consumables, spare parts, taxes, etc.	External expenses	Subcontract costs
Contingencies – a specific provision for unforeseeable elements of costs within the defined project scope	Taxes	Material costs
	Cost of nuclear fuel	Equipment costs
		Other costs

[37] Nuclear Energy Agency, International Structure for Decommissioning Costing (ISDC) of Nuclear Installations", 2012, available at: https://www.oecd-nea.org/rwm/reports/2012/ISDC-nuclear-installations.pdf.

Source: Author from ISDC and national sources

The case of Sweden stands out because of the detailed categorisation of the uncertainties provided for. The following six uncertainty categories are identified:

- Society – regulatory and political issues;
- Economics – economic condition (e.g. the real price trend for labour, materials, exchange rate);
- Implementation – schedule strategies, siting and decommissioning;
- Organisation – management and implementation issues in construction and decommissioning;
- Technology – technological uncertainties of future radioactive waste and spent fuel management and disposal facilities;
- Calculation – the risk of incorrect assessments in the calculation work.

Overall costs of the radioactive waste and spent fuel management

Most Member States do not provide a yearly breakdown of future radioactive waste and spent fuel management costs. Finland, Germany, Slovakia, Spain and Sweden are exceptions and provide a broad timeframe for the future cost breakdown (although not a yearly breakdown).

Detailed costs for units of radioactive waste and spent fuel

Countries in Category I do not provide information on costs for management of radioactive waste and spent fuel units.

3.5.2 Category II Member States

Figure 14 presents the availability of information on cost calculation items for Category II Member States. The overall availability of information is at the level of only 11% and is not equally distributed among different items. This can be explained by the fact that the six Member States in Category II only have only research reactor activities. Therefore, not all the cost calculation items are described at the same level of detail as for the Member States in Category I. Thus, for Category II Member States there is no data on the cost calculation approach, cost assessment reviews, information on cost management of radioactive waste or spent fuels units, and yearly breakdowns of the overall costs.

However, there is some availability of information for the Category II Member States on the overall costs of radioactive management and spent fuel management and, to a very limited extent, on categorisation of costs and costing processes. Further information is provided below.

Categorisation of costs

Of the six Member States in Category II, Denmark has to some extent developed a categorisation and cost calculation methodology which covers the commissioning of the long-term storage facility that would enable decommissioning of the existing nuclear facility.

Although Denmark does not provide the decommissioning costs for the Riso facilities[38], the scope of the country's cost calculation methodology provides a detailed cost calculation methodology for establishing the long-term storage facility. The costs are provided in three different scenarios (most likely price, minimum price and maximum price).

For example, the most likely price scenario is divided into the following cost categories:

- Preliminary costs: EUR 3.82 million;
- Site acquisition: EUR 1 million;
- Construction and outfitting: EUR 30.85 million;
- Design and tender: EUR 3.82 million;
- Preliminary conditioning: EUR 0.33 million;
- Salaries: EUR 116.20 million;
- Operational costs related to staff: EUR 11.06 million.

Overall costs of the radioactive waste and spent fuel management

The availability of information on the overall costs of the radioactive management and spent fuel is the most extensive for Category II Member States. Denmark, Latvia and Portugal provided information on the overall costs of the whole radioactive waste and spent fuel management programme. This information is not reported for two of the six countries, Austria, which does not plan any future nuclear investments, and Poland which is planning the construction of two nuclear reactors in 2025 and 2030. Thus, it the current Polish nuclear landscape is in transition. For the time being, estimation of costs is very limited but will be developed in future. The only available cost estimation in Poland refers to the costs of implementation of the National Plan of radioactive waste and spent fuel management in the years 2015-2025 and does not include costs associated with commissioning of the future nuclear power plants.

3.5.3 Category III Member States

Figure 14 presents the availability of information on cost calculation items for Category III Member States. The overall availability of information is low at only 13%. The low rate of information availability arises because five of the six Category III Member States have neither nuclear power plants nor research reactors and possess only institutional waste. The exception is Estonia. Thus, for five of the nine items information is not available for the Category III Member States on the costing process and cost assessment review, hypothesis development, categorisation of costs and finally yearly breakdown of the overall costs. The items referring to the information on cost management of radioactive waste or spent fuel units are not applicable under Category III.

However, there is some availability of information for the Category III Member States on the cost calculation approach and the overall costs of radioactive and spent fuel management.

[38] Denmark had three research reactors at the former Riso National Laboratory site. These have been shut down.

Cost calculation approaches

For the Category III Member States, although available, the information on the cost calculation approach is very limited in comparison to that available for the Category I Member States. Of the Category III countries, only Estonia estimates the cost of the safe inclusion of the radioactive waste made by the waste handler based on a developed price methodology, which also takes into account the cost of taking waste to the place of final disposal.

Cyprus and Ireland have developed an assessment of the resources needed to be recovered for radioactive waste management. However, these countries do not provide a detailed cost calculation approach in the way that Category I Member States did.

Overall costs of the radioactive management and spent fuel management

Of the Category III Member States, Estonia and Luxembourg provided an overall cost for the whole radioactive waste management, but Luxembourg provides the yearly estimation of such management costs (EUR 16 000 per year) while Ireland indicates only the funding mobilised in 2012 to cover the costs related to institutional waste.

3.6 Overview and analysis of the different types of financing scheme

The following information items were scrutinised in order to understand the financing schemes:

- Type of financing scheme and number of funds;
- Connection between the costs and the funds;
- Accumulation of the financial resources;
- Additional financing mechanisms;
- Internal functioning of the funds (governance, annual discount and interest rates);
- Size of the funds and availability over time.

Figure 15 provides an overview of the availability of information regarding the financing schemes.

Figure 15 – Overview of availability of information on financing schemes – per category of Member States and overall

		%	% cat I	% cat II	% cat III
	STEP 5 – FINANCING SCHEME(S) AND RAW/SF MANAGEMENT FUND(S)	57%	66%	32%	58%
43	What is the type of financing scheme(s)?	93%	100%	83%	83%
44	How many and what RAW & SF management funds exist in the MS?	75%	88%	33%	83%
45	Are there additional financial mechanisms for RAW management in the MS?	82%	88%	67%	83%
46	How are the fund means collected?	89%	94%	83%	83%
47	Governance of the RAW management fund	64%	81%	17%	67%
48	Is there a connection between the review of the costs and the accumulation of funds?	39%	44%	33%	33%
49	What are the annual discount rates of the fund(s)?	25%	31%	0%	33%
50	What is the annual interest rate of the fund(s)?	21%	25%	0%	33%
51	Size of the fund	50%	69%	0%	50%
52	Availability of the fund to timely cover the costs	29%	38%	0%	33%

Source: Authors' from data in National Programmes, National Reports or other official sources

3.6.1 Category I Member States

For Category I countries, Figure 15 provides an overview of the availability of relevant information retrieved from the sources that have been reviewed for this report.

Type of financing scheme and number of funds

Fifteen of the sixteen Category I Member States have segregated external funds for the financing of radioactive waste and spent fuel management. Of these fifteen Member States, nine (Czechia, Germany, Finland, Hungary, Italy, the Netherlands[39], Slovenia, Spain, Sweden[40]) have one fund in place and five Member States (Bulgaria[41], Lithuania, Romania, Slovakia, the UK) have two funds in place.

The case of France and Belgium differ from the other countries in this category. France and Belgium rely on segregated internal funds for the primary financing mechanism. These are established and managed by the nuclear operators.

[39] 'Segregated external fund' is fully appropriate in the case of COVRA since the funds for the active and the passive phase (geological repository) are included in COVRA's balance sheet (provision accounts) and are not part of a segregated (ring fenced) external fund. The available funds are invested by COVRA through a fund manager on the basis of an investment mandate.

[40] There is one fund in Sweden. However, all licensees have full responsibility for their own responsibilities and thus their liabilities. So, in practical terms, there is one fund per licensee.

[41] Two targeted funds are being operated in Bulgaria, namely the Radioactive Waste Management Fund and the Nuclear Facilities Decommissioning Fund. However, there is own financing provided by the Kozloduy NPP for SNF and RAW management, as well as for the decommissioning preparation before the establishment of the SERAW.

Segregated internal funds are also used in Czechia as an additional financing scheme for reactor decommissioning, while the external fund serves as a financing mechanism for radioactive waste and spent fuel management.

Until 2017, Germany was the only Member State with a financing scheme based on non-segregated internal funds. This financing scheme was replaced by a segregated external fund for radioactive waste and spent fuel management. Non-segregated internal funds continue to exist in Germany for the financing of reactor decommissioning.

There are different reasons why some Member States have established more than one fund:

- In the UK, there is one fund to finance the management of radioactive waste and spent fuel from privately owned facilities and a second fund to finance the management of waste and spent fuel from publicly owned facilities;
- In Bulgaria and Romania, one fund is destined for the financing of radioactive waste and spent fuel management, while the other fund is for reactor decommissioning;
- In Slovakia, one fund has been established specifically to finance the decommissioning of the Bohunice V1 unit which was shut down as part of Slovakia's EU accession agreement. For all other reactors, the second fund serves as a financing mechanism for waste and spent fuel management as well as decommissioning;
- Lithuania has one fund financed by operator contributions and from the State's budget and a second fund financed by the EU.

Accumulation of the financial resources

Information on how the resources are found to feed the funds is available for 94% of Category I Member States. The most common method is regular payments. These can take different forms, e.g. taxes, levies or tariffs levied on the energy price, or direct charges paid by power plant operators per unit of energy produced (in line with the 'Producer Pays Principle'). Germany is the only country which has not established a system of regular payments to accumulate the resources. Instead, power plant operators were obliged to make a one-time lump sum payment into the fund.
Bulgaria, Lithuania and Slovakia are a special case. Shutdown of some nuclear reactors was negotiations during the process of accession of these countries to the EU. As part of the agreement, the EU supports the three Member States in the decommissioning of these reactors with additional financing disbursed by the EBRD. These funds are dedicated to decommissioning activities and only partially cover the radioactive waste and spent fuel management.

Additional financing mechanisms

The funds in the Member States are mostly limited to financing the management of radioactive waste and spent fuel from commercial power generation and, in some cases, from installations being decommissioned. For other cost items laid out in the National Programmes (for instance state-owned sources or institutional waste), additional financing mechanisms have been identified for 88% of Category I Member States. The management of radioactive waste and spent fuel facilities under the ownership of the State is mostly financed from the State's budget (unless a specific fund has been established to this end, as, for instance, in the UK). In some countries where the fund covers only the costs for radioactive waste and spent fuel management (like Czechia, Germany or Sweden), power plant operators are obliged to hold additional internal funds, budget reserves or contingencies for the financing of reactor decommissioning. The management of institutional waste is financed by licensing fees and/or by direct charges that waste generators pay to waste treatment operators.

Internal functioning of the funds (governance, annual discount and interest rates)

The availability of information on the detailed functioning of the funds (governance, discount and interest rates, connection between the costs and the funds) is overall lower than for the other cost items. Information on the governance of the fund is available for 81% of the Member States in Category I. However, information relating to the financial details of the funds, such as annual discount rates, is available for about 30% of the Member States.

Size of the funds and availability over time

Lastly, information on the current size of the funds is available for about two thirds of Member States in Category I. The amounts range from EUR 0.14 billion (Romania) to EUR 92.1 billion (UK). Information on the funds' availability over time is only available for 38% of the Member States, where broad estimates can be made based on past performance of the funds or on the regular fees. The size of the funds and availability over time will be presented in more detail and compared to the costs in Chapter Error! Reference source not found..

3.6.2 Category II Member States

For the Member States in Category II, Figure 15 shows the availability of information retrieved from the sources reviewed for this report. In five of the six Category II Member States (83%), information is available on the type of financing scheme and the method of accumulating the financial resources. Member States in Category II do not have any nuclear power plants and the financing scheme structure is thus different from Category I: there are no radioactive waste management funds in place in the Category II Member States. Instead, the management of radioactive waste and spent fuel is financed from the public budget and/or from licensing fees or disposal charges paid by the generators of radioactive waste. Poland is the only country in Category II that plans the construction of new nuclear power reactors. A scheme to finance the management of waste and spent fuel from these reactors is, however, not yet in place.

3.6.3 Category III Member States

For Category III, Figure 15 provides an overview on the availability of information retrieved from the sources reviewed. Information on the general features of the financing scheme is available for 83% of the Member States in Category III. Member States in this Category only generate institutional radioactive waste. The management of this waste is financed by licensing fees and/or direct disposal charges paid by the waste generators, and by additional resources from the public budget. Like the Category II Member States, those in Category III (with the exception of Croatia) have not established any radioactive waste management funds. Therefore, the details on the functioning of the fund and the fund size and availability over time are not applicable to the Member States in Category III.

Croatia is an exception in Category III. There is no nuclear power plant in Croatia, but the country shares with Slovenia the responsibility for the Krško power plant which is located on Slovenian territory but was constructed under the government of former Yugoslavia. Croatia has thus established a radioactive waste management fund to ensure the financing of its liabilities. Cyprus also plans to establish a radioactive waste management fund, but as of 2018 this fund had not yet been established.

3.6.4 Availability of the funds over time

Only Category I Member States and Croatia have established radioactive waste management funds (Croatia is in Category III, but has nevertheless established a radioactive waste management fund). In most Member States, current funds do not match the total costs. This is not surprising, because the total costs cover a timeframe of several or many decades (more than 100 years) into the future: there is not enough information available for most Member States on how much the funds are expected to accumulate until the end of the National Programme.

Category II and Category III Member States finance waste management through the State budget and/or through licensing fees and charges on waste generators. Category I countries cover additional cost items not covered by the waste management funds in the same way. Therefore, the funds should theoretically always be available, although explicit figures were not available in the sources reviewed.

4 Key practices, methods and tools

4.1 Introduction

This chapter covers Tasks C and D of this assignment, i.e. identifying common trends, good practices and challenges across Member States, and then defining a set of tools, including a comprehensive structure of activities and cost items, as well as relevant Cost Assessment Indicators (CAIs), that can contribute to building common ground between Member States in the analysis of the cost assessment of radioactive waste and spent fuel management.

The review of the national frameworks for management of radioactive waste and spent fuel described in chapter 3 shows a variety of national approaches to cost calculation for radioactive waste and spent fuel management. Given the limitations of publicly accessible sources, the review described in chapter 3 was followed by a survey of EU Member States on cost calculation methodologies for radioactive waste. Fourteen Member States[42] responded to the survey. This chapter presents the results.

This chapter is in four main parts:

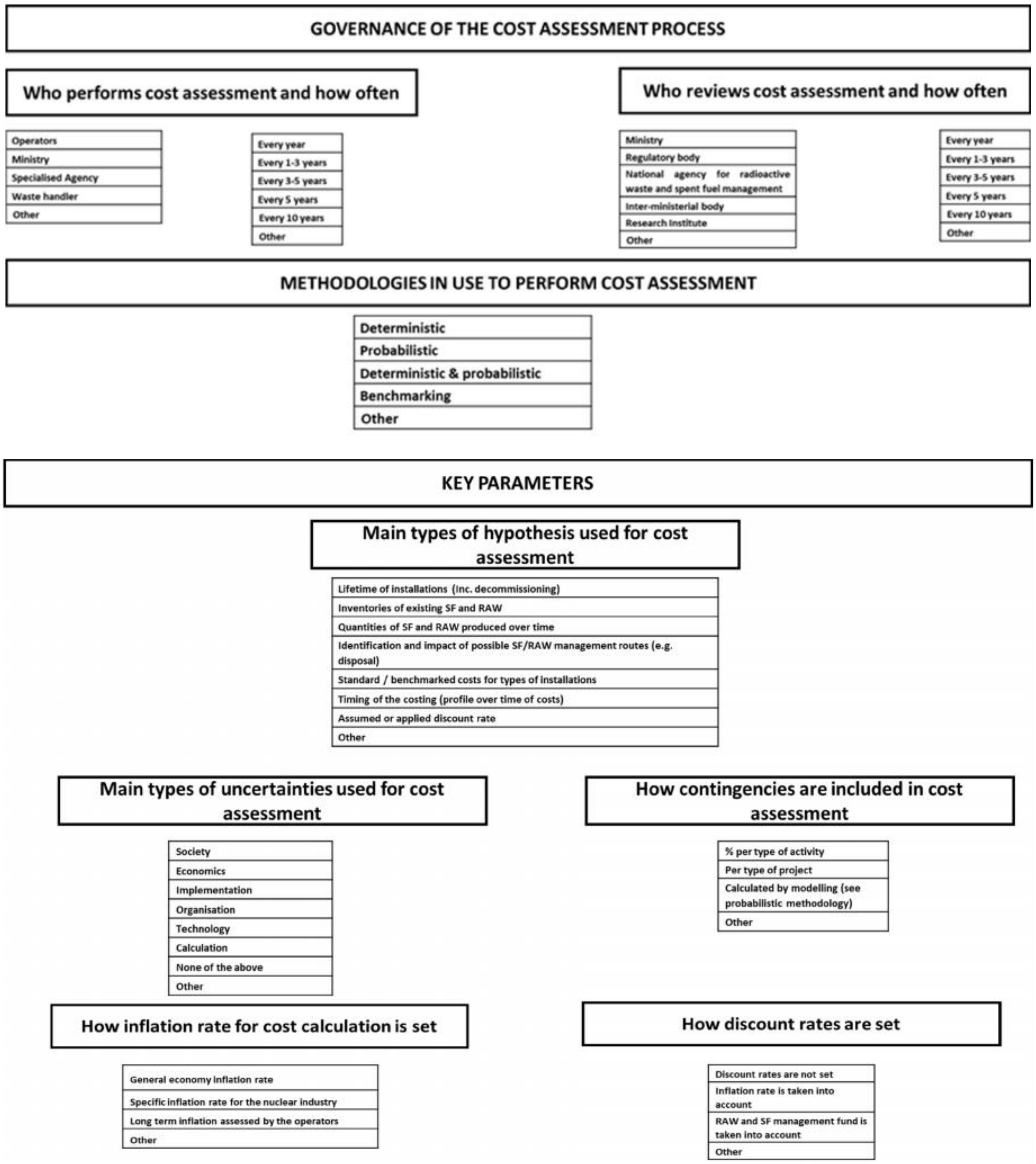
- Theoretical background on calculation of the costs of radioactive waste and spent fuel management;
- Results of the survey on calculation of the costs of radioactive waste and spent fuel management;
- Proposal for a high-level taxonomy for radioactive waste and spent fuel management activities;
- Approach for cost assessments indicators.

4.2 Theoretical background

There are three main elements in the process of cost assessment for radioactive waste and spent fuel management: the governance structure, the methodologies in use and the key parameters used for calculation. The figure below outlines the different elements of the process schematically. The following sections briefly describe the main methodologies in use (probabilistic, deterministic, benchmarking) and how contingencies and uncertainties are standardly dealt with. The section on the results of the survey looks at how EU Member States in practice handle governance and which methodologies they use for determination, and for dealing with uncertainties and conclusions.

[42] AT, BG, CZ, DE, ES, FI, FR, HR, HU, IT, LT, NL, SE, SK.

Figure 16 – Cost assessment process for radioactive waste and spent fuel in the EU: main elements



Source: Authors from various sources

4.2.1 Main steps in the cost calculation

For the cost assessment of spent fuel and waste management, it is necessary to take at least into account the following:

- Lifetime of installations (including decommissioning);
- Inventories of existing SF and RAW;
- Quantities of SF and RAW generated over time (until the end of the National Programme);
- Identification and impact of possible SF/RAW management routes (e.g. disposal);
- Standard / benchmarked costs for types of installations;
- Timing of the costing (profile over time of costs);
- Assumed or applied discount rate.

As a function of time, taking into account the national requirements for waste classification, based on the IAEA Safety Standard No. GSG-1 ("The classification of radioactive waste")[43], each waste generator is required to establish an operational classification of the waste that it manages, taking into account the different characteristics of the waste and the impact that has on the definition of the way in which they need to be managed, such as:

- Origin and types of the waste, nuclear and radiological properties, management;
- Options, other properties such as: physico-chemical and biological properties/hazards;
- Corrosiveness, content of free liquids, flammability, volatility, solubility, miscibility;
- Dispersibility, organic content, complexing/chelating agents, reactivity, sorption of radionuclides, swelling potential, chemically or biologically hazardous substances, etc.

4.2.2 Presentation of the main cost calculation methods

The different cost calculation methods performed at a given date are presented below. To calculate actual costs, the DCF (discounted cash flow) is used as a standard valuation method to estimate the value of an investment based on its future cash flows.

➢ Deterministic methods

Deterministic methods are considered to be the simplest and most common methods used for RAW and SF cost assessment and for establishing a contingency budget. The term deterministic implies that these methods offer a point estimate for cost assessment. Deterministic approaches cannot effectively address the risks specific to a project and consider the unique effects of project complexity, market conditions, location. Deterministic methods can, therefore, be summarised as falling into two main categories as follows:

- Predefined percentages (fixed/line items): this approach is the simplest method of contingency allocation. In this method, either an across-the-board predetermined (fixed) percentage of total base cost or various percentages of line items is added to

[43] https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1419_web.pdf

the project budget as a contingency. When a contingency is added separately for each line item, an overall contingency can be added to the project budget as unallocated contingency on top of the allocated contingency. Suggested percentages are given for different key phases of a certain type of project and may be a single value or range of values.

- Expert judgment: the only difference between this method and a predetermined percentage is that in this method an expert or a group of experts with strong experience in risk analysis defines the contingency percentage for the project under consideration.

The Electric Power Research Institute (EPRI) method[44] uses four levels of project contingency and five levels of technology contingency (Table 4).

Table 4 - Project and technology contingencies used in the EPRI method

Project Contingencies	
Simplified planning (conceptual screening)	30-50%
Preliminary planning (feasibility study)	15-30%
Detailed planning (budgeting stage)	10-20%
Final or near-final planning (tendering stage)	5-10%

Technology Contingencies	
New concept for which little or no comparison exists	≥40%
New design for which a preliminary design analysis has been performed	30-70%
New design for which a more advanced design analysis has been performed, possibly involving prototype testing	20-35%
Modified design derived from an existing design already commonly used in the industry	5-20%
Design commonly used in the industry	≤10%

Source: IAEA "Costing methods and funding schemes for radioactive waste disposal programmes", awaiting production as of July 2019 (https://www.iaea.org/sites/default/files/19/07/july2019_nes_under_preparation.pdf)

- Probabilistic methods

The main difference between probabilistic methods and deterministic methods is that in probabilistic methods uncertainties are explicitly modelled using appropriate statistical distributions.

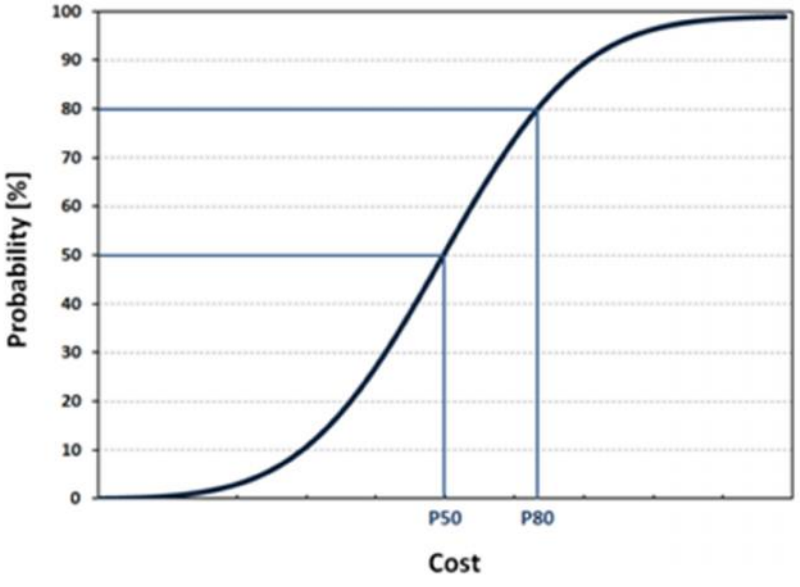
[44] IAEA "Costing methods and funding schemes for radioactive waste disposal programmes", in publication 2018.

In probabilistic models the uncertainties and risks are incorporated within the cost estimate. These types of models calculate a range of estimates rather than a point estimate. All mathematical operations such as addition, subtraction, multiplication, and others must be performed on data range, and require the use of probability theory. Probabilistic risk assessment may employ a set of tools such as a fault tree, a probability tree, decision analysis and Monte Carlo simulations.

- Simulation Methods (Monte Carlo): in this method, expert judgment and an analytical method usually come together to reach a probabilistic output using a simulation routine. In many cases analytical models become more complicated, simulation can help analyst to find the probabilistic output. Monte Carlo is one of the most common simulation methods in the construction industry.
  One of the most common methods employing Monte Carlo simulation is Range Estimating. In this method, first, the critical cost items are identified; the deterministic estimate of each critical cost item is considered as the most likely value; next, the minimum and maximum values of the critical items are defined by a project group; at the end, with the help of Monte Carlo simulation, the total cost cumulative distribution function (CDF) is calculated; this CDF is used to estimate the required contingency to reach the desired confidence level that the budget will not fall short.

- Cumulative probability distribution of cost: an overall cost contingency can be derived from a cumulative probability distribution of the cost. Such a distribution plots the estimated cost against the probability that the actual cost will be lower than or equal to that cost. This is shown in Figure 17. The P_{50} and P_{80} lines indicate the costs for which there is respectively a probability of 50% and 80% so that the actual cost will be lower than or equal to this cost

Figure 17 – Cumulative probability distribution of the cost



Source: IAEA "Costing methods and funding schemes for radioactive waste disposal programmes", in publication 2018

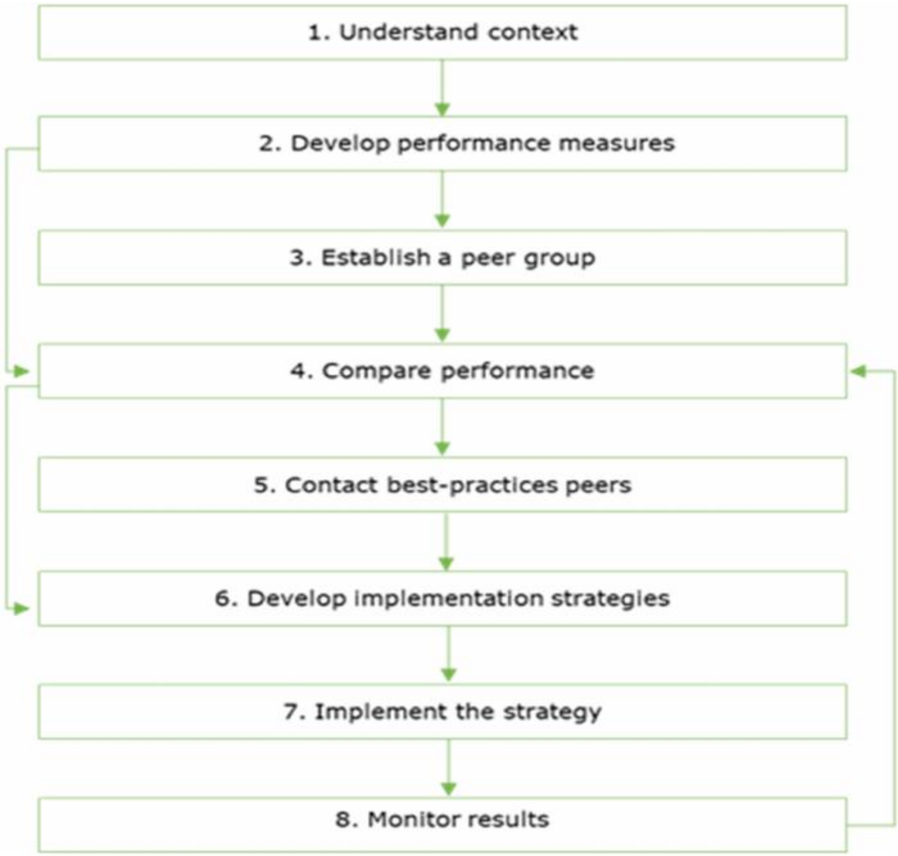
- Benchmarking methodology

Benchmarking is the practice of comparing business processes and performance metrics to industry bests and best practices from other companies. Dimensions typically measured are quality, time and cost.

Benchmarking is used to measure performance using a specific indicator (cost per unit of measure, productivity per unit of measure, cycle time of x per unit of measure or defects per unit of measure) resulting in a metric of performance that is then compared to others.

Figure 18 describes a step-by-step process, in eight steps, for conducting a trend analysis, peer-comparison or full-fledged benchmarking.

Figure 18 – Benchmarking steps



Source: National Academies of Sciences, Engineering, and Medicine. 2010. A Methodology for Performance Measurement and Peer Comparison in the Public Transportation Industry. Washington, DC: The National Academies Press. https://doi.org/10.17226/14402.

4.2.3 Methodologies used for contingency cost calculation - Overview

The Association for the Advancement of Cost Engineering (AACE) defines contingency as "An amount added to an estimate to allow for items, conditions or events for which the state, occurrence, or effect is uncertain and that experience shows will likely result, in aggregate, in additional costs. Typically estimated using statistical analysis or judgment based on past asset or project experience."

ACCE declares that contingency does not include costs caused by: 1) Major scope changes; 2) Extraordinary events, such as major strikes and catastrophes; 3) Management reserves, which are an amount added to an estimate to allow for discretionary management purposes outside of the defined scope of the project; 4) Escalation and currency effects.

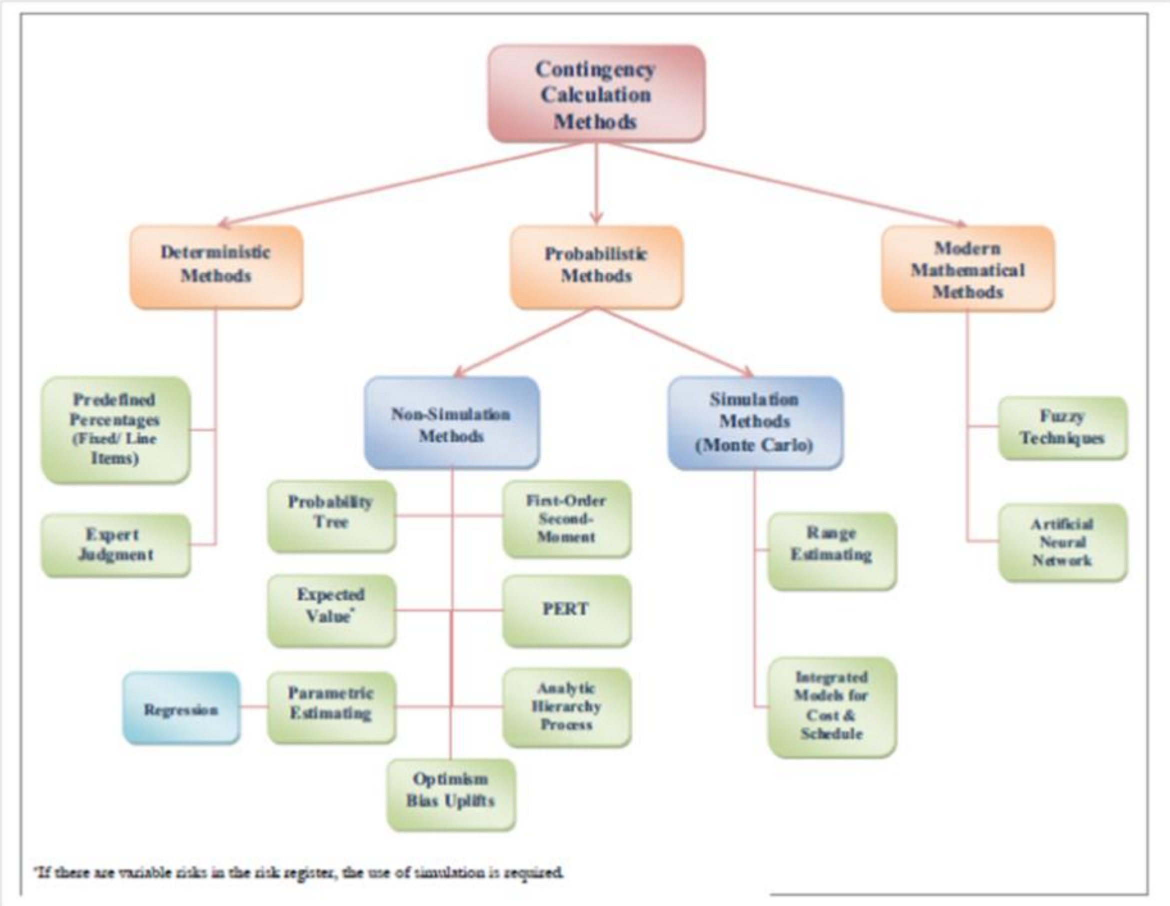
To absorb the cost impact of risk factors, a contingencies budget is added to the total project budget. This means that a total cost of project is broken down to: 1) base cost, and 2) contingency cost. Base cost is the cost of project with contingency cost. Contingency is defined as a reserve budget for coping with risks and uncertainties and help to keep the projects on budget. Contingency is traditionally estimated as a predetermined percentage of project base cost depending on the project phase. In recent years, some agencies have started conducting formal probabilistic risk assessment to estimate contingency budget rather than taking a deterministic approach.

Contingency is described as three basics types[45]: 1) Tolerances in specifications that must be taken into account in the management of the project; 2) Variations in the nuclear programme which have an impact on the management of the project; 3) Money in the budget that must be available for the duration of the project. There is unanimity that contingencies should be taken into account in project management for managing risks and uncertainty associated with cost and schedule of a project.

The common methods for establishing radioactive waste and spent fuel management cost assessment and contingency budgets are divided into three main groups as adapted in Figure 19: Deterministic methods, Probabilistic methods, and Modern mathematical methods. Feedback to identify best practices is also taken into consideration through benchmarking processes.

[45] Procedia Engineering 85 (2014) 52-60, Creative Construction Conference 2014, CC2014.

Figure 19 – Contingency Calculation Methods

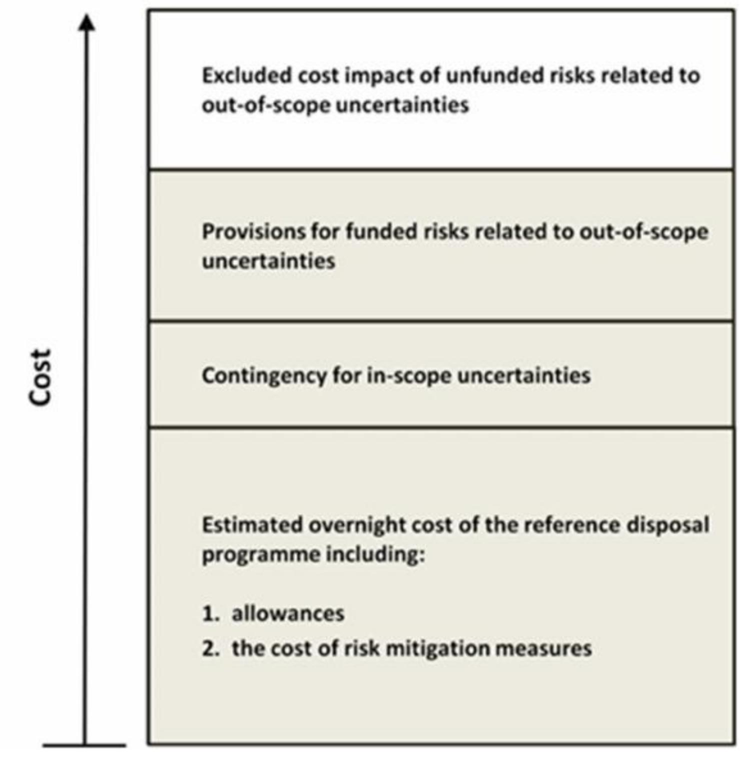


Source: Procedia Engineering 85 (2014) 52-60, Creative Construction Conference 2014, CC2014Types of out-of-scope uncertainties to be taken into consideration in the cost assessment

The difference between contingencies and provisions for funded risks is that it is anticipated that the former will be fully incurred during the development and implementation of the programme while the latter may or may not be spent. Consequently, contingencies should form an integral part of the estimate. Whether or not provisions are set aside for certain risks is an organisation's decision.

As an example, the different elements of the cost estimated are presented below (Figure 20 in the case of the IAEA study for radioactive waste disposal programme.

Figure 20 – Elements of the cost estimated



Source: IAEA "Costing methods and funding schemes for radioactive waste disposal programmes", awaiting production as of July 2019 (https://www.iaea.org/sites/default/files/19/07/july2019_nes_under_preparation.pdf)

There has been progress in most countries in the formulation of national policies, strategies and programmes for the management of spent fuel and radioactive waste which are based on international recommendations.

The types of out-of-scope uncertainty that can be taken into consideration in the cost assessment process are the following:

- Society – Regulatory and political issues, including changes in standards and regulatory requirements: public acceptance of spent fuel and radioactive waste management remains a challenge in most countries; this is especially true for disposal facilities, and a lack of acceptance has had a negative impact on the progress of programmes; efforts have been increased to enhance openness, transparency and public involvement. In the cases where progress is reported, local acceptance has been successfully achieved. There has been notable progress in Finland, where a licence to construct a deep geological repository for spent fuel was granted in 2015. France and Sweden have both been able to select sites for their deep repositories and are progressing with the licencing steps.

- Economics – Economic conditions (e.g. the real price trend for labour, materials, exchange rates);
- Implementation – Schedule strategies, siting and decommissioning, including scenarios for potential early shutdown of facilities: funding for decommissioning old reactors, and for remediation and management of legacy sites and waste remains a challenge, especially when the original owner or operator no longer exists; in these cases, funding often becomes the responsibility of the State and must compete with other funding priorities.
  States planning to embark on nuclear power or constructing new reactors are increasingly considering future requirements for the management of spent fuel and radioactive waste as well as eventual decommissioning as a precondition of licencing the new reactors.

  Uncertainties may be due to a change in the Member State's nuclear policy and premature shutdown of nuclear power plants or nuclear facilities.
- Organisation – Management and implementation issues in construction and decommissioning: decommissioning a large nuclear facility is a major project; thus, best project management practices, tools and techniques and QA processes are vital; a dedicated waste management strategy is essential for safe and cost-effective decommissioning. Procedures for the 'management of change' are essential; the safety of the workforce, public and environment is paramount throughout the decommissioning project, etc.
- Technology – Technological uncertainties of future radioactive waste and spent fuel management and disposal facilities: innovative technologies can be developed for waste treatment and nuclear facility decommissioning that can lead to uncertainties in project cost and planning.
- Calculations – The risk of incorrect assessments in the calculation work.

4.3 Survey submitted to Member States

Following the analysis in Tasks A and B (chapter 3), the team conducted a survey with the Member States to complete information gaps and to better understand how the cost calculation of radioactive waste and spent fuel is performed in the Member States. Fourteen responses were received.

The survey consisted of three main parts: i) Cost assessment processes for radioactive waste and spent fuel management in the Member States; ii) High level taxonomy for radioactive waste and spent fuel management activities in the Member States; and iii) Approach for cost assessment indicators.

4.3.1 Cost assessment processes in the EU Member States, based on review of national frameworks, desk research and survey

The part of the survey on cost assessment processes in the Member States consisted of ten questions and was built as follows:

- First, the processes of cost calculation for radioactive waste and spent fuel management are analysed, i.e. Member States were asked to answer questions on who performs and reviews the cost calculation and how often that is done;
- Second, the survey deals with the questions of what methods are in use to perform cost calculations;
- Finally, the survey presents key parameters that are in use to perform cost calculations.

Below is the list of questions of the survey:

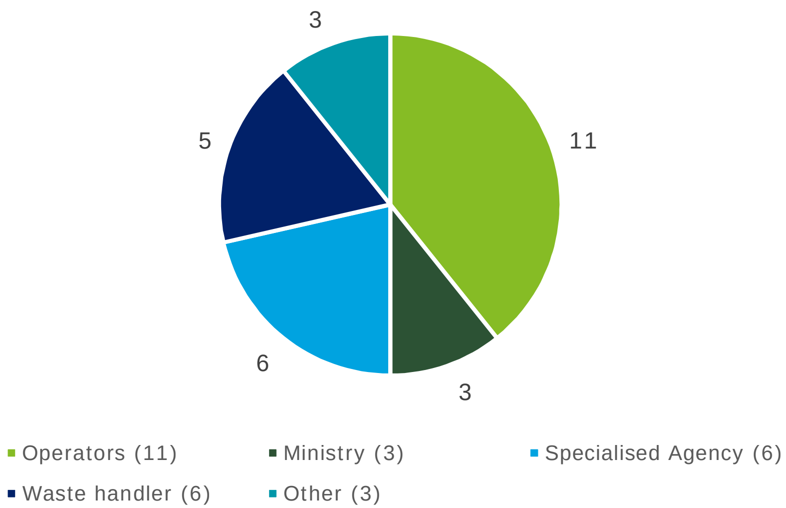
1. Who performs cost calculations for national programmes for RAW and SF management in your Member State?
2. How often are the cost assessments usually performed in your MS?
3. Who performs the review of cost assessment in your MS?
4. How often are the cost assessment reviews performed in your MS?
5. What methodologies are in use to perform cost assessment of the national programme for spent fuel and radioactive waste in your MS?
6. Which are the main hypotheses used for cost assessments in your MS?
7. What types of uncertainties are taken into consideration in the cost assessment in your MS?
8. How are contingencies included in the cost assessment?
9. Is a different expected inflation rate (vis-à-vis the general expected inflation rate for the entire economy) applied for spent fuel and radioactive waste management costs?
10. How are discount rates set when updating future costs?

The results of the survey are presented below, highlighting the answers of the Member States, additional details that Member States provided and a short analysis of the answers. Although fourteen Member States[46] responded to the survey, the analysis below highlights answers from more than fourteen Member States. The information on the Member States that did not respond to the survey was extracted from their National Programmes and Plans and other publicly available documents. Overall, the results demonstrate heterogeneity in methods and tools in Member States' approaches to cost calculation.

[46] AT, BG, CZ, DE, ES, FI, FR, HR, HU, IT, LT, NL, SE, SK.

Issue 1. Who performs cost calculations for National Programmes for RAW and SF management in your Member State?

	AT	BG	CY	CZ	DE	EE	ES	FI	FR	HR	HU	IE	IT	LT	NL	PL	SE	SK	UK
Operators	✓	✓		✓	✓			✓	✓				✓	✓		✓	✓		✓
Ministry			✓		✓				✓										
Specialised Agency					✓		✓		✓	✓		✓						✓	
Waste handler						✓			✓		✓			✓	✓				
Other										✓		✓			✓				



Trend identified: In most Member States cost calculations are carried out by the operators.

Member States use different methods. In most Member States the operators perform cost calculations, while six Member States have mixed approaches, where several different types of actors participate in different parts of the cost calculation process. One of the notable cases of the mixed approach is France, where several bodies are responsible for different aspects of the cost calculation.

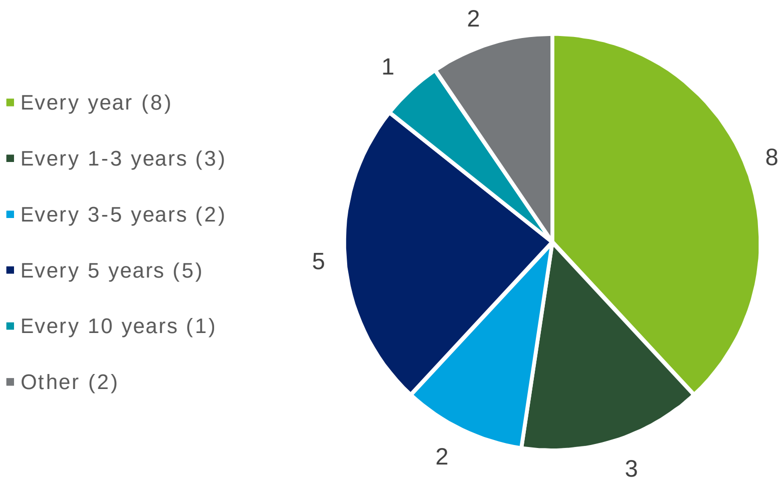
Member State	Additional information provided by Member States
Austria	According to the Radiation Protection Act, the calculations for radioactive waste must be made by an operator, Nuclear Engineering Seibersdorf GmbH (NES) and are checked by the Federal Ministry for Sustainability and Tourism. The spent fuel of the only Austrian research reactor will be taken back by the USA because the fuel is the property of the USA.
Croatia	Cost calculations for the National Programme for RAW and SF management is carried out by a specialised organisation (technical support organisation of the regulator) and also the Fund for financing the decommissioning of the Krško Nuclear Power Plant (NEK Fund) and the disposal of NEK radioactive waste and spent nuclear fuel and contracted expert organisations.
France	Operators (mainly Orano, EDF, CEA and Andra) are required to evaluate their “nuclear long-term charges”. When available, they take into account contract prices (SF reprocessing costs, VLLW, LLW/ILW-SL management costs, LLW-LL, ILW-LL and HLW processing, transportation and storage costs…). They are also required to take into account the evaluation of the cost of the deep geological disposal project (Cigéo). After receiving the comments from those liable to pay the additional taxes and the opinion of ASN (the nuclear regulator), the Minister responsible for energy finalises and publishes the evaluation of the costs of the Cigéo project. These also take into account the evaluation of the cost of the LLW-LL disposal project.
Germany	The cost calculation is performed by both the federal company for radioactive waste disposal (BGE Bundesgesellschaft für Endlagerung) and the federal company for temporary storage (BGZ Gesellschaft für Zwischenlagerung mbH).
Ireland	Environmental Protection Agency and the Government Department of Environment, Community and Local Government.
Lithuania	Ignalina Nuclear Power Plant (INPP) is currently acting as decommissioner and waste handler.
Netherlands	COVRA (a company owned by the Dutch State) is responsible for management of radioactive waste in the Netherlands) carried out a study known as OPERA.[47] The cost estimation of the ultimate repository for radioactive waste is part of the OPERA study. A review of the cost estimate was carried out by an independent expert. COVRA is also responsible for the intermediate storage of nuclear waste, and the cost and financing of the facilities. COVRA is designed to be an economically sound business in which the polluter pays the bill.
Spain	ENRESA is the state-owned company responsible for the implementation of the National Programme for radioactive waste management and decommissioning.

[47] Opera study (available in Dutch) https://covra.nl/downloads/general/Jaarrapport_COVRA_2017.pdf.

Member State	Additional information provided by Member States
Sweden	Operators (permit holders) are required to establish a cost calculation for these and supply this to the financial regulator of the Financing System every third year.
Slovakia	Costs calculated for decommissioning of nuclear installations including management and disposal of radioactive waste and spent fuel are included in decommissioning plans conducted by expert organisation as a service for the operator/licence holder. The costs for the planned deep geological repository are also calculated by an expert organisation. All the costs are summarised in the National Programme for RAW and SF under the coordination of the National Nuclear Fund (NNF). The NNF is responsible for ensuring of sufficient financial sources for covering whole backend process.

Issue 2. How often are the cost calculations usually performed in your Member State?

	AT	BG	CZ	DE	ES	FI	FR	HR	HU	IT	IT	MT	NL	PL	SE	SK	UK
Every year	✓			✓	✓	✓	✓		✓	✓			✓				
Every 1-3 years						✓	✓									✓	
Every 3-5 years											✓						✓
Every 5 years		✓	✓					✓						✓	✓		
Every 10 years												✓					
Other	✓				✓								✓			✓	



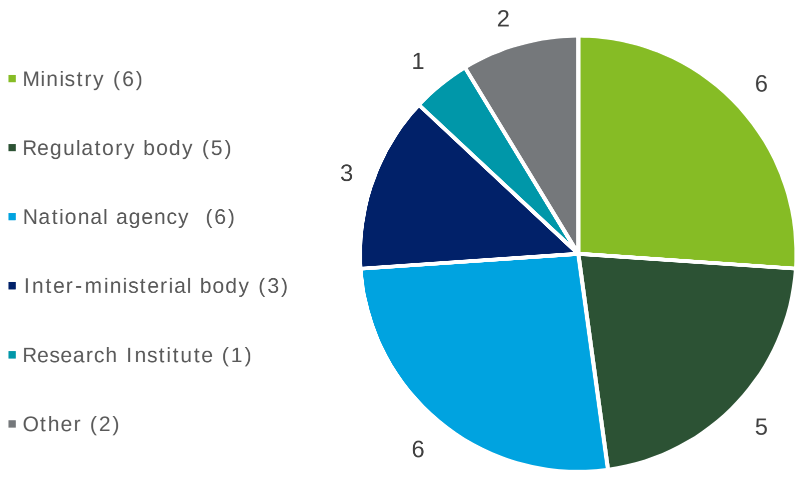
Trend identified: <u>In most Member States, the cost calculation is performed every year</u>

Member States use different methods. In most Member States cost calculation is performed every year. Finland and France have a mixed approach, where different aspects of the cost calculation are calculated at different times.

Member State	Additional information provided by Member States
Austria	The tariff list (for the conditioning, treatment, storage and other handling) of radioactive waste is calculated every year. There is also a contract in place between NES, the municipality of Seibersdorf and the Federal Ministry for Sustainability and Tourism, which regulates the tasks of NES and its financing. The financial basis for this contract is evaluated after an essential change of basic parameters (usually every 5 to 10 years).
Croatia	In accordance with the agreement between the governments of Slovenia and Croatia on the status and other legal issues related to investment, exploitation and decommissioning of the Krško nuclear power plant, , the signatories are obliged to carry out a cost assessment for every revision of the Krško NPP Decommissioning Programme and RW & SNF Disposal Programme. Revisions of both programmes have to be performed every 5 years. Revisions of cost assessments for the management of institutional RW and DSRS (design safety review services) are performed along with the above-mentioned tasks.
Czechia	In the event of decommissioning, the law specifies a period of 5 years; for other management stages, cost assessment is not required by law.
France	The licensees are required to send a report to the Ministers in charge of energy and economy every three years describing their evaluation of the long-term costs, the methods applied to compute reserves as well as the choices made regarding the composition and management of the assets covering reserves. The licensees publish an update of this report every year. Some inputs are not reassessed yearly. The evaluation of the cost of the Cigéo project has been published. It will need to be updated regularly (but not yearly) at least at the key steps in the development of the project (creation authorisation, commissioning, end of pilot industrial phase, periodic safety reviews). The National Waste Management Plan is updated every three years. This National Plan includes an assessment of the National Programme costs, the underlying basis and hypothesis for that assessment and the financing schemes in force. This cost assessment considers operators' cost assessments.
Germany	The cost assessment is performed every year as part of the preparation and approval of the fiscal budget of the Federal Government. The planning period covers 5 years.
Hungary	The so-called medium- and long-term plan containing the cost calculations is updated yearly.
Netherlands	The cost accounting of the facilities for the intermediate storage of standardised waste is updated on a yearly basis by COVRA as part of their operational management. The costs for final disposal are updated periodically but irregularly.
Spain	ENRESA updates the cost assessments every year and forwards a report to the Ministry for Ecological Transition. Additionally, every 4 years or when required ENRESA submits a proposal for revision of the National Programme (General Radioactive Waste Plan) to the Ministry.

Issue 3. Who performs the review of cost calculations in your Member State?

	AT	BE	BG	CZ	DE	ES	FI	FR	HR	HU	IT	LT	NL	RO	SE	SK	UK
Ministry	✓		✓		✓	✓	✓					✓					
Regulatory body			✓				✓				✓				✓		
National agency for radioactive waste and spent fuel management		✓		✓										✓		✓	✓
Inter-ministerial body								✓		✓							
Research Institute							✓										
Other									✓				✓				



Trend identified: <u>In most Member States ministries and/or regulatory bodies perform the review of cost calculations.</u>

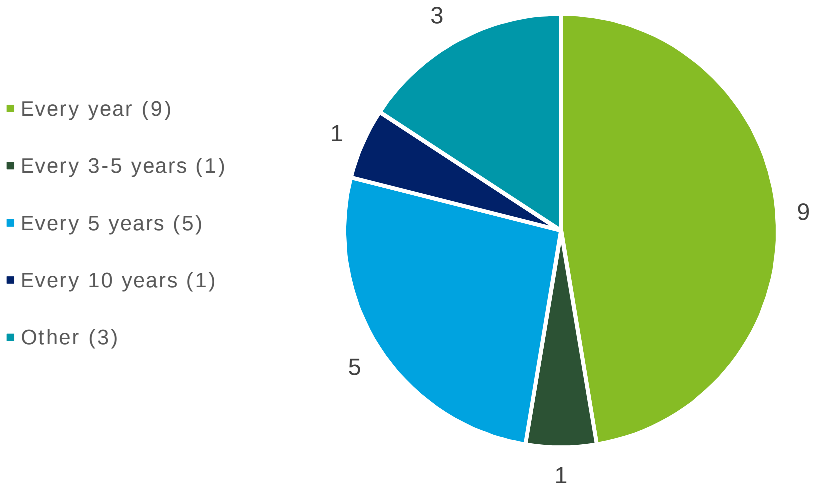
Member States use different methods in use. In most Member States ministries and/or regulatory bodies perform the review of cost calculation. Netherlands presents a different approach, where the cost calculation review is performed by an external expert. Another interesting example is Croatia. Since the Krško NPP is mutual responsibility of Croatia and Slovenia, cost calculation review is performed on different levels, inter-governmental bodies of the two Member States.

Member State	Additional information provided by Member States
Austria	The Federal Ministry for Sustainability and Tourism (in accordance with the Radiation Protection Act).
Belgium	National Agency for Radioactive Waste and enriched Fissile Material.
Croatia	Review of cost assessment for the revisions of the Krško NPP Decommissioning Program and RAW & SNF Disposal Programme is performed at several levels: - expert organisations that prepare the programmes (NEK Fund on the Croatian side and ARAO on the Slovenian side), - Project Implementation Coordination Committee, - regulatory body/ministry responsible for Intergovernmental agreement in Croatia and in Slovenia, - Intergovernmental commission for monitoring the implementation of Intergovernmental agreement. Review of cost assessment for the management of institutional RW and DSRS is done by regulatory body responsible for radioactive waste management and ministry responsible for NEK Fund.
Czechia	National agency for radioactive waste and spent fuel disposal (RAWRA) is responsible for cost assessment review of decommissioning plans according to the law (Nuclear Act No. 263/2016 Coll. https://www.sujb.cz/en/legal-framework/)
Denmark	Danish Decommissioning Agency.
France	Cost assessments are under the supervision of ministries in charge of energy and economy. This inter-ministerial body receives reports sent by operators and their yearly updates and may: - require transmission of additional information, - call on the expertise of nuclear safety regulators (ASN or ASND) to ensure that the report and their yearly updates are consistent with the decommissioning strategy as well as the spent fuel and radioactive waste management strategy, - mandate external audits on cost assessments, - prescribe the steps necessary for remedying non-compliance,

Member State	Additional information provided by Member States
	order financial penalties.
Germany	Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (Federal Ministry for the Environment, Nature Conversation and Nuclear Safety; BMU).
Hungary	An inter-ministerial body, a special body of the Central Nuclear Financial Fund annually reviews the medium- and long-term plan including the cost calculations.
Malta	Radiation Protection Board.
Netherlands	The cost estimate in the OPERA study for the final repository is reviewed by an external expert.
Poland	National Atomic Energy Agency.
Romania	Nuclear Agency and for Radioactive Waste.
Sweden	The financial regulator is responsible for regulatory review of the cost calculations and proposes nuclear waste fees and collateral amounts to the Government for the upcoming three-year period for each permit holder. The Government then decides on the levels of the fees and the collateral amounts. The fees and collateral amounts are calculated separately for each permit holder.
Slovakia	Review of the overall costs in the National Programme for RAW and SF is performed by the update of the National Programme under the responsibility of the NNF supported by an expert organisation.
UK	Nuclear Decommissioning Authority.

Issue 4. How often are the cost assessment reviews performed in your Member State?

	AT	BE	BG	CZ	DE	ES	FI	FR	HR	HU	IT	LT	NL	PL	SE	SK	UK
Every year	✓				✓	✓	✓	✓		✓	✓		✓		✓		
Every 1-3 years																	
Every 3-5 years												✓					✓
Every 5 years		✓	✓	✓					✓					✓			
Every 10 years																	
Other	✓					✓							✓			✓	



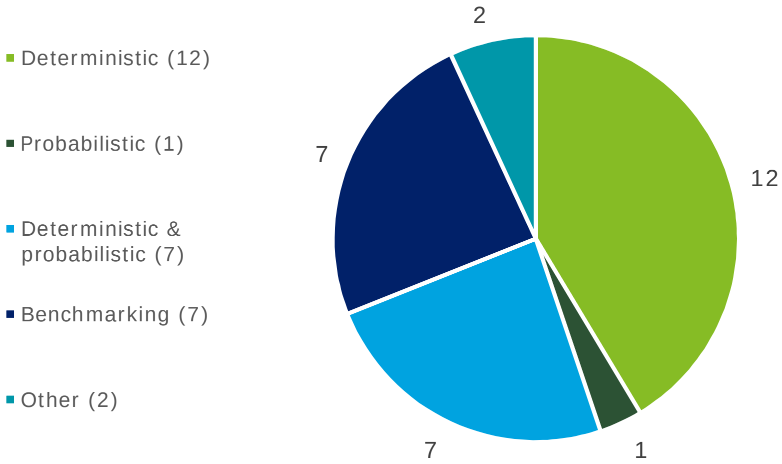
Trend identified: Most Member States review cost assessments every year

Most Member States review cost assessments every year on the basis of the cost assessments that are also performed every year in many Member States.

Member State	Additional information provided by Member States
Austria	The tariff list (for the conditioning, treatment, storage and other handling) of radioactive waste is updated every year. There is also a contract in place between NES, the municipality of Seibersdorf and the Federal Ministry for Sustainability and Tourism, which regulates the tasks of NES and its financing. The financial basis for this contract is evaluated after an essential change of basic parameters (usually every 5 to 10 years).
Croatia	The review is performed after every new cost assessment, i.e. every 5 years.
Czechia	Every 5 years for decommissioning plans or closure of repositories, for other management stages according to the needs (e. g. for update of National Programme).
France	When appropriate (and more than once a year for CEA, EDF and Orano), the inter-ministerial body conducts sampling checks to focus on specific projects, on specific cost items or on specific categories of underlying assumptions. Common methods are utilised: examinations of procedures, records and documentation, discussions... The inter-ministerial body also requests the opinion of ASN and ASND yearly. The regulator regularly mandates external audits to obtain a detailed analysis of operators' hypotheses. The results of day-to-day supervision as well as results of external audits are officially reported to operators through follow-up letters to improve their assessment of long-term charges.
Germany	The BMU reviews the cost assessment every year as part of the preparation and approval of the fiscal budget of the Federal Government.
Hungary	An inter-ministerial body, a special body of the Central Nuclear Financial Fund, annually reviews the medium- and long-term plan, including the cost calculations.
Malta	Self-assessment of the national framework as well as National Programme.
Spain	ENRESA updates the cost assessments every year and forwards a report to the Ministry for the Ecological Transition. Additionally, ENRESA submits a proposal for revision of the National Programme (General Radioactive Waste Plan) to the Ministry every 4 years or when required.
Slovakia	The National Programme for RAW and SF is reviewed every six years.

Issue 5. What methodologies are in use to perform cost assessment of the National Programme for spent fuel and radioactive waste in your Member State?

	AT	BE[48]	BG	CY	CZ	DE	EE	ES	FI	FR	HR	HU	IE	IT	LT	NL	SE	SK
Deterministic	✓	✓		✓	✓		✓		✓	✓		✓	✓		✓	✓		✓
Probabilistic										✓								
Deterministic & probabilistic			✓			✓		✓		✓	✓			✓			✓	
Benchmarking	✓		✓			✓		✓		✓				✓	✓			
Other										✓	✓							



Trend identified: Most use a combination of several methods. All Member States use at least the deterministic approach in cost calculations

The table shows that most Member States use a combination of several methods. All Member States use the deterministic approach in cost calculations. Of these, seven Member States also make use of the probabilistic cost calculation methodologies. Seven Member States use benchmarking as a tool for cost calculation.

[48] The Member State has more recent information which has not been possible to integrate to ensure a consistent and timely analysis.

Member State	Additional information provided by Member States
Austria	Calculations for treatment of RW and for RW treatment facilities are performed “bottom up”; analysis of projects & tasks, and cost assessment of different positions like personnel costs, external service; and partly benchmarking by considering experiences of similar projects.
Bulgaria	Deterministic and probabilistic – in terms of past experience and risks, and benchmarking – in terms of the experience of other Member State beneficiaries of EC funding.
Croatia	The deterministic approach is used on parts of the programme which are well known, such as costs for transportation or building a radioactive waste storage facility, where capacity, systems and building technologies are well known and cost estimates can be well inside contingency boundaries. The probabilistic approach is used on parts of the programme such as conditioning of radioactive waste prior to storage. In this case, for example, we are uncertain of the condition in which we may find radioactive waste packages generated in the 1980’s, which are stored in the back of current NPP’s storage, are inaccessible and cannot be inspected. We do not know the exact activity of packages, radionuclide composition, integrity of packages etc. These costs are based on assumptions and may vary.
France	Specific methodologies are developed by each operator. These methodologies depend on the maturity and the complexity of SF and RAW management projects. To ensure that the assessment is prudent, the decree of 23rd February 2007 requires these methodologies to be based on: - An analysis of the different reasonably possible options for conducting operations; - On this basis, the prudent choice of a reference strategy; - A provision for residual technical uncertainties within the reference strategy; - A provision for risks beyond the reference strategy. These methodologies also have to take into account the feedback from operations in progress. Thus: - For existing SF and RAW management installations, assessments are generally made using existing cost data and by making a prudent evaluation of SF and RAW quantities; - Some basic projects are assessed by using benchmarking (when available), for example for treatment and small storage installations. Depending on the case, a lump-sum margin may be used to ensure a prudent evaluation; - When the degree of complexity, maturity and uncertainty is intermediate, a detailed assessment of each cost item and qualitative and quantitative risk assessments may be considered as appropriate; - For more complex projects (for example the Cigéo project and some legacy waste retrieval projects), cost assessments may be very detailed, and in-depth qualitative and quantitative risk assessments, including a Monte-Carlo analysis, may be considered as appropriate.
Germany	Germany uses a combination of these methods for cost planning. For investment projects reference values are used.

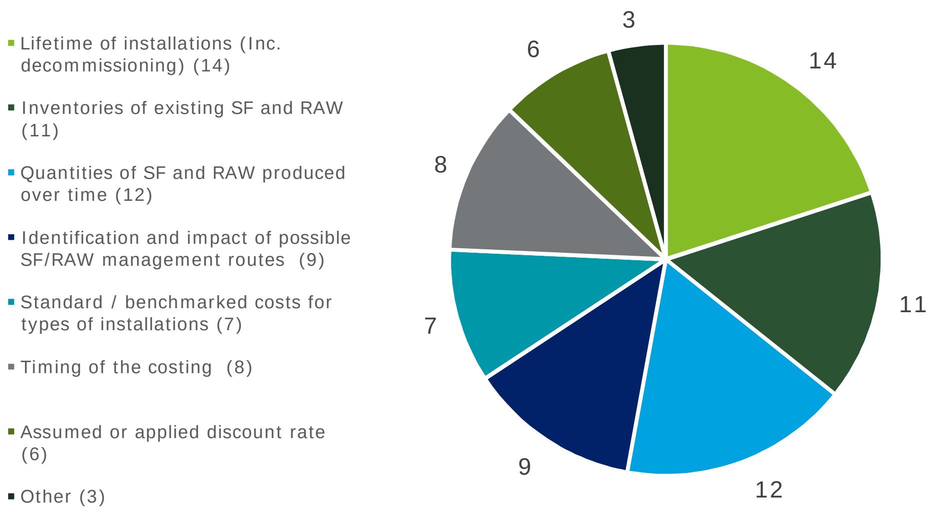
Member State	Additional information provided by Member States
Hungary	Cost elements based on previous experience (and consequently with lower uncertainty) are calculated as best-estimate values. The cost elements with a higher uncertainty are calculated taking into account conservative assumptions.
Netherlands	The polluter pays the bill which has been calculated by the company responsible for safe waste management (COVRA). The company has calculated the costs in a deterministic assessment based on available information. Margins for uncertainty have been added to (deterministically) calculated costs. These margins refer to the long duration of the project and the technologies used. These margins are based on the EPRI-methods (Electric Power Research Institute) and the maturity of the project.
Sweden	The deterministic costs are calculated in two steps. - The first step is to calculate the reference costs. The reference costs are based on the permit holder's current plans and assumptions in terms of operating times for the reactors and expected volumes of waste. For facilities in operation, the calculations are based on descriptions of each facility and forecasts for operating costs. For facilities that are not yet in operation, the calculation is based on existing information as well as experience from similar and prototype equipment. - In the second step, the reference costs are adjusted to fit the assumptions stipulated in the legislation, to obtain the remaining base costs. It is assumed that each reactor will have a total operating life of 50 years and that costs will not include the type of waste that constitutes operational waste. The remaining base costs for the permit holders and for supervision and other government services are calculated in fixed base year prices. To obtain inflation-adjusted future costs, the base costs are adjusted with respect to real price and cost changes[49] in e.g.: - Payroll costs[50] - Labour productivity - Price for machinery investments. The forecasts (year on year percentage change) for prices for input factors are at present estimated based on historical data using econometric models. The liabilities are calculated by discounting the expected value of remaining total base costs to present value by real discount rates.
Slovakia	For the assessment of decommissioning costs (including costs for RAW and SF), ISDC methodology is used.

[49] Real price changes are defined as price changes relative to the Swedish Consumer Price Index

[50] Payroll costs and labour productivity can either be measured at sector level or for the aggregate Swedish economy.

Issue 6. Which are the main hypotheses used for cost assessments in your Member State?

	AT	BE	BG	CZ	DE	ES	FI	FR	HR	HU	IT	LT	NL	SE	SK
Lifetime of installations (inc. decommissioning)	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
Inventories of existing SF and RAW	✓		✓	✓		✓	✓	✓	✓	✓		✓	✓	✓	
Quantities of SF and RAW generated over time	✓		✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓
Identification and impact of possible SF/RAW management routes (e.g. disposal)			✓	✓		✓		✓	✓	✓		✓	✓	✓	
Standard / benchmarked costs for types of installations			✓		✓	✓	✓	✓	✓		✓				
Timing of the costing (profile over time of costs)					✓	✓		✓	✓	✓	✓		✓	✓	
Assumed or applied discount rate						✓		✓	✓	✓			✓	✓	
Other								✓					✓	✓	

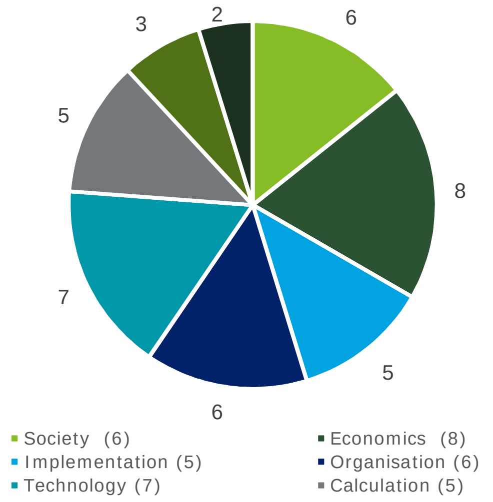


Trend identified: <u>Member States use various hypotheses in their cost calculations.</u>

Lifetime of installations, inventories of existing SF and RAW, and quantities of SF and RAW generated over time are the most common hypotheses in use.

Issue 7. What types of uncertainties are taken into consideration in the cost assessment in your Member State?

	AT	BG	CZ	DE	ES	FI	FR	HR	HU	IT	LT	NL	SE	SK
Society[51]		✓		✓	✓		✓					✓	✓	
Economics[52]		✓		✓	✓	✓	✓			✓			✓	✓
Implementation[53]					✓	✓	✓			✓			✓	
Organisation[54]		✓			✓	✓	✓					✓	✓	
Technology[55]		✓			✓		✓	✓				✓	✓	✓
Calculation[56]		✓					✓	✓				✓	✓	
None of the above	✓		✓								✓			
Other								✓	✓					



Trend identified: Nine of fourteen Member States consider multiple categories of uncertainties in their cost calculation.

Hungary and Croatia use other categorisations for uncertainties (see table in the next page).

[51] Society: regulatory and political issues (including changes in standards and regulatory requirements)
[52] Economics: economic condition (e.g. the real price trend for labour, material, exchange rate)
[53] Implementation: schedule strategies, siting and decommissioning (including scenarios for potential early shutdown of facilities)
[54] Organisation: management and implementation of construction and decommissioning issues
[55] Technology: technological uncertainties of future radioactive waste and spent fuel management and disposal facilities
[56] Calculation: the risk of incorrect assessments in the calculation work

Member State	Additional information provided by Member States
Austria	Uncertainties are usually not taken into consideration in the cost assessment.
Croatia	Both technology and calculation uncertainties are intertwined. For example, one of the problematic waste streams for Croatia to manage are spent resins from the primary circuit. Currently, the exact composition of spent resins is an unknown. The waste treatment technology selected depends on the composition, and one kind of technology can significantly vary from another financially.
France	Early shutdown risk is generally considered by operators as an out-of-scope risk as the lifetime of their installations should be assessed prudently. However, sensitivity analysis may be performed to manage this kind of risk. More generally, according to accounting standards (IAS 37), uncertainty does not justify the creation of excessive provisions or a deliberate overstatement of liabilities. Thus, depending on the case, some extreme risks may be considered by operators as out-of-scope.
Hungary	Cost elements based on previous experience (and consequently with lower uncertainty) are calculated as best-estimate values. The cost elements with a higher uncertainty are calculated taking into account conservative assumptions.
Lithuania	Uncertainties or risks are identified in INPP final decommissioning plan without a calculated estimation of costs. These risks include society, regulatory and political issues relating to long-term decommissioning financing, changes in legal framework, implementation risks - delay in SF removal from units, delay in commissioning appropriate new buffer/storage/disposal facilities, absence of waste management strategy (including logistics, buffer storages, containers, in-unit waste management), organisation issues during transitioning redeployment, lack of skilled human resources in the long run.
Netherlands	Worldwide lack of experience with construction of disposals hampers the cost calculation. Over time, the types of uncertainties taken into the cost assessment will change.
Sweden	• Society. This area includes legislation and regulatory matters as well as political issues in general. • Economics. This area has an emphasis on economic conditions, such as the real price trend for labour and the prices of input materials, business cycle factors and currency exchange rate risks. • Implementation. This includes time schedule strategies, siting questions, the strategy for decommissioning NPPs, etc. • Organisation. This mainly relates to how future construction or decommissioning projects will be implemented and managed in terms of organisation. • Technology. All purely technical matters are referred to this area. The greatest uncertainties are linked to the future facilities for management and disposal of both spent nuclear fuel and radioactive waste. • Calculation. This area takes into account the risks of incorrect assessments in the actual calculation work. They may consist of both overestimations of difficulties (pessimistic assessment) as well as underestimations (optimistic).

Issue 8. How are contingencies included in the cost assessment?

Trend identified: Most common answer provided is 10-20%

The ways in which contingencies are included in the cost assessment differ between the Member States. The most common answer provided is 10-20%, but answers vary in the range of 5-50% for specific cost categories.

Member State	Additional information provided by Member States
Bulgaria	Contingencies applied vary from 5-50% of the cost of each typical activity estimate (depending on the risk result from the quantitative risk assessment) and represent on average approx. 14% of the programme cost for 2017-2030.[57]
Czechia	In some cases, contingencies are included (usually around 10%).
Croatia	In estimating costs due to different uncertainties, contingency was added to the costs. Contingency covers costs for those activities that cannot be determined at this stage of planning. Contingencies were determined by general experience and existing recommendations that unpredictable costs in the planning and construction phase of infrastructure facilities range from 7% (low), through 10% (medium) up to 15% of total investment costs[58]. The contingency was estimated depending on the type of work and expressed in percentages as follows: - transport 10%; - conditioning and costs of IRC containers 10%; - preparatory work on long-term storage and LILW repository 10%; - construction and equipment for long-term storage facilities 10%; - construction and equipment for LILW repository 15%; - operation of long-term storage and LILW repository 10%; - decommissioning of long-term storage 10%; - closure of the repository 15%.

[57] The Member State has more recent data which has not been possible to integrate to ensure a consistent and timely analysis.

[58] Source: AACE® International. (2011). Cost estimate classification system – As applied in engineering, procurement and construction for the process industries - Recommended Practice No. 18R-97. Morgantown, WV: Association for Advancement of Cost Engineers (AACE®) International; Project Management Institute. (2013). A guide to the project management body of knowledge (PMBOK®Guide) (5th ed.). Newtown Square, PA: Project Management Institute; England, K. & Moreci, J. (2012). Contingency—are you covered? Paper presented at PMI® Global Congress 2012 —North America, Vancouver, British Columbia, Canada. Newtown Square, PA: Project Management Institute; RTA (2008). Project Estimating. PMO-EST-UG001

<table>
<tr><th>Member State</th><th>Additional information provided by Member States</th></tr>
<tr><td>Finland</td><td>Average contingency is 20%, but it is difficult to present it by components.</td></tr>
<tr><td>France</td><td>Some basic projects are assessed by using benchmarking (when available), for example for treatment and small storage installations. Depending on the case, a lump-sum margin may be used to ensure a prudent evaluation.
When the degree of complexity, maturity and uncertainty is intermediate, a detailed assessment of each cost item and qualitative and quantitative risk assessments may be considered appropriate.
For more complex projects (for example, the Cigéo project and some legacy waste retrieval projects), cost assessments may be very detailed and in-depth qualitative and quantitative risk assessments, including a Monte-Carlo analysis, may be considered appropriate.</td></tr>
<tr><td>Germany</td><td>Contingencies are covered by surcharges included in planned costs. For construction projects, costs for unforeseen circumstances are covered. The amount of the surcharge depends on the estimation uncertainty.</td></tr>
<tr><td>Hungary</td><td>No contingencies are applied in the cost calculations.</td></tr>
<tr><td>Italy</td><td>In order to better evaluate cost and time variation ranges, a probabilistic analysis (Monte Carlo Simulation) has been performed. The aim was to provide a statistical evaluation of the uncertainty, thus defining an adequate level of contingencies to be considered in such estimates. This analysis was performed for each site (8 Sites). All activities have been split in 4 groups:
Licensing,
Engineering,
Procurement,
Execution.
Activities within each group were modelled through a triangular distribution by defining three points:
Minimum,
Most Likely,
Maximum.
The “Most Likely” value was considered to be coincident with deterministic values for cost and duration. Definition of Minimum and the Maximum values for cost and duration variables were based on a historical data analysis by means of “distribution fitting”. Assumptions defining variation ranges are the same for all sites.</td></tr>
<tr><td>Netherlands</td><td>The costs of storage of waste are calculated on the basis of experience. A model is used to calculate the costs per waste stream. COVRA considers that the specific figures on the contingencies that are applied are confidential.</td></tr>
<tr><td>Spain</td><td>Contingencies are included in the cost assessment. The amount varies by type of cost item.</td></tr>
</table>

Member State	Additional information provided by Member States
Sweden	The expected value for future costs is calculated by SKB using a comprehensive model in Excel with around 50 cash flows and 100 mostly uncorrelated uncertainty factors. Risk factors are estimated according to the method of successive calculation developed by Steen Lichtenberg. The expected value of all simulations is the basis for calculation of the liabilities. One implication is that the programme will be expensive; another is that there are major internal and external uncertainties in the cost estimates. These uncertainties range from the complexity of the operations to shifts in laws and ordinances. Previously, the calculation of risks and the previous risk margin only included the programme costs and was made entirely by SKB using the model described above, with the difference that the risk margin was determined at the 90th percentile of all simulations. In contrast, the nuclear waste fee, is calculated at the expected value of all simulations (typically 2000 simulations). In previous regulatory reviews there has been criticism of the SKB model for underestimating risks in the programme. The criticism has included the large number of risks factors, the use of fixed preconditions to limit which risks are evaluated and the overall application of the method of successive calculation. However, one of the strongest criticisms of the model is the fact that risks are not time-dependent, i.e. Monte Carlo simulation is performed on summarised present values. This means that the SKB model cannot produce stochastic time series for the cash flows of the programme's costs. Recently Parliament has changed the Financing Act, and from 2018 it is the responsibility of the Debt Office to calculate the risk margin. In addition, the definition of the risk margin has changed. Previously, the risk margin only included uncertainties related to the financing system's liabilities. Now, the risk margin must also cover uncertainties related to the financing system's asset side, for example the uncertainties associated with the future nuclear fee payments and the expected return of the Fund.
Slovakia	It depends on the case of each nuclear installation (range between 10-20%). It is fixed as a contingency for unexpected costs.

Issue 9. Is a different expected inflation rate (vis-à-vis the general expected inflation rate for the entire economy) applied for spent fuel and radioactive waste management costs?

Trend identified: Most Member States apply the inflation rate expected for the entire economy.

Two interesting examples are Sweden and Croatia. In Croatia, a preliminary analysis for a different (from the entire economy) expected inflation rate was performed in 2018 (University of Zagreb, Faculty of economy), but it was decided not to use the different expected inflation rate. In Sweden, the expected value for future costs is calculated by SKB using a comprehensive model in Excel with around 50 cash flows and 100 mostly uncorrelated uncertainty factors. Risk factors are estimated according to the method of successive calculation, developed by Steen Lichtenberg. The expected value of all simulations is the basis for calculation of the liabilities.

Member State	Additional information provided by Member States
Austria	The general expected inflation rate for the entire economy is applied.
Czechia	No. Cost assessment is performed on the basis of overnight cost,[59] the price level of the year the cost assessment update is used.
Croatia	For RAW & SF management costs the general expected inflation rate for the entire economy is used. Preliminary analysis for different expected inflation rate were performed in 2018 (University of Zagreb, Faculty of economy), bit it was decided not to use different expected inflation rate.
Finland	The general expected inflation rate for the entire economy is applied.
France	The long-term inflation rate is assessed by operators and updated each year. Currently, Orano, EDF and CEA consider that using a different expected rate is not relevant for such very long-term costs.

[59] "Capital costs are incurred while the generating plant is under construction and include expenditure on the necessary equipment, engineering and labour. These are often quoted as 'overnight' costs, which are exclusive of interest accruing during the construction period. For convenience, it is assumed that the plant is built literally overnight so that the capital costs can be separated from the financing costs". In Nuclear Power Economics and Project Structuring 2017 Edition, https://www.world-nuclear.org/getmedia/84082691-786c-414f-8178-a26be866d8da/REPORT_Economics_Report_2017.pdf.aspx

Member State	Additional information provided by Member States
Germany	A specific expected inflation rate is applied, as safety requirements have increased in the past, which is expected to lead to higher costs in the future.
Hungary	The general expected inflation rate for the entire economy is applied.
Italy	The general expected inflation rate is applied if it is necessary to consider an inflation rate.
Lithuania	The expected inflation rate is used based on official data provided by the Bank of Lithuania.
Netherlands	The general expected inflation rate for the entire economy is applied.
Spain	The general expected inflation rate for the entire economy is applied.
Sweden	The expected value for future costs is calculated by SKB using a comprehensive model in Excel with around 50 cash flows and 100 mostly uncorrelated uncertainty factors. Risk factors are estimated according to the method of successive calculation, developed by Steen Lichtenberg. The expected value of all simulations is the basis for calculation of the liabilities.
Slovakia	The update of the National Programme for RAW and SF considers the inflation rate for the next period (6-10 years). The estimated price level (including the estimated future price level) for the decommissioning process is calculated in the decommissioning plan (e.g. decommissioning plan from 2016 with inflation rate of 2%).

Issue 10. How are discount rates set when updating future costs?

The "Study on the risk profile of the funds allocated to finance the back-end activities of the nuclear fuel cycle in the EU" provides insights on how the discount rate is calculated and the assumptions and limitations of the approach (pp. 39-41):

- "The "best estimate" discount rates have been set such that a fund's investments have an equal (50%) probability of exceeding or underperforming the discount rate. This means that two funds with different investment strategies (even if they have the same future costs to meet) will have different best estimate discount rates and hence best estimate liabilities.
- Where a Member State has disclosed a specific inflation assumption, this has been used without adjustment. Where no assumption was disclosed (i.e. Spain and Hungary), a simplifying assumption of 2% to reflect the ECB's long-term inflation assumption has been used.
- It is recognised that the use of different inflation assumptions for different Member States introduces an apparent element of inconsistency. This is primarily the result of the inclusion of a specific assumption for nuclear related inflation over and above general market inflation (e.g. in the UK and Germany) …
- To the extent the inflation assumptions for Spain, Slovakia, Hungary and the French licensees (EDF, Orano and CEA) are understated due to the exclusion of a specific nuclear related inflation component, the resulting best estimate liabilities may be understated (and therefore the best estimate funding levels may be overstated). Further assessment of this point is beyond the scope of this study."

Member State	Additional information[60] provided by Member States
Czechia	No discount rates are used, calculation is performed on an overnight basis.
Croatia	Currently, discount rates are determined by differentiation between an annual inflation factor and an annual discounting factor. The estimated costs are discounted by the resulting real discount rate of x% per year. In future, it is planned to set the discount rate as the IRR (Internal Rate of Return) of the project. IRR is a discount rate that equalises the present value of the assets with the present value of the liabilities.
Finland	Discounting is not in use. The process related to cost assessment is performed every year. The costs are presented in the price level of the current year.

[60] Discount rate percentage numbers taken from the "Study on the risk profile of the funds allocated to finance the back-end activities of the nuclear fuel cycle in the EU", p. 39

Member State	Additional information[60] provided by Member States
France	2.7%[61]
Germany	3.5%.
Hungary	Prime rate given by the Hungarian National Bank
Italy	The general expected inflation rate is applied.
Lithuania	Inflation rate only is taken into account.
Netherlands	COVRA has compared different inflation rates applied in different countries and from different sources (for example ECB, EIOPA, Warth and Klein Grant) and has – on that basis and in combination with other data - set the discount rate at 4.3%.
Spain	1.4%.
Sweden	2.4%[62].
Slovakia	1.1%.

[61] The Member State has more recent data which has not been possible to integrate to ensure a consistent and timely analysis. Notably, the rates applied at the end of 2018 include:

- Nominal discount rates: EDF (3.9%), Orano (3.95%) and CEA (3.97%)
- Long-term inflation rates: EDF (1.5%), Orano (1.6%) and CEA (1.65%)

Therefore, real discount rates are currently between 2.3% and 2.4%.

[62] The Member State has more recent data which has not been possible to integrate to ensure a consistent and timely analysis.

4.3.2 Good practices in cost assessment processes in the Member States

Cost assessment processes are different in each Member State and the review of them demonstrates a wide range of approaches, methods and practices in the cost assessment of radioactive waste and spent fuel management. The results of the document review and survey with the Member States also illustrates similarities. This is an opportunity for mutual learning and exchange of experiences that together might bring better solutions for all the Member States. There are a number of good practices in cost assessment processes that can be identified in the following domains:

- Governance of cost assessment processes – who calculates the costs, who reviews the calculations and how often it should be done;
- Methodologies for cost calculation – what are the possible ways of properly calculating the costs;
- Key parameters in cost calculation – how Member States take into account uncertainties, contingencies and the several additional parameters to build cost estimations.

Governance of cost assessment processes:

- Cost calculations - In most Member States the operators perform cost calculations, while some Member State have mixed approaches, where several different types of actors participate in different parts of the cost calculation process.
- Reviews of cost calculations - In most Member States ministries and regulatory bodies perform the review of cost calculation.
- How often cost calculations and their reviews are performed - In most Member States both cost calculations and their reviews are performed annually.

Governance of cost calculation processes - good practices
• Cost calculations and cost calculation reviews are performed by different organisations (e.g. operators perform cost assessments and government bodies (ministry, national agency) perform the reviews. • Synchronisation of recurrence of the reviews of cost calculations (e.g. if cost calculations are performed annually, the review should also take place annually).

Methodologies - What are the possible ways of calculating costs appropriately?

The review of the National Programmes and Plans, and answers to the survey by the Member States, shows a variety of methodologies used for cost calculation. A deterministic approach is in use in all the Member States; some Member States combine the deterministic approach with probabilistic and/or benchmarking as methodologies for cost calculation. These classes of methodology are, of course, “umbrella” concepts; tools within each can vary (i.e. Member States use various deterministic methods).

> Methodologies - good practices
>
> - There is a constant need to ensure reliability and effectiveness of the chosen methodology.
> - Methodologies need to be regularly back-tested. One way is to ask for an independent assessment of the methodology.

Key parameters in cost calculation - How Member States take account of uncertainties, contingencies and the several additional parameters to build cost estimations.

Uncertainties - The review of the National Programmes and Plans, and answers to the survey, show that a wide range of various types of uncertainty are considered in the cost calculation: factors relating to society, the economy, implementation, organisation, technology, calculation and others. They can affect cost calculation in different ways; for instance, societal uncertainty can be experienced in opposition from a local community to construction/operation of a storage/disposal facility for radioactive waste (known as Not In My Back Yard (NIMBY) effect); technological uncertainty (future innovative technologies, for example) can lead to uncertainties in costs and project planning.

Most Member States that participated in the survey consider multiple categories of uncertainties in their cost calculation.

> Uncertainties - good practices
>
> - A good practice would be to include a variety of relevant uncertainties in cost calculation

Contingencies - Similar to the case of uncertainties, the review of the National Programmes and Plans, and answers to the survey, show a wide range of various types of contingencies and the ways they are applied in cost calculations. Most Member States apply contingencies in cost calculation and do it in various ways. For example, in Croatia contingencies are estimated depending on the type of work and then expressed in percentages.[63] The most

[63] Types of contingencies in Croatia: transport 10%; conditioning and costs of IRC containers 10%; preparatory work on long-term storage and LILW repository 10%; construction and equipment for long-term storage facilities 10%; construction and equipment for LILW repository 15%; Operation of long-term storage and LILW repository 10%; decommissioning of long-term storage 10%; closing of the repository 15%.

common answer provided on the contingencies in cost calculations is 10-20% but answers vary in the range of 5-50% for specific cost categories.

Contingencies – good practices

- A good practice would be to include contingencies in cost calculations.
- Contingencies should also be linked to uncertainties, different types of uncertainties can lead to different types of contingencies (e.g. societal uncertainties and technological uncertainties may lead to different contingencies).

Uncertainties - good practices

- A good practice would be to include a variety of relevant uncertainties in cost calculation.

Inflation rate – This is a parameter that directly affects future costs. Most Member States use the general economy inflation rate. However, the nuclear sector's inflation rate might be different from that of the general economy. Major reasons include the uniqueness of the technologies and at times high levels of uncertainty (e.g. societal, economic, etc.)

Inflation rate - good practices

- A good practice would be to consider the need to use a specific inflation rate for the nuclear industry, as opposed to a general inflation rate for the whole economy

Discount rates – This is a key parameter, since it makes a connection between the cost calculation on one hand and funds for radioactive waste and spent fuel management on the other. Future costs of radioactive waste and spent fuel management are supposed to be covered by dedicated funds. Most of the money in the funds is typically invested in low risk government bonds, although in some Member States recent legislation also permits investments in equity (e.g. up to 40% in Sweden). Therefore, there is a connection between future costs and funds.

Discount rate - good practices

- A good practice would be to link the calculation of discount rate to:
    - the inflation rate used in the Member State, and
    - the ROI (return on investment) of the investments made with the money of the fund (for example, inflation rate higher than fund's ROI might need an adjustment for the fund to be able to cover the future costs).

4.4 High-level taxonomy for radioactive waste and spent fuel management activities

4.4.1 Background

Directive 2011/70/EURATOM imposes clear reporting obligations on Member States, notably in terms of radioactive waste and spent fuel quantities generated, cost structures and as funding mechanisms. This makes it possible to verify that radioactive waste management is indeed being addressed, that there is an exchange of best practice and, overall, that the burden of the radioactive waste generated today is not left for future generations. However, waste category classification in different Member State is not homogenous. The following tables present the waste classification systems of four Member States. They demonstrate the diversity of approaches in the EU (and the diversity of the national contexts).

Table 5 – French Waste Category Classification

Waste Categories	France
Very Short Lived Waste (VSLW)	✓
Very Low Level Waste (VLLW)	✓
Intermediate Level Waste –Long Lived (ILW-LL)	✓
Low & Intermediate Level Waste – Short Lived (LILW - SL)	✓
Low & Intermediate Level Waste – Long Lived (LILW - LL)	✓
High Level Waste (HLW)	✓

Source: Author from various sources

Table 6 – Finnish Waste Category Classification

Waste Categories	Finland
Very Low Level Waste (VLLW)	✓
Low Level Waste (LLW)	✓
Intermediate Level Waste –Long Lived (ILW-LL)	✓
Low & Intermediate Level Waste – Short Lived (LILW - SL)	✓
Low & Intermediate Level Waste – Long Lived (LILW - LL)	✓

Waste Categories	Finland
High Level Waste (HLW)	✓

Source: Author from various sources

Table 7 – Swedish Waste Category Classification

Waste Categories	Sweden
Exempt Waste (EW)	✓
Short Lived Very Low Level Waste (VLLW - SL)	✓
Short Lived Low Level waste (LLW - SL)	✓
Short Lived Intermediate Level Waste (ILW-SL)	✓
Low & Intermediate Level Waste – Long Lived (LILW - LL)	✓

Source: Author from various sources

Table 8 – UK Waste Category Classification

Waste Categories	UK
Very Low Level Waste (VLLW)	✓
Low Volume Very Low Level Waste (LV – VLLW)	✓
High Volume Very Low Level Waste (HV – VLLW)	✓
Low Level Waste (LLW)	✓
Lower Activity Waste (LAW)	✓
Intermediate Level Waste –Long Lived (ILW-LL)	✓
High Level Waste (HLW)	✓
Higher Activity Waste (HAW)	✓

Source: Author from various sources

It is natural that Member States will choose the radioactive waste classification systems that best fit their individual needs, but this can nevertheless be the source of notable challenges.

These emerge most obviously during cross-border radioactive waste management processes. Furthermore, seeing that there are such widely different and yet similar waste classification systems clearly indicates that there are some grounds for developing a more homogeneous system.

The aim of this section is to provide a comprehensive view of the processes behind the management of radioactive waste by proposing a high-level taxonomy for radioactive waste and spent fuel management activities and costs. To do that, the challenges behind the construction of a systematic approach to of analysing radioactive waste and spent fuel management activities are first described. Hence, a description of the key radioactive waste activity is given. Finally, a high-level taxonomy for activities and costs is proposed.

4.4.2 The benefits and challenges of a high-level taxonomy for radioactive waste and spent fuel management activities

Constructing a reference taxonomy for radioactive waste management would have several benefits for stakeholders, namely:

- Providing a description of the radioactive waste streams: Ideally, a taxonomy should contribute to better knowledge of how radioactive wastes and spent fuel are managed. In other words, interested stakeholders should be able to follow the routes that each type of waste takes until disposal.
- Contributing to the spread of best practice: As stakeholders would have a general point of reference on the appropriate path that each type of waste takes after it is generated, they should be in a position to better compare different systems. This would enable them to identify current inconsistencies and areas of potential improvement in waste management practices.
- Facilitating radioactive waste management reporting: This implies that the high-level taxonomy is applied by all. Indeed, not only would all countries apply the same waste classification as a result of the taxonomy, which would therefore allow greater cross-country comparability, but it would also make it more efficient as the added detail of each component of the taxonomy would give greater user-value to reporting.

Nevertheless, several practical issues stand in the way of the establishment of a universally applicable system for representing radioactive waste and spent fuel cycles. These issues, often interrelated, are fundamentally inherent to the subject of radioactive waste generation.

- Difference in radioactive waste classification systems: If the establishment of a taxonomy aimed to correct the inconsistencies found in national waste classification systems, differences would nevertheless still exist and might pose difficulties in the application of the taxonomy. This is particularly problematic in light of the principle of subsidiarity that is inherent in the Directive and does not impose any particular waste classification system on Member States.
- Systematic routes for radioactive waste do not exist: A major challenge to the establishment (and the effective use) of a taxonomy is that there is no single well-defined path for each waste category. This is mostly due to the wide variety of waste-

processing technologies as well as to the related ever-changing outlook on waste. One good example of this point is the fact that what can be treated as waste today might be considered as a resource tomorrow. This is exemplified by the varying national positions on spent fuel reprocessing or the possibilities of next generation nuclear reactors reusing more of the fissile products of the nuclear reaction. This creates ambiguities, notably on the question of disposal that by definition implies the irretrievability of the waste and that thus would prevent future usage of potential resources, challenging the construction of a universally applicable taxonomy.

- Comparable wastes have different origins: Linked to the previous point is the fact that wastes of all categories are generated at several stages. Given the fact that similar wastes have several origins (transuranic wastes are, for instance, both the result of waste reprocessing, regular reactor operations and nuclear weapons' manufacture), identifying single routes to disposal becomes more challenging. Furthermore, it creates an incentive for an ever-more precise classification of wastes that overall, might be neither pragmatic nor even practical.

4.4.3 Definition and description of main activities

In order ultimately to build the high-level taxonomy, it is necessary to go over the entire radioactive waste journey, from its generation to its disposal. This section will define and describe the main radioactive waste management activities from the generation of the waste through to its disposal.

4.4.3.1 Radioactive waste generating activities

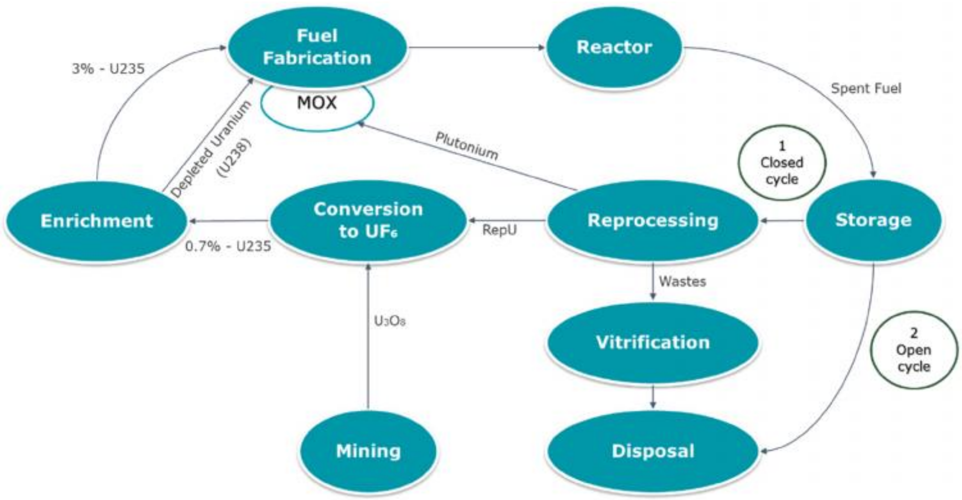
A general principle underlies the entire logic of radioactive waste management: to dispose of or emplace radioactive materials, for which no more use is foreseen in approved, specified facilities without the intention of retrieval[64]. For that purpose, it is necessary to understand where and how radioactive waste originates. The main sources of radioactive wastes are:

Energy generation and reprocessing

The figure below represents the current model utilised to understand the nuclear fuel cycle, describing the entire nuclear energy process from the extraction of the resources to the disposal of the radioactive waste.

[64] Definitions of "radioactive wastes" and "disposal" from IAEA.

Figure 21 – Nuclear Fuel Cycle



Source: World Nuclear Association

As already mentioned, radioactive waste is generated at every step of the energy-generation process, thereby requiring individual accommodation.

- Waste from uranium mining wastes – The IAEA reports that waste generated during mining differs widely from that generated in NPPs or during other activities. Volumes are characterised as large, radioactivity as low and decay-life as long[65]. While only marginal amounts of uranium are mined in the EU, the question of their wastes is still relevant and deserves attention as certain Member States are actively researching the extraction of the ores in their soil[66].
- Conversion wastes – The process of converting the mined materials into Uranium Hexafluoride (UF_6) ready for enrichment generates a wide variety of LLW wastes from dry active waste to scrap metals, calcium fluoride sludges and other mixed wastes that all require different waste management processes. Certain reactors, however, such as the Pressurised Heavy Water Reactor (PHWR) that produces around 20% of Romania's energy today, do not need conversion, hence eliminating this waste stream.
- Enrichment wastes – Two types of LLW wastes arise from the enrichment process: depleted uranium hexafluoride that can be converted to U_3O_8 for disposal or reuse as well as filters and sludges.
- Fabrication Wastes - The fuel fabrication process generates complex waste streams that depend on the types of reactor used. The largest type of waste generated tends to be ILW as a result of the Mixed Oxide Fuel (MOX fuel) fabrication process. Wastes are also the result of the contamination of materials as well as the discarding of processing equipment.

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[65] Management of the Radioactive Wastes from the Mining and Millings of Ores, IAEA, 2002.

[66] Euratom Supply Agency, Annual Report, 2017.

- Reactor Operation Wastes – Obviously, wastes from reactor operations depend on the type of reactor. Wastes that arise as a result of neutron activation, corrosion products or chemical additives are, however, considered LLW or ILW.
- Reprocessing wastes – the largest waste stream from the reprocessing of spent fuel is composed of HLW. ILW and LLW are also generated in reprocessing plants in both solid and liquid form.
- Interim Storage wastes – ILW and LLW are generated from the storage of spent fuel.
- Disposal Wastes – As spent fuel needs to undergo some processing prior to disposal, disposal also generates amounts of LLW and ILW.

Decommissioning

Waste streams from decommissioning are numerous as they arise from all the activities concerned by the fuel cycle, namely the decommissioning of conversion, enrichment, and fuel fabrication plants among others as well as the decommissioning of the nuclear reactors themselves. Decommissioning wastes are traditionally separated into three components:

- Primary wastes which only include waste from dismantling, the bulk of which consists of concrete rubble and metal;
- Secondary wastes which include waste from both dismantling as well as decontamination activities, such as the decontamination of components or flushing processes to lower quantities of primary wastes;
- Contaminated tools and equipment which include all materials contaminated during the process of decommissioning itself. Such contaminated tools and equipment can be decontaminated as well to reduce the amount of radioactive waste generated.

Naturally, all those streams are difficult to categorise due to their variety. Indeed, decommissioning waste includes all levels of radioactivity from exempt wastes to ILW as well as all lengths of decay time. Even though the amounts of long-lived materials are non-negligible, most of it can however be categorised as short-lived Low and Intermediate Level Waste (LILW). Furthermore, the European Commission currently distinguishes another category of decommissioning wastes known as “transition wastes” which includes all waste for which a sufficient decay-delay would exempt it from regulatory oversight.

Other (weapons manufacture, industry, medicine, research, NORM/ TENORM, etc.)

For simplicity’s sake, these radioactive waste-generating activities have been considered as one. However, each waste stream has its own specificities, but a full description of each sector would go beyond the scope of this task.

4.4.3.2 Treatment and conditioning

Given that the generation of radioactive waste occurs at every stage of the nuclear fuel cycle, there are a number of waste management processing activities to accommodate for the different types and forms of waste generated and to facilitate the objective of disposal. One of the main keys is to be able to transport wastes easily and safely to their destination at every stage along their route: this requires materials not to be too voluminous, to preferably be in solid form and safely packed so as not to contaminate their close surroundings. All these processing activities are referred to as treating and conditioning the waste.

Waste Treatment

Treatment refers to all operations that change waste streams' characteristics for safety or economic purposes, mostly with the aim of reducing waste volumes. Naturally, the way to treat the waste depends on its form and therefore origin. Wastes can be liquid (aqueous or organic) or solid (compactible or non-compactible) and therefore will require different types of treatment. The table below lists a few of the treatment techniques used for different types of wastes.

Table 9 – Treatment of radioactive wastes

Liquid Aqueous	Liquid Organic	Solid
• Chemical precipitation • Ion exchange/sorption • Evaporation • Flocculation • Sedimentation	• Incineration • Wet oxidation • Acid digestion • Distillation	• Decontamination • Compaction • Cutting • Crushing • Shredding • Incineration • Electromediation

Waste conditioning

After the waste is treated, it still needs to undergo a phase of conditioning to finally allow storage and later disposal. While treatment ensures that the physical form of the waste would not make it too cumbersome for transport, conditioning consists of properly immobilising and packaging the waste, preventing it from contaminating its environment and therefore mitigating risks. In short, conditioning is the first barrier of protection of many others to come in the storage and disposal process.

Obviously, the choice of the packaging depends on the radioactivity of the waste as well as the speed at which the materials decay.

- VLLW and LLW – The conditioning process for low activity wastes, in particular short lived low activity wastes, is not too complicated as these wastes are the least harmful and can thus be handled more easily. Thus, fewer requirements are imposed on the most voluminous categories, namely VLLW and LLW, than on other waste categories. VLLW and LLW can be aggregated into normal containers (steel/alloyed steel). For liquid materials such as sludge, it will sometimes be necessary to immobilise the materials by mixing them with cement, bitumen or other polymer-based materials prior to putting them into containers.

VLLW, due to their very low radioactivity, can go through very basic conditioning. Indeed, waste from dismantling, mostly composed of rubble or earth, can simply be put into bags before disposal.

- ILW – Several processes are used for to conditioning ILW. Solid waste in the form of contaminated cladding hulls and end caps used to contain the uranium oxide pellets that fuel the nuclear reaction constitutes a major source of long-lived ILW. These wastes, which mostly include the radioactive isotope Nickel-63, are conditioned in special stainless steel containers. The conditioning for long lived liquid ILW follows a similar process in that the radioactive material is also put into stainless steel drums after an initial cementation process where the waste is mixed with grout.

  A lot of legacy waste was conditioned in bitumen, but this technology is now hardly ever used.

- HLW – Vitrification is the technology of choice to condition the highly radioactive wastes that arise from reprocessing. Residues containing all the radioactive actinides first undergo a cool-down period of a few months in stainless steel tanks before being embedded in glass matrices. These borosilicate glass matrices are commonly considered appropriate for handling the long decay periods for these highly radioactive wastes. These can amount to tens of thousands of years. The final mix is then poured into stainless steel canisters ready for storage and disposal.
- SF – Spent Fuel undergoes a different kind of conditioning from other reprocessed highly radioactive materials. The technology used in such countries as Finland or Sweden is known as engineered encapsulation and consists in putting the pellets of used fuel into special canisters with a cast iron or boron steel internal structure for additional confinement.

4.4.3.3 Radioactive waste storage

After appropriate conditioning, radioactive wastes can safely be transported to be stored in equally appropriate facilities before disposal. Given that most wastes today (around 90% of total radioactive waste volumes) can be sent directly to land-based disposal after treatment and conditioning thanks to their low radioactive activity, the question of storage mostly arises for more complicated wastes, namely ILW, HLW and spent fuel. The question of how to achieve this is still an open one as clear solutions for the disposal of highly radioactive wastes have only been implemented in the USA at the Waste Isolation Pilot Plant (WIPP) with notable complications.

- Spent Fuel – The first step in the storage process of spent fuel designated as HLW occurs at the reactor where spent fuel is stored in ponds, allowing for decay of the heat and radioactivity of the fissile products. The pond storage of spent fuel typically lasts a minimum of nine months to a year, during which time water covers the conditioned materials, shielding them and cooling them. Spent fuel will then either be sent to:

  i) Reprocessing facilities in the case of closed fuel cycles where it will await reprocessing in buffer storage pools or to;

ii) 'Away from Reactor' (AFR) fuel storage facilities (which may in fact still be on the reactor site) in the case of open fuel cycles where the spent fuel will undergo dry storage in vaults or casks, pending the availability of appropriate disposal facilities.

- HLW – After undergoing the proper conditioning processes described above, such as vitrification in the case of liquid HLW from reprocessing, the waste is typically sent to special storage facilities in the abovementioned steel canisters. Reprocessing plants contain such storage facilities where the containers await and cool by natural or forced air convection depending on the heat generated. Akin to the storage pools used for spent fuel, the air is filtered to mitigate the risks of contamination. This storage can last for over fifty years, awaiting the development of proper long-term disposal options.
- Miscellaneous wastes – Other lower activity wastes still require storage as disposal options might still be unavailable. This explains why long lived ILW or even LLW, requiring special disposal which, will be described later, might also need interim storage. Such waste may be 'legacy waste', as is the case in France where the waste from the dismantling of the earliest nuclear power plants, is currently held for storage.

4.4.3.4 Radioactive waste disposal

The goal of radioactive waste management is disposal, in theory providing a protected environment in which the waste will rest, decaying until it is harmless. This is also the most complicated part in the process for both theoretical and practical reasons.

Indeed, while the disposal of short lived and low radioactivity wastes is easier to manage due precisely to the low risks posed by the wastes as well as their relatively short decay time, the disposal of long lived wastes poses serious issues. These relate notably to the adequacy of the facilities as well as the possibility that future technologies might enable the reuse of what is today considered as waste. This raises a question as to the very nature of disposal which has in the past commonly been taken to mean irretrievability. The political reluctance to develop long-term disposal facilities is not only the result of the complications involved in designing the facilities but also by the fact that most of the concepts for disposal today hardly allow for long-term waste retrieval. Nevertheless, some countries, such as Finland and Sweden, have made considerable advances on the question of highly radioactive wastes disposal; others are only just starting to consider it.

The following options are commonly accepted as the favoured means of radioactive waste disposal:

- Near-Surface Disposal – This type of disposal is designed for LLW as well as for short lived ILW in a few countries such as Finland, Sweden, or Spain. There are two types of near-surface disposal facilities:

i) At ground level – the waste is deposited in surface-level disposal facilities, protected by barriers of a few metres.

ii) In caverns, tens of metres underground – unlike the former, these facilities require underground excavation. The waste is deposited in cavities or boreholes, protected by a thick layer of rocks.

In both cases, near-surface disposal facilities involve engineered structures although facilities providing simpler isolation might be used for very low level wastes.

- Deep geological Disposal – Although deep geological disposal has been used for ILW in the past (e.g. the Morsleben radioactive waste repository in Germany), this type of disposal is now envisaged for long lived and highly radioactive wastes. The idea behind deep geological disposal is that, over such long timescales (tens of thousands of years), dangerous materials need to be buried in stable geological formations that will resist the test of time as well the impact of the radioactive activity of the wastes. This method is thus often referred to as 'multi-barrier' as the wastes are covered by special packages that act as a first barrier, with the disposal facility and the geological formation itself definitively secluding the material. As such, deep geological disposal is the preferred means of disposal and the one promoted by Directive 2011/70/Euratom.

Two options are currently considered credible for deep geological disposal:

i) Mined repositories – This is the most common option. The waste containers are cemented or buried in another material that provides additional protection. This option can, depending on the design of the facility, allow for retrievability in both the short term or the long term;

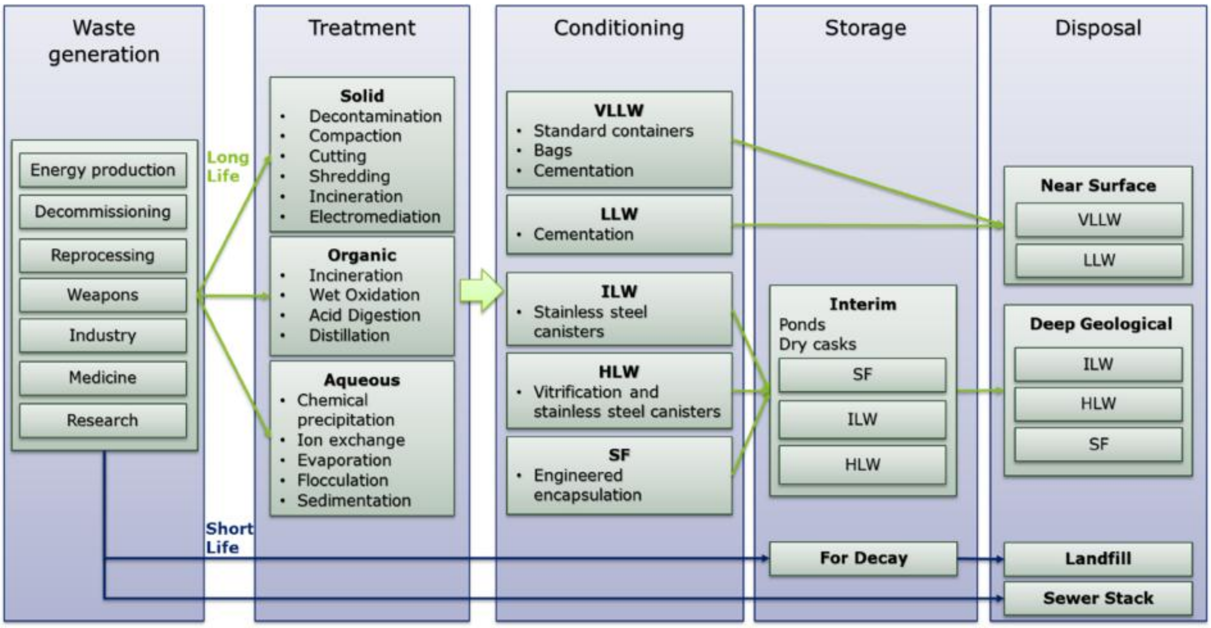
ii) Deep boreholes – The underlying idea behind this type of facility is to drill boreholes in the ground in which to place waste canisters at up to 5000 metres underground. This option has been explored by many countries, but it has never been implemented: the first reason is the economic cost, which makes it quite unaffordable for large waste volumes; the second is that, in contrast with the former option, this type of facility does not allow the wastes to be retrieved.

There are advanced concepts today in the EU for disposal: considerable progress has been made in plans for the disposal of HLW and SF in Finland, France and Sweden while the UK is in the process of selecting a site.

4.4.4 Synthesis of the radioactive waste management processes

The following figure maps the waste management routes described in the previous sections.

Figure 22 – Waste management routes



Source: Author

As can now be understood, a considerable number of elements need to be taken into account in order to envision the entirety of the radioactive waste management process holistically. A proper taxonomy designed to facilitate reporting that would help policymakers in their duty, particularly in relation to cost estimates and thus funding needs, would need therefore to distinguish clearly between:

i) The different half-lives of the wastes: as can be shown in the cases where certain types of ILW (or even LLW) require forms of disposal that resemble those designed for HLW, decay length is an important parameter of the waste management process;

ii) The different radioactivity levels of the wastes: this is perhaps the most important parameter to the waste management process, as it will determine both conditioning, the storage and ultimately, the disposal of the waste.

As such, similar to the IAEA waste classification, the taxonomy identified below attempts to combine these two parameters:

- Spent Fuel (SF)
- High Level Waste (HLW)
- Intermediate Level Waste (ILW)
- Low Level Waste (LLW)
- Very Low Level Waste (VLLW)
- Very Short Lived Waste (VSLW)
- RAW for clearance

- NORM waste
- Orphan waste / Legacy Waste.

This breakdown of the wastes is simple and efficient as it would provide stakeholders with a waste classification with low ambiguity, an ambiguity that can often be found with the often-used waste category "Low and Intermediate Waste (LILW)", for instance. By contrast, this taxonomy separates the different types of wastes so as to direct the wastes to their individual storage and disposal facilities.

There is no case, however, for an added level of detail that would include the physical form of the waste in the taxonomy as every component of the taxonomy can itself be subdivided into waste streams in a different physical form. Furthermore, this would not be necessary as the waste streams are all finally united during the storage and disposal process, in which the physical form is no longer an issue thanks to the treatment and conditioning processes.

4.4.5 Suggested high-level taxonomy

The following high-level taxonomy attempts to provide an instrument contributing to a systematic analysis of various costs in relation to radioactive waste and spent fuel management. The aim would be to develop the equivalent of the International Structure for Decommissioning Costing in the area of RAW and SF management. The high-level taxonomy suggested below can be considered as a starting point for further discussions with Member States and international organisations to facilitate cost assessments of the total cost for the National Programmes and their reporting. Moreover, this high-level taxonomy might also help Member States exchange and learn from each other, as well as serve generators in estimating their costs for individual projects.

By also including as general references the radioactive waste classification of the IAEA[67] and the ISDC[68] (for the part related to radioactive waste and spent fuel management), radioactive waste and spent fuel management activities and facilities are subdivided into four levels[69]. <u>Level I</u> applies a distinction according to the categories/classes of waste, and spent fuel. <u>Level II</u> further specifies the management processes according to a structure of broad cost items. <u>Level III</u> introduces an additional level of granularity by introducing segregation according to the various management stages. To these three levels, an additional <u>Level IV</u> could be possibly be added based on key cost categories, to be based on the ISDC cost categories and additional recurring cost categories used by Member States. In such a case, each Level III could be further split based on the following common cost categories:

- Labour costs;
- Investment costs;

[67] See appendix 1 for a brief overview of the IAEA cost classifications and the following link for more information: https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1419_web.pdf.

[68] See appendix 1 for a brief overview of the ISDC cost classifications and the following link for more information: Report NEA (2012) "International Structure for Decommissioning and Costing of Nuclear Installation".

[69] As explained further below, the categories in blue are additions recommended by some Member States.

- Expenses;
- Contingencies;
- Regulatory costs;
- Research and development costs;
- Training costs;
- Licensing costs;
- Transparency and public engagement costs.

Table 10 – Proposed high-level taxonomy

Level I: SF/RAW Categories or Classes	Level II: Cost Item Structure	Level III: Management Stages	Comments
SF	Predisposal	Characterisation	
		Conditioning / encapsulation	If dedicated facilities are needed, this also refers to costs for siting, design, construction, operation, closure and decommissioning
	Transportation to storage / reprocessing (in Member State or abroad)		
	Storage	Siting	
		Design	
		Construction	
		Operation	
		Closure	
		Decommissioning	
	Reprocessing	Siting	Applies only in a closed-fuel cycle Wastes from reprocessing to go to HLW disposal
		Design	
		Construction	
		Operation	
		Closure	
		Decommissioning	
	Transportation to disposal		
	Disposal	Siting	
		Design	
		Construction	
		Operation	

Level I: SF/RAW Categories or Classes	Level II: Cost Item Structure	Level III: Management Stages	Comments
		Decommissioning[70]	
		Closure	
		Post-closure	
		Retrievability	When foreseen
HLW	Processing	Characterisation	If dedicated facilities are needed, this also refers to costs for siting, design, construction, operation, closure and decommissioning
		Pre-treatment	
		Treatment	
		Conditioning	
	Transportation to storage / processing (in Member State or abroad), including return of by-products		
	Storage	Siting	These costs may be shared with those for SF management
		Design	
		Construction	
		Operation	
		Closure	
		Decommissioning	
		Remediation	
	Transportation to disposal		
	Disposal	Siting	These costs may be shared with those for SF management. Retrievability, only when foreseen
		Design	
		Construction	
		Operation	
		Closure	
		Post-closure	
		Retrievability	
		Remediation	
ILW	Processing	Characterisation	

[70] The terms highlighted in blue in the abovementioned taxonomy were not part of the initial taxonomy presented to the Member States. They were added at a later stage based on suggestions made by some Member States who replied to the survey, which were deemed applicable to a broader number of Member States (and not only to one).

Level I: SF/RAW Categories or Classes	Level II: Cost Item Structure	Level III: Management Stages	Comments
		Pre-treatment	If dedicated facilities are needed, this also refers to costs for siting, design, construction, operation, closure and decommissioning
		Treatment	
		Conditioning	
	Transportation to storage / processing (in Member State or abroad), including return of by-products		
	Storage	Siting	
		Design	
		Construction	
		Operation	
		Closure	
		Decommissioning	
		Remediation	
	Transportation to Disposal		
	Disposal	Siting	
		Design	
		Construction	
		Operation	
		Closure	
		Post-closure	
		Remediation	
		Retrievability	When foreseen
LLW	Processing	Characterisation	If dedicated facilities are needed, this also refers to costs for siting, design, construction, operation, closure and decommissioning
		Pre-treatment	
		Treatment	
		Conditioning	
	Transportation to storage / processing (in Member State or abroad), including return of by-products		
	Storage	Siting	
		Design	
		Construction	
		Operation	
		Closure	

Level I: SF/RAW Categories or Classes	Level II: Cost Item Structure	Level III: Management Stages	Comments
		Decommissioning	
		Remediation	
	Transportation to disposal		
	Disposal	Siting	
		Design	
		Construction	
		Operation	
		Closure	
		Post-closure	
		Remediation	
		Retrievability	When foreseen
VLLW	Processing	Characterisation	If dedicated facilities are needed, this also refers to costs for siting, design, construction, operation, closure and decommissioning
		Pre-treatment	
		Treatment	
		Conditioning	
		Clearance of material from regulatory control	
	Transportation to storage / processing (in Member State or abroad), including return of by-products		
	Storage	Siting	
		Design	
		Construction	
		Operation	
		Closure	
		Decommissioning	
		Remediation	
	Transportation to disposal		
	Disposal	Siting	
		Design	
		Construction	
		Operation	
		Decommissioning	
		Closure	

Level I: SF/RAW Categories or Classes	Level II: Cost Item Structure	Level III: Management Stages	Comments
		Post-closure	
		Retrievability	
VSLW	Processing	Pre-treatment	
		Treatment	
		Characterisation	
	Storage	Siting	
		Design	
		Construction	
		Operation	
		Closure	
		Decommissioning	
		Remediation	
	Transportation to disposal		
	Disposal	Siting	
		Design	
		Construction	
		Operation	
		Decommissioning	
		Closure	
		Post-closure	
		Retrievability	
RAW for clearance[71]	Processing	Characterisation and sorting	
		Pre-treatment	
		Sorting	
		Monitoring	
	Transportation to sites (for monitoring, re-use or clearance)		

[71] Refers to material to be released from control.

Level I: SF/RAW Categories or Classes	Level II: Cost Item Structure	Level III: Management Stages	Comments
NORM Waste[72]	Processing	Pre-treatment	
		Treatment	
		Characterisation	
	Storage	Siting	
		Design	
		Construction	
		Operation	
		Closure	
		Decommissioning	
		Remediation	
	Transportation to disposal		
	Disposal	Siting	
		Design	
		Construction	
		Operation	
		Closure	
		Post-closure	
		Retrievability	
Orphan waste[73] /	Processing	Characterisation and sorting	This category is to be used only if orphan and legacy waste has not been included in other sections (orphan / legacy wastes comprise all types of wastes and this
		Pre-treatment	

[72] This section applies to NORM waste that is considered as radioactive waste by Member States. Note: the Directive 2011/70/Euratom applies to NORM waste outside extractive industries. However, some Member States consider waste from extractive industries as radioactive waste.

[73] Radioactive waste without known generator or responsible licence holder.

Level I: SF/RAW Categories or Classes	Level II: Cost Item Structure	Level III: Management Stages	Comments
Legacy Waste[74]		Treatment	implies that they do not typically follow any specific pathway).
		Conditioning	
	Transportation to storage / processing (in Member State or abroad), including return of by-products		
	Storage	Siting	
		Design	
		Construction	
		Operation	
		Closure	
		Decommissioning	
	Transportation to disposal		
	Disposal	Siting	
		Design	
		Construction	
		Operation	
		Closure	
		Post-closure	
		Remediation	

Source: Author

This taxonomy tries to take into account all the possible radioactive waste and spent fuel management activities and costs. As some countries may not generate one category of waste or not be engaged in the production of electricity from nuclear sources, parts of the high-level taxonomy will not be relevant for them. Likewise, some countries may not bear direct costs because waste is sent abroad for treatment and packaging.

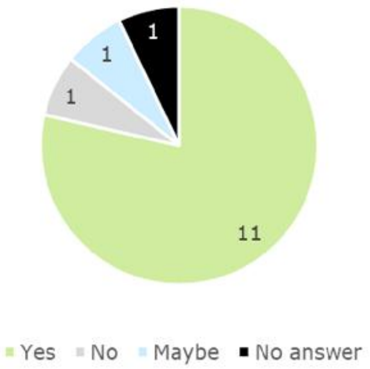
[74] In some Member States another terminology is used, such as "radioactive waste from past practices". This may include radioactive waste from defence activities that has been transferred to civilian facilities. This document addresses only radioactive waste and spent fuel from civilian activities/facilities.

This high-level taxonomy (with some exceptions) was presented as part of a survey to the different Member States, in which they were asked three "yes" or "no" questions on this, with the possibility of adding a comment to complete the answer. The questions presented to them were:

1. Do you think the levels proposed (Level I – SF/RAW categories or Classes, Level II-Cost Item Structure and III- Management Stages) represent a useful reference for building a high-level taxonomy?
2. Would you like to suggest an alternative approach to the development of a high-level taxonomy for spent fuel and radioactive waste management activities (both in terms of levels and items to be considered at each level)?
3. Would you have any (additional) comments?

Of the 28 Member States contacted, 14 responded to the survey[75], one of which gave two responses: one from the storage point of view and another from the disposal point of view[76]. The analysis below is based on the answers received to the three questions from these 14 countries, which are analysed in a combined manner as the questions feed into each other.

Figure 23 – High-level taxonomy: Overview of replies to question 1 of the survey to Member States: are the levels proposed a useful reference?



Source: Author

As shown in Figure 23, when asked if the levels represent a useful reference for building a high-level taxonomy, the majority of Member States agreed. In fact, even those who responded "maybe", "no" or did not answer with a "yes" or "no", acknowledged in their comments that levels I and II of the proposed taxonomy could both provide an added value to their work. Nevertheless, 9 of the 14 respondents suggested changes or additions to the proposed taxonomy.

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[75] Austria, Bulgaria, Croatia, Czechia, Finland, France, Germany, Hungary, Italy, Lithuania, Netherlands, Slovakia, Spain, Sweden.

[76] To ensure Member State replies are treated on an equal footing, the two answers coming from the same Member State are counted as a single view and, if the two replies are mutually exclusive and contradictory, this will be made apparent and explained.

In general, suggestions for changes were due to an inclination on the part of Member States to adapt further the taxonomy to their individual context. However, some of the changes are relevant to other Member States and can be of value to the high-level taxonomy, which is why they have been included in blue.

Furthermore, several Member States, notably those who either were against or responded "maybe", emphasised their concern about the potential aim of this high-level taxonomy and its potential use for comparison. They considered that this taxonomy may represent a substantial administrative burden with unclear benefits if used for mandatory reporting. Moreover, many Member States expressed concern about any intent to harmonise fully and compare costs in the EU. Some of the reasons put forward included:

- "only a few MS have a comprehensive programme for radioactive waste management, especially when it comes to spent fuel. Subsequently, the maturity of the cost estimates differ significantly";
- "the methods for cost estimation also differs between countries, some use a deterministic estimation, and others use probabilistic approach";
- "comparing the cost estimates for the different levels between Member States will be difficult due to differences in economic parameters";
- "countries with centralized storage and countries with de-centralized storage cannot be compared";
- "definitions should be very well specified to ensure interpretation is aligned".

The Member States pointed out that these aspects would need to be considered if the data were to be used for analytical purposes, and explanatory notes would be needed (qualitative information) to provide background for the different cost items.

Finally, the Member State who replied "no" to the usefulness of the proposal to build a high-level taxonomy, recommended starting small and first looking at one entry (e.g. costs for design and construction of the disposal). Then, lessons learned could lead to a more detailed table.

As shown from the results of the survey, the suggested high-level taxonomy could be a good basis for embarking on discussions on defining a tool that would make it possible to build common ground between Member States in the analysis of the cost assessment in the field of radioactive waste and spent fuel management.

Some initial reflections for further discussion are:

- The need for each category in each level of the high-level taxonomy to be very clearly defined;
- The need to have an open text box available to complement any data put forward by the country in relation to the high-level taxonomy;
- The possibility of starting small (by potentially only including two of the levels of the high-level taxonomy) and then expanding progressively;
- The need to refrain from using such a tool simply to compare very different contexts.

4.5 Approaches for cost assessments indicators

The aim of this section is to suggest a list of Cost Assessment Indicators which can be used to help Member States deal with cost assessments in the field of radioactive waste and spent fuel management. Two main approaches to the construction of this kind of indicators are possible:

- A top-down approach;
- A bottom-up approach.

The top-down approach aims to build Cost Assessment Indicators (CAI) in line with the high-level taxonomy developed in the previous section. As the proposed taxonomy does not represent an accepted industry standard, this approach discounts the fact that only some of the categories proposed in the high-level taxonomy could today be concretely used by Member States in building indicators. The bottom-up approach is expected to be more directly accessible to Member States. In fact, some of these indicators are already being used by some Member States today (e.g. Denmark, Estonia, Germany, Spain, UK, etc.)

The two sub-sections below present these approaches, as well as some examples based on the data available.

4.5.1 Top-down approach to Cost Assessment Indicators

As explained in the introduction of this section, this approach builds on the high-level taxonomy presented above. The top-down approach presented below can also be considered to be broadly in line with the ISDC[77] and, thus, easier to comprehend. It could be based, but depending on the availability / granularity of data, on the recognition of nine main categories of costs (which represent Level IV of the proposed high-level taxonomy)[78]:

- Labour costs;
- Investment costs;
- Expenses;
- Contingencies;
- Regulatory costs;
- Research and development costs;
- Training costs;
- Licensing costs;
- Transparency and public engagement costs.

[77] See appendix 1 for a brief overview of the ISDC cost classifications.

[78] As mentioned earlier in this document, these categories of costs could possibly be a Level IV of the high-level taxonomy proposed for discussion in point 1.2.

Following such an approach, some relevant key cost assessment indicators may be built on the basis of the Level II of the high-level taxonomy proposed, i.e. on the basis of the following:

- Processing;
- Transportation to storage and/or processing of RAW;
- Storage;
- Reprocessing (only for spent fuel);
- Transportation to disposal;
- Disposal.

A few examples of key Cost Assessment Indicators are given in Table 11 below.

Table 11 – Example of Cost Assessment Indicators[79]

Level II of the high-level taxonomy (parts)	Key Cost indicator
VLLW – Repository	$\boldsymbol{C} \quad \boldsymbol{I}_1 \quad \boldsymbol{o}\ \boldsymbol{W} \quad (\boldsymbol{C} \quad) = \frac{\text{Investments and Operation costs over } X \text{ years}}{\text{Volume of waste (nominal capacity)}}$
ILW – Storage	$\boldsymbol{C} \quad = \frac{\text{Investments and Operation costs over } X \text{ years}}{\text{Volume of waste (nominal capacity)}}$
LLW – Repository	$\boldsymbol{C} \quad = \frac{\text{Investments and Operation costs over } X \text{ years}}{\text{Volume of waste (nominal capacity)}}$
SF – Storage	$\boldsymbol{C} \quad \boldsymbol{I}_1 \quad \boldsymbol{o}\ \boldsymbol{F} \quad (\boldsymbol{C} \quad) = \frac{\text{Investments and Operation costs over } X \text{ years}}{\text{Weight of heavy metal or number of elements (nominal capacity)}}$
HLW – Storage	$\boldsymbol{C} \quad = \frac{\text{Investments and Operation costs over } X \text{ years}}{\text{Volume of waste (nominal capacity)}}$
HLW – Repository	$\boldsymbol{C} \quad = \frac{\text{Investments and Operation costs over } X \text{ years}}{\text{Volume of waste (nominal capacity)}}$

Notes: "Repository" here refers to disposal. X is a relatively long period of time (e.g. 50 years). In the table, under "Investments" at least the sum of the two cost categories investment costs and contingencies and under "Operation" the two cost categories labour costs and expenses should be included. The other cost categories (regulatory costs, research and development costs, training costs, licensing costs, transparency and public engagement costs) might also be included under "Investments" and/or "Operation", based on the availability of data and the country-specific practices.

Source: Author

[79] The following indicators are examples based on the suggested approach. Today, many Member States do not provide a breakdown between all the types of waste in their storage and repository, which entails that the CAI that more commonly be calculated is "LLW and SL-LILW - repository", instead of "LLW - repository" and "SL-LILW – repository", with the data publicly available.

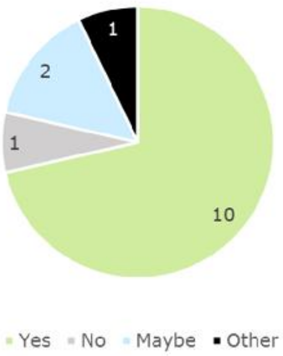
Survey results on the applicability and effectiveness of the approach

Like the taxonomy, the top-down approach to Cost Assessment Indicators was presented as part of a survey to the different Member States. The questions were also three "yes" or "no" questions, with the possibility of adding a comment to complete the answer. The questions presented were:

1. Do you think, in particular based on the availability of data in your Member State, that it would be possible to calculate cost indicators following the approach described?
2. If other approaches to Cost Assessment Indicators for radioactive waste and spent fuel management are used in your country that you consider to be a best practice, please describe them.
3. Would you have any (additional) comments?

The response rate was the same as for the taxonomy (14 responses[80], with one country providing two views[81]) and the analysis is also based on the answers received, taken together.

Figure 24 – Cost Assessment Indicators: Overview of replies to question 1 of the survey to Member States: calculating cost indicators following the proposed approach[82]



Source: Author

As shown in Figure 24, the responses are very similar to those received for the taxonomy. The majority of the respondents agreed that, based on the available data in their Member State, it would be possible to calculate cost indicators following the approach described. From those Member States who responded favourably, 6 of the 10 did so without any additional suggestions. As for the other 4 and the rest who did not respond "yes", they generally referred to the same or similar comments made in the section on the taxonomy, as these topics are interlinked. The appropriateness of suggesting "standard" Cost Assessment Indicators for

[80] Austria, Bulgaria, Croatia, Czechia, Finland, France, Germany, Hungary, Italy, Lithuania, Netherlands, Slovakia, Spain, Sweden.

[81] To ensure Member State replies are treated on an equal footing, the two answers coming from the same Member State are counted as a single view and, if the two replies are mutually exclusive and contradictory, this will be made apparent and explained.

[82] The "other" category represents the view of the Member State who submitted to answers, and whose answers differ one from another. The suggested cost indicators seem to be ok with for storage, while the disposal side flags some concerns, although they do not reply "no" to the question.

Member States who have very different contexts was the main recurring concern. Some Member States referred back to their comments of certain wastes not being applicable to their case and others to the risks behind looking for indicators to compare between countries. This was stressed in particular due to the differences between Member States in wages, prices per square metres, etc. Moreover, four Member States stated their preference for continuing to use their current methodology for ease of calculation and to avoid additional administrative burden. One particularly highlighted that the availability of certain data could be a problem because of the confidentiality of specific information or the amount of time passed since the expense took place.

In line with this, 3 Member States suggested alternative Cost Assessment Indicators. The first referred to a cost estimation based on the price of electricity sold, which is a long-standing practice undertaken in some countries in the past. The second referred to a more generic approach, which would not differentiate between management phases and would concentrate on the overall cost of waste management (also possibly per type of waste), i.e.:

$$\frac{\text{Global RAW class management costs (excluding retrieving and processing costs)}}{\text{Volume of waste}}$$

The third referred to separating fixed and variable costs. In this particular case, the expert team acknowledges that not all costs are related to the amount of waste, and that fixed costs (e.g. the construction of storage or disposal facilities) in the early stages of the management of waste can lead to very high indicators. Fixed and variable costs could be calculated separately, determining in a first step the basic costs for the establishment of the necessary infrastructure and then a variable sum depending on the amount of waste[83].

Finally, for illustrative purposes we have carried out the exercise of calculating some of these Cost Assessment Indicators based on the information available for the study[84].

The calculations of the Cost Assessment Indicators were performed using data from Belgium, Hungary, Lithuania, Romania and Sweden for VLLW, LILW-SL, HLW and spent fuel repositories. Category I Member States have more sources of radioactive waste, which leads to a more controlled and calculated assessment of costs.

Since it is difficult to obtain, per Member State, information about the cost of each stage (construction, operation) of waste disposal, the following formula was used:

$$\frac{\text{Global RAW class disposal management costs (2015), excluding processing and transportation costs}}{\text{Volume of waste}}$$

[83] However, this is not the aim of the Cost Assessment Indicators provided above, which are intended to provide a quantity-related cost assessment indicator. This concern can be mitigated through the inclusion of explanatory text about the background and current state of the radioactive waste and spent fuel situation in the Member State.

[84] Please refer to the work for tasks A and B in chapters 3 for more information.

Calculation of indicators from publicly available information

Table 12 consolidates the key data necessary for the illustration, taking into account the RAW and spent fuel management strategy of each Member State studied, notably:

- Name of the facility: to understand on which particular case this example is based;
- Generation capacity (m^3): which refers to the denominator (volume of waste) to calculate the formula;
- Cost (€ million): which refers to the numerator to calculate the formula;
- Indicators (rough) € '000/m^3: A rough result of the indicator based on the data available.

The cost takes into account the total needs of the Member State for disposal of each category of radioactive waste, i.e. mainly investment and operating costs.

These results are then corrected by a Correction Salary Factor (EUROSTAT data) to better reflect the particularities of the countries. Consequently, two other elements are part of the table:

- Correction Salary Factor;
- Indicators (corrected) € '000/m^3: which provides the result of the indicator considering the salary in the country.

The sources for all the information used to develop this table are available in Appendix 2.

Table 12 – Examples of Cost Assessment Indicators for 2015[85]

Member State	Name of the facility (type of CAI)	Capacity or generation (m^3)	Cost (€ mn)	Indicators (rough) € '000/m^3	Correction Salary Factor	Indicators (corrected) € '000/m^3	Comments
BELGIUM	Geological disposal of LL-LILW (Category B) and HLW (Category C)	Generation: (C) = 5 475 tHM+ (B): 11 100 m^3 Or 18 954 m^3 (B)+(C)	3 200 (2012) 3 250 (2015)	593.6 € '000/tHM (without B waste) Or 171.46 € '000/m^3	1.31	453.1 € '000/tHM (Without B waste) Or 130.89 € '000/m^3	(C): 3 800 tHM +2.4 tHM + 250 m^3 (=1 672 tHM reprocessed) Hypothesis 1 tHM= 2 m^3 package?
BELGIUM	Surface Disposal for SL-LILW (Category A) at Dessel	Generation: 70 500 m^3	1 250 (2012) 1 400 (2015)	19.86	1.31	15.16	
FRANCE[86]	SL-LILW- Disposal Centre de l'Aube (existing)	Capacity: 1 000 000 m^3		2.44 (2005) 2.93 (2015)	1.19	2.05 (2005) 2.46 (2015)	Ref.: ANDRA Real cost (mean value)
HUNGARY	Deep Geological Repository (SF +HLW)	Generation: 5 309 tHM + 1 019 m^3 HLW	2 400 (2015)	452.06 € '000/tHM (without HLW)	0.27	1674.31	2 100 tHM→ 4 200 m^3 HLW

[85] Facilities in bold are SL-LILW

[86] The indicator for France already exists and is publicly available in a report from Andra.

Member State	Name of the facility (type of CAI)	Capacity or generation (m³)	Cost (€ mn)	Indicators (rough) € '000/m³	Correction Salary Factor	Indicators (corrected) € '000/m³	Comments
		Or 10 618 m³ HLW+ 1 019 m³ HLW		Or 206.24 € '000/m³		€ '000/tHM (without HLW) Or 763.85 € '000/m³	
HUNGARY	LLW and SL-LILW National Radioactive Waste Repository at Bátaapáti ('NRWR')	Generation: 87 830 m³	252.9 (2015)	2.88	0.27	10.66	
LITHUANIA	Deep Geological Disposal	SF = 2 416 tHM + LL-LILW = 9 700 m³ Or 1 400 canisters (5852 m³)+ LL-LILW = 9 700 m³	2 600 (2015)	1 076.15 € '000/tHM (Without LILW waste) Or 167.18 € '000/m³	0.26	4 139 € '000/tHM (Without LILW waste) Or 643 € '000/m³	Ref. Program ENER-2015-00790-00-00-EN-TRA-00 1 copper canister SNF= 4.18 m³
LITHUANIA	LLW and SL-LILW new surface repository	90 000 m³	412 (2014) 412 (2015)	4.58 € '000/m³	0.26	17.6	

Member State	Name of the facility (type of CAI)	Capacity or generation (m^3)	Cost (€ mn)	Indicators (rough) € '000/m^3	Correction Salary Factor	Indicators (corrected) € '000/m^3	Comments
LITHUANIA	VLLW management Landfill	60 000 m^3	42 (2014) 42 (2015)	0.7 € '000/m^3	0.26	2.69	
ROMANIA	Deep Geological Disposal (SF + LL-LILW)	SF = 20 400 tHM + LL-LILW = 2 235 m^3 Total Packages = 42 500 m^3	2 200 (2015)	107.84 € '000/tHM (Without B waste) 51.76 € '000/m^3	0.21	513.5 € '000/tHM (Without B waste) or 246.5 € '000/m^3	Cost ref.: SWD(2017) 158
ROMANIA	SL-LILW Disposal facility (DFDSMA)	Capacity: 122 000 m^3 Generation:29 500 m^3	344 (2014) 344 (2015)	2.82	0.21	13.43	
SWEDEN	Final repository for LLW and SL-LILW (SFR)	Existing: 63 000 m^3 Extension: 108 000 m^3 (Generation = 153 200 m^3)	519.9 (2015)	4.81	1.27	3.79	Calculation for extension
SWEDEN	Final Spent Fuel Forsmark Repository	6 000 canisters (Generation = 5 700) Or 12 000 tHM	3 376.3 (2015)	281.36 € '000/tHM Or 134.62 € '000/m^3	1.27	221.5 € '000/tHM Or 106 € '000/m^3	1 copper canister = 4.18 m^3

Member State	Name of the facility (type of CAI)	Capacity or generation (m^3)	Cost (€ mn)	Indicators (rough) € '000/m^3	Correction on Salary Factor	Indicators (corrected) € '000/m^3	Comments
SWEDEN	Repository for LLW and LL-LILW (SFL)	16 400	217.1 (2015)	13.24	1.27	10.42	

Source: Author based on available information (See appendix 2 for details).

Definitions: HLW: High Level Waste; LILW: Low- and Intermediate Level Waste; LLW: Low Level Waste; LL-LILW: Long-lived Low- and Intermediate Level Waste; SF: Spent Fuel; SL-LILW: Short-lived Low- and Intermediate Level Waste; tHM: Tons of Heavy Metal; VLLW: Very Low Level Waste.

For SL–LILW repositories, presented in bold above, the calculations with Belgian, Hungarian, Lithuanian, Romanian and Swedish data provide interesting information on the cost of disposing of 1 m^3 of waste, which shows

- A same order of magnitude of the Cost Assessment Indicator (CAI), of EUR 10.4-17.6 ‘000 / m^3 (corrected EUR 2015) for the near-surface disposal of LILW-SL;
- If the infrastructure of the disposal already exists, a lower CAI, with a value of EUR 3.7 ‘000 / m^3 (corrected EUR 2015) in the case of Sweden; this result could be compared with the LIWL-SL management indicator cost of 2.46 EUR ‘000/m^3 for the Centre de l’Aube repository in France (from ANDRA public information);
- A lower value of CAI of EUR 2.69 ‘000 / m^3 in the case of Lithuania VLLW landfill disposal.

In the case of LILW-LL, HLW and Spent Fuel geological disposal, the calculation results in more dispersed values:

- The indicator factor is between EUR 246.5 and 763.4 ‘000 / m^3 (corrected EUR 2015), depending on the spent fuel management strategy, the types of waste which have to be disposed of, the waste packages, etc.; usually the costs are provided globally, without separating the management of each type of waste, i.e. LILW-LL, HLW and SF; in particular, it is necessary to make assumptions about the packages for Spent Fuel (copper canisters, special containers or packages);
- If the infrastructure or studies on the disposal already exist (as is the case of the cost of disposal above), the indicator factor is lower, with an indicator value in the range of EUR 106-131 EUR ‘000 / m^3.
- NB: the CAI values for spent fuel disposed of, expressed in tHM, assuming that there is no other waste in the repository at the same time, are given as an indication.

4.5.2 Bottom-up approach to Cost Assessment Indicators

The aim of this section is to present an alternative list of Cost Assessment Indicators based on a bottom-up approach, which it is expected Member States would find it easier to implement in the short term. The choice of Cost Assessment Indicators presented below takes into account that Member States are very different in terms of their radioactive waste and spent fuel profile, and that this area is a sensitive one for most countries. In this context, while we present a more or less extensive list of cost categories, not all will be put forward as necessary for cost assessment analysis[87].

The subsections below are divided into five categories that have been identified for the grouping of the different cost indicators. Concretely:

- Quantity-related costs (based on quantities of stored and disposed waste);
- Non-quantity related costs;
- Overhead costs;
- Rates capturing cost escalation and inflation; and

[87] Please refer to appendix 3 to see which are set forward.

- Rates for unforeseen factors and risks.

The following sub-sections describe each category and the cost indicators that they comprise, all of which are defined to facilitate understanding. Moreover, as the costs of the first two categories can be quite disparate depending on the different types of waste stream, we suggest breaking them down on that basis. Concretely, we would propose to use the following common waste streams, which differ slightly from the classification introduced in the chapter on taxonomy:

- High Level Waste,
- Low and Intermediate Level Waste-Long Lived,
- Low and Intermediate Level Waste-Short Lived,
- Very Low Level Waste,
- Spent fuel, and
- NORM waste, exempt waste and materials.

Overall, we have observed that most Member States do not provide detailed enough information on the correspondence between costs and the waste stream they are linked to. When Member States report on these costs, it is more common to provide the overall figure instead of the breakdown per waste stream.[88]

Quantity-related costs

Some of the costs linked to radioactive waste and spent fuel management vary depending on the quantity and type of radioactive waste. Four types of cost correspond to this category and are set out in detail below. These are:

- Construction and design costs represent costs incurred at the initial stages of management of radioactive waste, and should thus be key when reporting. These include all the costs for designing and building civil works to store or dispose of waste with the appropriate level of safety in the long-term. This can include other cost categories, on- and off-site, such as access to infrastructures (e.g. roads, utility connections), boundary fences, service buildings and drainage systems, visitor and public information facilities, etc.
- Transport costs are an important element of the waste management cycle. All costs linked to the transport of radioactive waste from their source to the place of treatment, storage, and/or disposal should be considered. They can include such costs as shipment, rail and truck transport;
- Operational personnel refers to all the operational costs including personnel, monitoring, expenses and transport. These do not include decommissioning costs;
- Decommissioning costs refer to all technical and administrative costs of activities supporting the release of nuclear facilities, clearing (part or all) the regulatory requirements and delivering something apt for other uses.

As explained in the introduction to 4.5.2, the cost indicators under this category would be further broken down and reported on the basis of the different waste streams identified. The only exception to this would be the cost indicators for NORM waste, exempt waste and materials.

[88] As mentioned in the introduction, for more in-depth information on this approach, please refer to appendix 3.

Exempt waste and very short lived waste containing only very short half-life radionuclides do not require future long-term management or disposal, as their short-lifetime and/or levels of radioactivity allow for the exemption or clearance from regulatory control. Accordingly, exempt waste and very short lived waste are in most cases not reported by Member States.

Waste containing naturally occurring radioactive material – NORM (e.g. from uranium mining and milling) is not categorised as radioactive waste in some Member States, although a few Member States declare this waste in the scope of their National Programmes.

These CAIs could be reduced to two:

- Construction and design costs,
- Operational personnel costs.

While Member States normally have these costs, not all report them entirely and in a clear manner, and very few report on them per waste stream.

For example, Bulgaria reports on the construction and design costs but does not differentiate completely between waste streams. Bulgaria is building a storage facility for the long-term storage of HLW from the reprocessing of SNF, HA SIR and ILW-LL. For this activity, the Bulgarian authorities have set 2025 as a deadline and expect to invest around EUR 60 million.[89]

Denmark is an example of a Member State which reports on operational personnel costs by presenting three scenarios of the potential cost of these, but does not clearly differentiate between waste streams. The table below shows Denmark's estimates for the long-term storage facility.

Table 13 – Estimates of long-term facility costs (operational staff), Denmark

Type of cost	Most likely price DKK million	Minimum price DKK million	Maximum price DKK million
Operational costs related to staff	82.5 (€ 11.06 million)	55.0 (€ 7.37 million)	110.0 (€ 14.75 million)

Non-quantity related costs

Other types of cost linked to radioactive waste and spent fuel management do not relate to the quantity and type of radioactive waste. Four types of costs correspond to this category. These are:

- Allowances for unspecified items are an allocation that is added to the cost estimations to cover items that are not considered in the calculations from the start, but that experience shows should be accounted for. This allowance is not to be mistaken for that of unforeseen factors and risks, which relates to circumstances that could take place and could have a financial impact, but for which there is no certainty.

[89] In addition, Bulgaria is also building a National Disposal Facility for the disposal of low and intermediate level short-lived RAW.

- Operational costs are those costs that are linked to the resources necessary to keep facilities running. Contrary to the operational personnel costs referred to under the quantity-related costs section, these costs are fixed and do not vary on the basis of the degree of waste.
- Compensation to authorities are allowances negotiated with local governments to compensate for establishing nuclear (management) facilities in their area. In some Member States this compensation represents a major part of the costs, which makes it a crucial category to report on.
- Research and development costs are linked to activities generating the necessary capabilities (in terms of know-how and technologies) to improve and guarantee the performance of the management of waste.

As explained in the introduction under 4.5.2, the cost indicators in this category would be further broken down and reported on the basis of the different waste streams identified. However, research and development costs would not be relevant under the NORM waste, exempt waste and materials waste stream.

Here again, while Member States have normally estimated operational costs, not all report them in a clear manner and very few report on them per waste stream. For example, Poland reports on its costs for operations from 2021-2141 (PLN 30.7 million), but does not differentiate between waste streams.

Overhead costs

When establishing a cost classification, the costs are mainly classified in the quantity-related and non-quantity related categories. Therefore only the costs that cannot be clearly allocated to one of the six waste streams will be classified as overhead costs. These costs include:

- Administration costs: Administration or administrative costs are those that are related to general costs necessary to provide for a company and the maintenance of its business, but are not directly linked to a concrete department (e.g. corporate administration and administration of the research centres).
- Procurement costs: Procurement costs are those costs incurred in the acquisition of the necessary resources to carry out the management of radioactive wastes.
- Project management: Project management costs are those linked to the everyday management of specific projects.
- Training/qualification of personnel: Training/qualification costs are linked to those activities aimed at transmitting knowledge and guidance to the personnel in order to guarantee and/or improve the performance of the management of waste.
- Consultants and expert activities: This category includes all expenses dedicated to external experts and consultants contracted for concrete activities or tasks in the management of radioactive waste.
- Licensing costs: Fees paid to the competent authority to obtain the approval of a licence to undertake the necessary activities to manage radioactive waste. This might include construction licences, operation licences, etc.
- Environmental monitoring: Environmental monitoring costs include all costs linked to the assessment and supervision to ensure compliance with environmental requirements.

- Consumable goods: Costs for consumable goods are those linked to products that are frequently used and are worn out after use. In the case of radioactive waste management, these are mainly water, industrial gases, small equipment, detectors, gloves, etc.
- Utilities: Utility costs are those costs incurred for water, gas, and electricity, etc. to run the facilities. Contrary to the utility costs under the quantity-related costs, the utility costs under overhead costs are those that will remain regardless of the amount of radioactive waste.
- Data management and preservation of knowledge: Data management and preservation of knowledge costs include all costs related to data collection, storage, access, preservation, security, availability and reuse. These can be both employee and technology related.
- Regulatory costs: Regulatory costs refer to those costs incurred as a consequence of regulatory compliance.

Most Member States do not seem to report these costs in a distinct manner although they can generally obtain consolidate them. The UK does reports on the administration costs as part of the authority administration expenditure. These amounted GBP 15 million in 2015 and GBP 19 million in 2014.

Rates used for capturing cost escalation and inflation, and discount rates

Two Cost Assessment Indicators have been identified under this category:

- Inflation rate: The inflation rate captures the level at which prices of goods and services increase and consequent purchasing power.
- Discount rate: The discount rate represents an interest rate to determine the present value of a specific amount of money.

While Member States normally estimate these rates, not all report them entirely and in a clear manner. Nonetheless, there are some exceptions. For example, in line with the benchmark rate for the EU, Bulgaria considers an annual inflation rate of 2%. Some countries also report on their discount rates and their figures include Hungary's 2.5%, Spain's 1.4% and Slovakia's 1.1%.

Rates for unforeseen factors and risks

The main cost assessment indicator under this category is the Contingency rate. The contingency rate is an allowance to account for unforeseeable circumstances and events.

While Member States normally account for these rates, not all report them entirely and in a clear manner as is typical of the other categories. In Bulgaria's case, the contingency costs for the main groups of activities in the decommissioning of units 1 to 4 are reported for the period 2003-2030. The following table showed this reporting.

Table 14 – Bulgarian contingency costs (Units 1-4, 2003-2030)[90]

Code	Activity	Contingency (EUR million)
01	Decommissioning preparatory activities	376
02	Activities at the time of closure	1 910
03	Supply of equipment and materials	1 689
04	Dismantling activities	13 972
05	RAM and RAW treatment and delivery for disposal	21 055
06	Site management and maintenance	10 089
07	Project management and engineering	1 491
08	Fuel and nuclear materials management	0
	TOTAL	50 206

4.5.3 General observations

As demonstrated above, there are currently a number of possible approaches to developing Cost Assessment Indicators, including those already used by the Member States. In line with the objective of the high-level taxonomy in this study, two concrete approaches are proposed that may contribute to building common ground between Member States in the analysis of cost assessment in the field of radioactive waste and spent fuel management.

The first approach builds further on the suggested taxonomy developed in this study. However, as the high-level taxonomy is, as such, not an instrument currently in use (and only some of the categories are used today by all Member States in their reporting), it is an approach that cannot be put forward systematically.

The second looks into a bottom-up approach that is considered easier for Member States to use, as some of the indicators and types of waste streams are already being used by some of them. This could be considered as an intermediate approach or an alternative, if the other cannot be achieved (although the results of the consultation survey would suggest it could be).

Based on the results of the survey, the suggested top-down Cost Assessment Indicators would be a feasible option for the majority of Member States having responded. This would suggest that such Cost Assessment Indicators could be used in the future by a majority of Member States to assess their costs.

Discussions on this matter could be fruitful, taking also into account the discussion points from the high-level taxonomy, i.e.

[90] The Member State has more recent data which has not been possible to integrate to ensure a consistent and timely analysis.

- The need to refrain from using such a tool to simply compare very different contexts;
- The possibility of starting small and then expanding progressively;
- The need to have an open text box available to complement any data a country provides.

5 Conclusions

The scale of the nuclear programmes, technological approaches and governance of the nuclear industries are different in each Member State. The results of this study demonstrate a wide range of approaches, methods and practices in cost assessment of radioactive waste and spent fuel in the Member States. Despite many differences, there are also many similarities, as the document review and survey of Member States demonstrate. This can be seen as an opportunity for mutual learning and exchanges of experience that together might bring better solutions for all the Member States. Five main topics have been analysed and identified as being of interest to set the path for further discussion in the near future:

- Governance of cost assessment processes – who calculates the costs, who reviews the calculations and how often it should be done;
- Methodologies for cost calculation – what are the possible ways of properly calculating the costs;
- Key parameters in cost calculation – how Member States take into account uncertainties, contingencies and the several additional parameters to build cost estimations;
- High-level taxonomy – how to reach a common basic high-level taxonomy
- Cost Assessment Indicators (CAI) – what cost assessments indicators could be developed based on the basis of a standard high-level taxonomy.

5.1 Governance of cost assessment processes

The governance of cost assessment of radioactive waste and spent fuel consists of two main steps: cost calculation, which is typically performed by operators, and the review of cost calculation, which in most Member States is performed by the ministries and/or regulatory bodies. The trends identified in the governance processes for cost assessment in the Member States[91] are:

Cost calculation

Trend identified: In most Member States operators perform the cost calculation.

There is no single approach. In most Member States the operators perform cost calculation, while six Member States have mixed approaches where several different types of actor participate in different parts of the cost calculation process. One of the outstanding cases of the mixed approach is France, where several bodies are responsible for different aspects of cost calculation.

Trend identified: In most Member States cost assessment is performed every year.

[91] Based on replies from 14 Member States.

There is no single approach. In most Member States cost calculation is performed every year, Finland and France have mixed approaches, where different aspects of cost calculation are calculated at different time.

Cost calculation review

Trend identified: In most Member States ministries and regulatory bodies perform the review of cost calculations.

There is no single approach. In most Member States ministries and regulatory bodies perform the review of cost calculation. The Netherlands differs as the cost calculation review is performed by an external expert. Another interesting example is Croatia. As the Krško NPP is the joint responsibility of Croatia and Slovenia, the cost calculation review is performed at different levels by inter-governmental bodies of the two Member States.

Trend identified: Most Member States review cost calculations every year.

Most Member States review cost calculations every year, just as the cost assessments are also performed every year in many Member States.

5.2 Methodologies for cost calculation

Trend identified: Most Member States use a combination of several methods. All Member States include the deterministic approach in their tool-kit for cost calculations.

Several methodologies are used for calculating the costs for radioactive waste and spent fuel management: deterministic, probabilistic, benchmarking and a mix of methods. All Member States use the deterministic approach in cost calculations. Seven Member States also make use of the probabilistic cost calculation methodologies. Seven Member States use benchmarking as a tool for cost calculation.

Deterministic methods are the most common methods used for radioactive waste and spent fuel cost assessment. The term deterministic implies that these methods offer a point estimate for cost assessment. The main difference between probabilistic methods and deterministic methods is that probabilistic methods explicitly model cost calculations using appropriate statistical distributions.

In probabilistic models the cost calculation, uncertainties and risks are incorporated within the cost estimate. These types of model calculate a range of estimate rather than a point estimate. All the typical mathematical operations are performed on data ranges, and require use of a probability theory. Probabilistic risk assessment may employ a set of tools, such as a fault tree, probability tree, decision analysis and Monte Carlo simulations.

Benchmarking is the practice of comparing business processes and performance metrics to industry bests and best practices from other companies. Dimensions typically measured are quality, time and cost. Benchmarking is used to measure performance using a specific indicator (cost per unit of measure, productivity per unit of measure, cycle time of x per unit of measure or defects per unit of measure) resulting in a metric of performance that is then compared to others.

5.3 Key parameters in cost calculation

Trend identified: All Member States use numerous different hypotheses in their cost calculation.

Additional criteria that impact the cost assessment process and results are key parameters considered in cost assessment. The main three key parameters are hypotheses, contingencies and the expected inflation rate.

Hypotheses

Hypotheses include lifetime of installations, inventories of existing SF and RAW, quantities of SF and RAW generated over time and others. For instance, there would be a significant difference in costs over time for radioactive waste and spent fuel if a nuclear power plant has a 30-year life or if it is extended to 50 years because more radioactive waste and spent fuel will be generated. Extended operation will defer the generation of decommissioning wastes, and will extend the period available to set aside funds to cover the cost of decommissioning. The years of additional electricity production will also reduce the cost of waste management and decommissioning per unit of electricity produced.

Contingencies

Trend identified: The range most commonly cited by Member States for inclusion of contingencies in the cost assessment is 10-20%.

Contingencies are another type of key parameter in cost assessment and are calculated differently in the Member States. Contingency covers costs for those activities that cannot be determined at a present stage of planning and are typically determined by general experience or modelling exercises.

There is no single approach. The most common answer is 10-20%, but answers vary in the range of 5-50% for specific cost categories.[92]

Expected inflation rate

Trend identified trend: Most Member States apply the expected inflation rate for the entire economy.

[92] Example of contingency estimations in Croatia: contingency was estimated depending on the type of work and expressed in percentages as follows:

- transport 10%
- conditioning and costs of IRC containers 10%
- preparatory work on long-term storage and LILW repository 10%
- construction and equipment for long-term storage facilities 10%
- construction and equipment for LILW repository 15%
- Operation of long-term storage and LILW repository 10%
- decommissioning of long-term storage 10%
- closing of the repository 15%.

Since radioactive waste and spent fuel management require specific labour and material inputs, an inflation rate different from the inflation rate of the entire economy might be applied to cost calculation.

Two interesting examples are Sweden and Croatia. In Sweden, the expected value for future costs is calculated by SKB using a comprehensive model in Excel with around 50 cash flows and 100 mostly uncorrelated uncertainty factors. Risk factors are estimated according to the method of successive calculation, developed by Steen Lichtenberg. In Croatia, a preliminary analysis for different expected inflation rate were performed in 2018 (University of Zagreb, Faculty of economy), but it was decided not to use different expected inflation rate.

5.4 Good practices

Overall, there are a number of good practices in cost assessment processes that can identified in the following domains:

- Governance of cost assessment processes – who calculates the costs, who reviews the calculations and how often it should be done
- Methodologies for cost calculation – what are the possible ways to properly calculate the costs;
- Key parameters in cost calculation – how Member States take into account uncertainties, contingencies and the several additional parameters to build cost estimations;

Governance of cost assessment processes:

- Cost calculations and cost calculation reviews are performed by different organisations (e.g. operators perform cost assessments and government bodies (ministry, National agency perform the reviews).
- Synchronisation of recurrence of the reviews of cost calculations (e.g. if cost calculations are performed annually, the review should also take place annually).

Methodologies for cost calculation - possible ways to properly calculate the costs.

- There is a constant need to ensure reliability and effectiveness of the chosen methodology.
- Methodologies need to be regularly back-tested.
- An independent assessment of the methodology is a good practice in back testing.

Key parameters in cost calculation - how Member States take into account uncertainties, contingencies and the several additional parameters to build cost estimations.

- Include a variety of relevant uncertainties in cost calculation, e.g. including societal, economic, implementation, organisational, technological, calculation and other uncertainties.
- Include contingencies in cost calculation; link contingencies to uncertainties;
- Take into account that different types of uncertainties can lead to different types of contingencies (e.g. societal uncertainties and technological uncertainties may lead to different contingencies);
- Consider the need to use a specific inflation rate.
- Link the calculation of the discount rate to:
  - The inflation rate used in the Member State, and
  - ROI (return on investment) of the investments made with the money from funds being built up for spent fuel and radioactive waste management.

5.5 High-level taxonomy

Key finding: <u>Most Member States agree that the levels proposed represent a useful reference for a high-level taxonomy.</u>

To promote better understanding and potentially foster peer learning in what is currently a very heterogeneous landscape, it could be worthwhile to develop an equivalent of the International Structure for Decommissioning Costing (ISDC) in the area of radioactive waste and spent fuel management.

Chapter 4.4.5 of this study presents a first attempt at developing such an equivalent through a high-level taxonomy comprising four levels.

- Level I operates a distinction according to the categories/classes of waste, and spent fuel;
- Level II further specifies the management processes according to a structure of broad cost items;
- Level III introduces an additional level of granularity by means of segregation according to the possible management stages;
- Level IV is a possible addition of key cost categories, based on the ISDC cost categories and additional recurring cost categories used by Member States.

The results of a survey of Member States suggest that the proposed high-level taxonomy could be a good basis to start further discussions with Member States and relevant international organisations (in particular IAEA and OECD-NEA).

5.6 Cost Assessment Indicators

Key finding: <u>Most Member States agree that it would be possible to calculate Cost Assessment Indicators using the top-down approach presented to them based on their available data.</u>

Chapter 4.5 demonstrated that there are many approaches to developing Cost Assessment Indicators, including those used by the Member States. In line with the objective of the high-level taxonomy (i.e. developing the equivalent of the ISDC for radioactive waste and spent fuel management activities), two concrete approaches that could facilitate peer learning between Member States have been identified:

- A top-down approach; and
- A bottom-up approach.

The top-down approach builds on the suggested taxonomy developed in chapter 4.4.5 However, as the high-level taxonomy is still only a proposal and only some of the categories are used today by Member States in their reporting, it is an approach that cannot yet be put forward systematically. The aim is to be able to build up towards it over time.

The bottom-up approach is considered more accessible to Member States, as some of the indicators are already being used by some of them as shown in the examples in appendix 3. This could be considered as an intermediate approach or an alternative, until the top-down approach becomes feasible, which the consultation survey suggests it might be. This would suggest that such Cost Assessment Indicators could be used in the future by a majority of Member States to assess their costs.

Appendix 1: Brief overview of relevant classifications

1. IAEA classification of radioactive waste

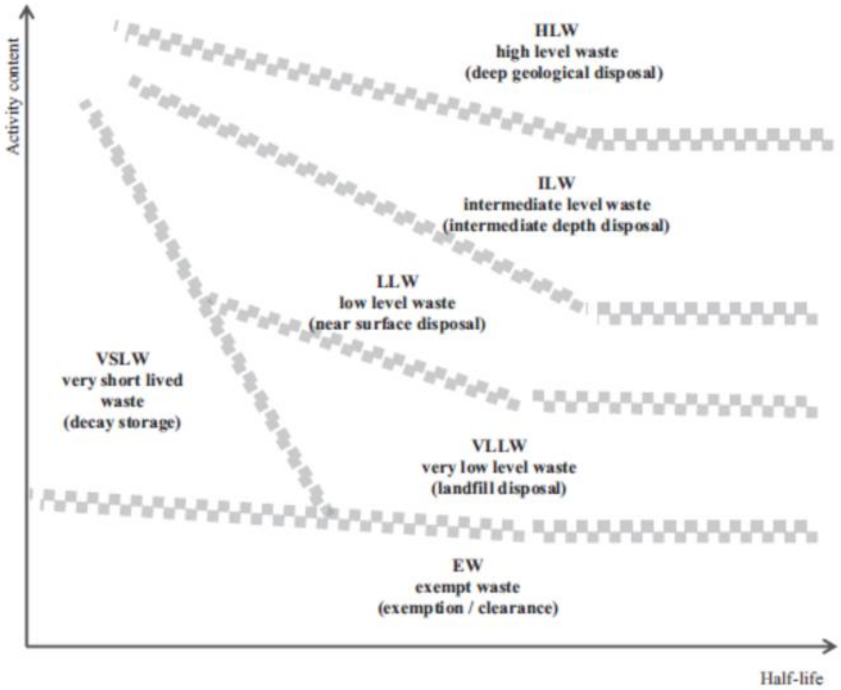
“A conceptual illustration of the waste classification scheme is provided in the figure below. The vertical axis represents the activity contents of the waste and the horizontal axis represents the half-lives of the radionuclides contained in the waste.

Considering this figure vertically, the level of activity content can range from negligible to very high, that is, very high concentration of radionuclides or very high specific activity. The higher the level of activity content, the greater the need to contain the waste and to isolate it from the biosphere. At the lower range of the vertical axis, below clearance levels, the management of the waste can be carried out without consideration of its radiological properties.

Considering this figure horizontally, the half-lives of the radionuclides contained in the waste can range from short (seconds) to very long time spans (millions of years).

Limitations placed on the activity (total activity, specific activity or activity concentration) of waste that can be disposed of in a given disposal facility will depend on the radiological, chemical, physical and biological properties of the waste and on the particular radionuclides it contains.”

Figure 25 – Conceptual illustration of the waste classification scheme



Source: IAEA

In accordance with this approach, six classes of waste are derived and used as the basis for the classification scheme:

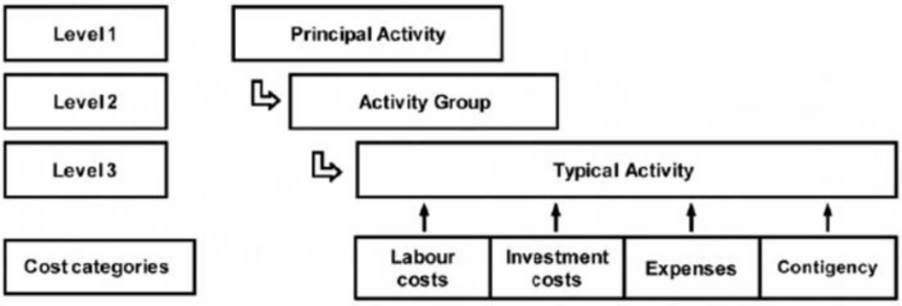
- Exempt waste (EW);
- Very short lived waste (VSLW);
- Very low level waste (VLLW);

- Low level waste (LLW);
- Intermediate level waste (ILW);
- High level waste (HLW).

2. The International Structure for Decommissioning Costing (ISDC)[93]

The standard decommissioning activities identified in the ISDC are presented in a hierarchical structure, with the first and second levels being aggregations of the basic activities identified on the third level. The cost associated with each activity may be subdivided according to four cost categories (see below).

Figure 26 – Hierarchical structure of the ISDC



Source: ISDC

At the highest level, Level 1, 11 Principal Activities are identified:

01 Pre-decommissioning actions;

02 Facility shutdown activities;

03 Additional activities for safe enclosure or entombment;

04 Dismantling activities within the controlled area;

05 Waste processing, storage and disposal;

06 Site infrastructure and operation;

07 Conventional dismantling, demolition and site restoration;

08 Project management, engineering and support;

09 Research and development;

10 Fuel and nuclear material;

11 Miscellaneous expenditures.

Four cost groups are defined at each level as:

- Labour costs – payments to employees, payments to social security and health insurance according to national legislation and overheads;
- Investment costs – capital/ equipment/ material costs;
- Expenses – consumables, spare parts, taxes etc.;
- Contingencies – a specific provision for unforeseeable elements of costs within the defined project scope.

[93] https://www.oecd-nea.org/rwm/reports/2012/ISDC-nuclear-installations.pdf

Appendix 2: Data sources for a top-down approach to cost assessment indicators

1. References:

- Sweden_TR-17-02
- 2016_National_Profile_Sweden
- NaPro ENER-2016-809-0-0-EN-TRA-0 (Hungary)
- 2016_National_Profile_Hungary
- 2016_National_Profile_Romania
- NucInfoDay 2017, “Acceptanta publica, o etapa esentiala in derularea proiectului DFDSMA”, 14 – 15 septembrie 2017, Consiliul Judetean Constanta
- National report Belgium, Ares(2015)3484035 – 24/08/2015
- EC SWD(2017) 158
- 2016_National_Profile_Lithuania
- Program ENER-2015-00790-00-00-EN-TRA-00 -Lithuania
- http://www.andra.fr/download/site-principal/document/editions/201b.pdf

2. Sweden

The facilities that are in operation today are the interim storage facility for spent nuclear fuel (Clab), the final repository for short-lived radioactive waste (SFR), facilities and near-surface repositories at the nuclear power plants.

What remains to be done for final management of spent nuclear fuel is to construct and commission large parts of the system of facilities needed for final disposal of spent nuclear fuel. This includes a new facility part for encapsulation of the spent nuclear fuel adjacent to Clab (the integrated facility is called Clink), transport casks for shipping encapsulated spent nuclear fuel and a final repository for spent nuclear fuel.

Radioactive Waste Management

For disposal of the low- and intermediate-level waste, SFR needs to be extended, an additional repository – the final repository for long-lived waste (SFL) – needs to be established and containers for transport of long-lived waste need to be procured.

- If SFR closes before SFL, short-lived waste goes to SFL.
- Today, long-lived waste is stored at the nuclear power plants, in Clab and at the Studsvik site. Interim storage of long-lived waste is planned to take place in SFR.

Near-surface repositories are located at the nuclear power plants sites in Forsmark, Oskarshamn and Ringhals. At the Studsvik site, there are similar near-surface repositories for waste from industry, research and medical care.

SFR is located near the Forsmark nuclear power plant. The repository is situated beneath the Baltic Sea, covered by about 60 metre of rock. Two one-kilometre-long access tunnels lead from the harbour in Forsmark to the repository area. The facility consists today of four 160-metre-long rock vaults, plus a 70-metre-high rock cavern in which a concrete silo has been built. The facility's total storage capacity is 63 000 cubic metres. The design of each waste vault is adapted based on the activity level of the waste that is deposited.

Low-level waste is disposed in one of the four rock vaults. Intermediate-level waste with lower activity levels is disposed in two of the rock vaults. The intermediate-level waste with the highest activity levels is disposed in the fourth rock vault. The silo will contain most of the radioactive elements in SFR.

SFR's disposal capacity will be extended to provide room for additional short-lived waste from both operations and decommissioning.

SFL will be the last final repository in the nuclear waste system to be commissioned. The design of the repository is in an early stage. A proposed repository concept is being evaluated at present with respect to post-closure safety. The assumption used in the reference and financing scenario is that the repository will be located adjacent to SFR in Forsmark. With the existing construction and transport tunnels in SFR as a starting point, it is assumed that the facility will be sited at a depth of approximately 300 m.

The storage capacity of SFL will be relatively small compared with SKB's other final repositories. The total storage capacity is estimated to be about 16 000 cubic metres. The proposed repository concept includes two repository parts, one for core components from the NPPs and one for legacy waste from AB SVAFO and Studsvik Nuclear AB. The core components, which are metallic waste, comprise about one-third of the volume, but contain (initially) the main part of the radioactivity.

Spent fuel management

The interim storage facility for spent nuclear fuel, Clab, was commissioned in 1985 and is situated adjacent to the nuclear power plant in Oskarshamn. The facility consists of a receiving section at ground level and a storage section more than 30 metres below the ground surface. In the receiving section, the transport casks with spent nuclear fuel are received and unloaded under water.

Before the spent nuclear fuel is disposed of, it will be encapsulated in copper canisters. SKB plans to do this in a new facility part adjacent to Clab. When this encapsulation part has been connected with Clab, the two parts will be operated as an integrated facility, Central interim storage and encapsulation plant for spent fuel, Clink.

After evaluation of the site investigations, SKB selected Forsmark as the site for the Final Spent Fuel Repository.

The final repository will consist of a surface facility and an underground facility. The underground facility consists of a central area and a number of deposition areas plus connections to the surface facility in the form of a ramp for vehicle transport and shafts for elevators and ventilation.

The deposition areas, which together comprise the repository area, will be located about 470 metres below ground and consist of a large number of deposition tunnels with bored deposition holes at the floor of the tunnels.

After the canisters have been emplaced in the deposition holes, surrounded by bentonite clay, the tunnel is backfilled with clay that will swell in contact with water and sealed with a concrete plug. When all fuel has been deposited, other openings are also backfilled and the surface facilities are decommissioned.

3. Hungary

Hungary has three nuclear facilities generating spent fuel: Paks Nuclear Power Plant (VVER -440), the Budapest Research Reactor in the Centre for Energy Research of the Hungarian Academy of Science (Budapest Research Reactor), and the Training Reactor of the Institute of Nuclear Techniques at Budapest University of Technology and Economics (Training Reactor).

Radioactive waste management

The solid and liquid radioactive wastes that are generated during the operation of the nuclear power plant are processed and temporarily stored in the plant. In addition to these wastes, radioactive wastes are generated in research institutes, in medical, industrial, and agricultural institutions and in laboratories.

The repository for institutional low and intermediate level radioactive wastes, the Radioactive Waste Treatment and Disposal Facility (radioactive waste from institutions) is situated at Püspökszilágy some 40 km north-east of Budapest. The repository is a typical near-surface facility, composed of concrete trenches (vaults) and shallow wells for spent sealed sources.

The low-level, solid waste from the Paks Nuclear Power Plant was transported to the repository in Püspökszilágy only as a provisional solution.

To find a solution for the final disposal of LLW/ILW, a proposal was made to carry out further exploration for a geological disposal site in granite in the vicinity of Bátaapáti about 45 km south-west of Paks. As the first phase of the construction of the repository, the above-surface facilities were completed in 2008. It has enabled the temporary storage of solid waste from the nuclear power plant. The competent Radiation Health Centre of the National Public Health and Medical Officer Service granted a licence for commissioning the National Radioactive Waste Repository (radioactive waste from nuclear power plants) on 25 September 2008.

The first two disposal shafts were completed by the end of 2011 (I-K1, I-K2); in 2012 the licensing authority granted the operating licence for the completed portion of the National Radioactive Waste Repository.

High level and/or long-lived radioactive waste is generated through the management of spent fuel, and cannot be finally disposed in the NRWR or RWTDF. These radioactive wastes will have to be finally disposed of later in the deep geological repository to be set up in Hungary

Spent fuel management

Based on analyses a decision was made that Hungary considers the direct disposal of the spent fuel as a reference scenario.

In the future, it might become necessary to revise and amend the long-term policy as well as the reference scenario taking into consideration the tasks arising from the implementation of the two new nuclear power plant units planned at the site of the Paks NPP.

Between 1989 and 1998, Hungary repatriated most of its spent fuel to the Soviet Union (later to Russia). However, in the 1990s, deviating from the stipulations of the original agreement – albeit in line with international practice – the Russian party requested that Hungary take back the radioactive waste and other by-products generated in the course of reprocessing. However, Hungary was not – and is still not – able to dispose of high-level or long-lived radioactive waste.

That was why the licensing and construction of the Interim Spent Fuel Storage Facility ('ISFS facility') commenced in 1993. The power plant commissioned British company GEC Alsthom to build the dry storage facility of a modular type. One advantage of this type of storage construction and storage technology is that the number of storing chambers can be increased in a modular system. The ISFS is a building on the surface, in which the fuel elements are placed individually in closed steel tubes of vertical position, thick walls and hermetic closing. The tubes stand in vaults surrounded by concrete walls. The concrete vault around the storing tubes provides proper shading against radiation.

The facility providing storage for spent fuel offers a solution for storing the assemblies in Hungary for 50 years.

The spent fuel from the BRR and Training Reactor might be the subject of future repatriation to Russia, if this option were available at the time of decommissioning. Currently, after having repatriated the former used highly enriched spent fuel to the Russian Federation, the storage facility is empty.

The deep geological repository suitable for high level and long lived wastes is in the phase of selecting a site.

4. Romania

Cernavoda NPP Units 1 and 2 (CANDU reactors) are located at 1 km distance of Cernavoda town, close to the Danube River, with the following management facilities on the site:

- Spent Fuel Handling System (for each unit);
- Interim Spent Fuel Dry Storage Facility - DICA.

ICN Pitesti, the operator of TRIGA reactor, has the following spent fuel management facilities:

- Spent Fuel Pool;
- Dry Storage Pits.

IFIN-HH is the owner of VVR-S reactor, which is under decommissioning. Now, there is no nuclear fuel on site. The entire inventory of spent nuclear fuel has been shipped back to the country of origin, the Russian Federation.

<u>Radioactive waste management</u>

- CNE Cernavoda has the designated facilities for proper current management of its operational radioactive wastes. After pre-treatment (collection, segregation, decontamination) and treatment (compaction or shredding, as appropriate), the solid wastes (except spent resins and reactivity control rods) are confined in 220L stainless steel drums (type A container) and transported to the Solid Radioactive Waste Interim Storage Facility – DIDR, on the NPP's site.
- ICN Pitesti (TRIGA reactor): the management of own radioactive wastes is performed at ICN Pitesti;

- FIN-HH: the management of the institutional radioactive wastes is performed at IFIN–HH through a specialised department. The Radioactive Waste Management Department (DMDR) is the operator of two important facilities at the national scale:
  - Radioactive Waste Treatment Plant (STDR);
  - National Repository for Low and Intermediate Level Waste, Baita – Bihor (DNDR) – disposal.

The implementation of the Romanian national strategy for radioactive waste management aims to create an operating repository for low- and intermediate-level radioactive waste (DFDSMA) by 2020 at the Saligny site. It is planned that the first phase will be built and licensed for waste disposals starting in around 2026. The second and subsequent phases will be constructed on a schedule depending on the rate at which waste arises in future. The facility will be suitable to accommodate short-lived radioactive waste originating from operation and decommissioning of four units at Cernavoda NPP assuming 30 to 40 years of operational lifetime per unit. The concept proposed for disposal of the waste is a near-surface repository with multiple barrier system.

The disposal of institutional radioactive waste is performed in the National Repository for Low and Intermediate Level Wastes Baita – Bihor (DNDR Baita). The repository is located at an elevation of 840m in two disused exploration galleries of the Baita uranium mine; the first waste disposals were made in 1985 and it is assumed that disposals will continue until 2040.

Spent fuel management

The Interim Spent Fuel Dry Storage Facility (DICA): After at least six years in the wet storage facility, the spent fuel is transferred to the dry storage facility. Due to the limited capacity of the wet storage facility, dry storage facilities were constructed on the CNE Cernavoda site.

DICA is located at around at 700 m SW-W from the first reactor, close to the envelope of the initially fifth planned reactor on-site.

The DICA was designed to accommodate the spent fuel generated from 30 years operation of the 2 CANDU units. The first module of DICA was put into operation in 2003, the second in 2006, the third module in 2008, and the fourth has been in operation since 2010.

According to the National Strategy for RW management, a geological repository should be available for HLW and SF disposal by 2055.

The total anticipated volume of wastes considered for geological disposal is 95% spent fuel from the Cernavoda NPP. Note that Government policy is for all spent fuel from the research reactors to be repatriated under an agreement, and so will not be disposed in Romania.

5. Belgium

About 70% of the radioactive waste generated today in Belgium derives from the nuclear power generation activities (7 PWR reactors). Nuclear industry waste is generated during nuclear power plant operations, the reprocessing of spent fuel is carried out by Orano (formerly COGEMA) in France, uranium and MOX fuel fabrication, and decommissioning. The remaining 30% of Belgian radioactive waste is generated by nuclear research, production of radioisotopes by the National Institute for Radioisotopes (IRE), the use of such isotopes in medicine, industry and in private laboratories, and the European Joint Research Centre's Institute for Reference Materials and Measurements (IRMM).

Radioactive waste disposal

The national policy in terms of the long-term management of category A (LILW-SL) waste is surface disposal on the territory of the municipality of Dessel. This solution is designed to ensure long-term passive safety. Surveillance and monitoring of the facility for a period of more than 100 years is foreseen as part of the strategy for long-term safety. The disposal project itself comprises mainly a modular repository, composed of adjoining modules in reinforced concrete designed to receive monoliths, in other words concrete caissons in which waste packages or bulk waste have been immobilized in mortar.

For over 40 years, SCK-CEN and ONDRAF/NIRAS have been studying geological disposal in poorly indurated clay as a solution for the long-term management of high-level waste and low- and intermediate-level waste, long-lived (HLW/LILW-LL or category B&C waste).

ONDRAF/NIRAS proposed the basis of a national policy for B&C waste to its supervising authority in May 2015; this proposal was based on the technical solution recommended in the Waste Plan, namely geological disposal in poorly-indurated clay on a single site. In November 2016, ONDRAF/NIRAS was entrusted by its supervising authority with adaptation its proposal.

Spent fuel management

Seven commercial nuclear reactors of the PWR type are operated in Belgium, leading to approximately 5 000 tHM spent fuel to be unloaded during 40 years of operation. Until the mid-nineties the Belgian strategy for the management of the back end of the fuel cycle was the reprocessing of spent fuel from all commercial nuclear power reactors. This policy led to the reprocessing of 672 tHM of spent uranium-oxide fuel type by COGEMA (now Orano) at La Hague: the last Belgian fuel elements sent to La Hague were reprocessed in late 2001.

Currently, commercial spent fuel is separately stored in dedicated facilities on the sites of the nuclear power plants (pool storage in Tihange and dry storage in Doel). The main assumptions are as follows:

- The Doel 1 and 2 and the Tihange 1 commercial nuclear reactors will be operated during 50 years and the four other reactors will be operated during 40 years;
- A total of about 1 000 tHM spent fuel from commercial nuclear reactors will still be reprocessed (including 66 tHM MOX spent fuel), in addition to the 672 tHM UOX that have already been reprocessed in the past.
- The spent fuel from the BR02 zero-power reactor was reconditioned by CERCA, a subsidiary of Orano, which fabricated new assemblies for the BR2 reactor.
- The spent fuel from the BR2 reactor is considered a resource and, hence, is subject to reprocessing. The intermediate-level and high-level reprocessing waste generated so far has been conditioned on the sites of the reprocessing facilities (first at UKAEA Dounreay (now DSRL), then at COGEMA la Hague (now Orano Cycle)), repatriated to Belgium and taken charge of by ONDRAF/NIRAS. It is stored in ONDRAF/NIRAS building 136 at Belgoprocess. The contract with COGEMA, signed

in 1997, required a bilateral agreement between France and Belgium that was ratified in 2014. It provides for the reprocessing of the BR2 spent fuel delivered at la Hague by 31 December 2025 and for the repatriation of the corresponding reprocessing waste before the end of 2030. It also provides for the transfer of ownership of the residual quantities of uranium and plutonium to Orano Cycle.

- The spent fuel from the Thetis reactor was declared as radioactive waste to ONDRAF/NIRAS by Ghent University and conditioned by Belgoprocess with a view to geological disposal. It is stored in ONDRAF/NIRAS building 155 at Belgoprocess.
- The fuel from the VENUS-F reactor of the GUINEVERE subcritical reactor project does not belong to SCK•CEN. It is supplied by the French Commissariat à l'énergie atomique et aux énergies alternatives (Alternative Energies and Atomic Energy Commission) and will eventually be returned to France.

In view of the existing national policies, the owners of the spent fuel from the commercial nuclear reactors and of the spent fuel from some SCK•CEN reactors will have to propose hypotheses regarding the further use of their spent fuel, this with a view to the later integration of these proposals in the national policies.

6. Lithuania

There is only one nuclear power plant in Lithuania - Ignalina NPP (2 RBMK-1500). The INPP reactors were commissioned in December 1983 and August 1987. After the accident at Chernobyl, the safety systems were re-evaluated and it was decided to decrease the maximum thermal power of the units from 4800 to 4200 MW. Now both units are being prepared for decommissioning. Unit 1 of INPP was shut down on 31 December 2004 and the second unit of INPP was shut down at the end of 2009 according to the obligations in the Treaty of Accession of Lithuania to European Union.

It should be noted that according to the Law on Nuclear Energy the spent fuel in Lithuania is radioactive waste. Geological disposal is considered the final solution. However, a possibility of shipping the fuel abroad for reprocessing also has to be analysed.

All radioactive waste management facilities in Lithuania are considered nuclear facilities. The operators have to obtain a licence in order to operate these nuclear facilities. All these facilities are situated within the territory of the INPP, with only one exception, the Maišiagala storage facility, which is about 30 km northwest of Vilnius.

Radioactive waste management

VLLW will be disposed of in a licensed landfill facility at the site near Ignalina NPP. The licence for construction and operation of a landfill facility has already been provided by VATESI (State Nuclear Power Safety Inspectorate) to Ignalina NPP.

LILW-SL will be disposed of in a Near Surface Repository (NSR) at the site near Ignalina NPP. LILW-LL will be stored in the storage facilities for LL waste up to the moment of construction of intermediate or deep geological repository. This repository will be constructed along with a deep geological repository for High Level Waste (HLW) or, in the Lithuanian case, along with a geological repository for SF.

The NSR is at the time of writing at the review stage of the Technical Design and PSAR by VATESI (State Nuclear Power Safety Inspectorate). The planned date for start of operations of the NSR 2021.

High Level Waste (HLW) and spent fuel are to be placed in a deep geological repository.

The concept of deep geological repository: a Safety Analysis Report with all necessary studies (the most important geological study is location selection) will be prepared up to 2038.

Institutional waste generators pay for their waste collection, transport, treatment, and storage and disposal services according to a contract with RATA (State Enterprise Radioactive Waste Management Agency). RATA is also an operator of a “Radon type” disposal facility for institutional waste; all waste from this facility will be extracted up to 2023 and will be transferred to the retrieval facilities of INPP and later to the disposal facilities of INPP.

Class D and F waste are divided into two streams: graphite waste from dismantling the reactors and other waste. Graphite waste from the reactor dismantling will be stored in containers in a temporary storage facility. The operation period of this facility is up to 2066. Other Class D and F waste will be sorted by waste types in the Solid Waste Treatment and Storage Facilities (SWMSF). The operational period of SWMSF is 50 years, up to 2068. All Class D and E waste should be disposed of in a Deep Geological Disposal Facility.

Class F waste (Spent Sealed Sources) should be separated from other waste. Separation will be carried out in the Solid Waste Management and Storage Facilities (SWMSF) and then it should be stored in drums within storage within the storage container of SWMSF. All Class F waste should be disposed of in a Deep Geological Disposal Facility.

Spent fuel management

The spent nuclear fuel is stored at INPP by means of two methods. “Wet” storage in spent fuel storage pools near the reactor and “dry” storage in the detached storage facility at the NPP site. The wet storage facility was provided in the initial design of NPP. NPP’s design was developed in the 70s of the last century in the former Soviet Union. It was intended to store the fuel unloaded from the reactor for several years and then to transfer it for processing. In the beginning of the 90s, when it became finally obvious that the matter of spent fuel processing is not considered any more, a decision was made to build a dry type interim storage facility for spent nuclear fuel at INPP and store it for 50 years.

The Deep Geological Disposal facility will be built between 2036 and 2066 in crystalline rock in the south eastern part of Lithuania.

7. France

Agence national pour la gestion des déchets radioactifs, « Les colis de déchets radioactifs au centre de stockage FMA de l’Aube - Un stockage sélectif et maîtrisé ».

8. Salary

European average salary = EUR 30.34 per hour

	Eurostat Salary (per hour)	Correction Salary Factor
AT	34.06	1.12
BE	39.65	1.31
BG	4.93	0.16
CY	15.97	0.53
CZ	11.27	0.37
DE	34.09	1.12
DK	42.48	1.40
EE	11.74	0.39
EL	14.52	0.48
ES	21.17	0.70
FI	32.72	1.08
FR	35.97	1.19
HR	10.64	0.35
HU	9.11	0.30
IE	30.97	1.02
IT	28.17	0.93
MT	13.79	0.45
NL	34.77	1.15
LT	8.00	0.26
LU	37.58	1.24
LV	8.06	0.27
PL	9.36	0.31
PT	14.01	0.46
RO	6.33	0.21
SE	38.33	1.26
SI	17.02	0.56
SK	11.07	0.36
UK	25.68	0.85

Appendix 3: Detailed bottom-up approach to cost assessment indicators, including examples

The aim of this section is to present a more comprehensive list of cost assessment indicators to contribute to the future development of a common ground in cost assessment between the Member States.

As explained in the core of the report, the choice of cost assessment indicators presented below takes into account that Member States are very different in terms of their radioactive waste and spent fuel profile, and that this area is a sensitive one for most countries. Therefore, while we present a more or less extensive list of cost categories, not all are set forward as necessary for an adequate common basis for reporting and cost assessment analysis. Concretely, the sections below specify if the costs are deemed easily reportable, non-commercially sensitive and a key cost assessment indicator.

The different cost indicators are grouped in five categories:

- Quantity-related costs;
- Non-quantity related costs;
- Overhead costs;
- Rates capturing cost escalation and inflation; and
- Rates for unforeseen factors and risks.

To facilitate the understanding of each cost indicator, these are described with a definition, the recommended calculation method, the recommended precision of the timing, any relevant considerations and, when possible, an illustration of reporting from a Member State.

As the costs of the two first categories can be quite disparate depending on the different types of waste stream (HLW, LILW-LL, SF, etc.), these sub-sections are structured in relation to these and the cost indicators identified are customised to them, as relevant. In general, the description of the cost assessment indicators will not vary, so the definition will be presented in the introduction of the sections of these first two categories to avoid repetition. However, the recommended calculation method, the precision of the timing, and the relevant considerations are included and adapted to the different waste streams. We would like to point out that, although these aspects are tailored to the different waste streams, some aspects are still common to all waste streams and, thus, some repetition is to be expected when reading these.

For the examples of practices in the Member States, there is usually not enough sufficiently detailed information provided on the correspondence between costs and the waste stream they are linked to. Therefore, some of the examples are not always waste stream-specific, and in some cases an illustration is not available on the basis of the information received and reviewed. When countries differentiate between waste streams for the specific cost at hand, that is used; otherwise, a general example of how Member States report on the cost assessment indicator in general is given. If the cost is not apparent in the reporting or it is deemed to be unnecessary, then no example is given.

Quantity-related costs

Some of the costs linked to radioactive waste and spent fuel management vary depending on the quantity and type of radioactive waste. Four types of costs correspond to this category and are:

- Construction and design costs represent costs incurred at the initial stages of management of radioactive waste, and should thus be key when reporting. These include all the costs for designing and building civil works to dispose of waste with the appropriate level of safety in the long term. This can include other cost categories, on- and off-site, such as access to infrastructure (e.g. roads, utility connections), boundary fences, service buildings and drainage systems, visitor and public information facilities, etc.
- Transport costs are an important element of the waste management cycle. All costs linked to the transport of radioactive waste from their source to the place of treatment, storage, and/or disposal should be considered. They can include such costs as shipment, rail and truck transport;
- Operational personnel refers to all the operational costs including personnel, monitoring, expenses and transport. These do not include decommissioning costs;
- Decommissioning costs refer to all technical and administrative costs of activities supporting the release of nuclear facilities, clearing (part or all) the regulatory requirements and delivering something apt for other uses.

1. Management of High-Level Waste (HLW)

Relevant quantities

- Quantity of stored waste (cubic metres)
- Quantity of disposed waste (cubic metres)

Design and construction costs

Recommended calculation method:

The basic scope for calculation should include the design and construction costs of:

- new storage facilities (on the NPP site or on a dedicated site or on the reprocessing site),
- the extension or upgrading of existing storage facilities,
- the creation or extension of reprocessing facilities,
- a long-term storage facility (if any),
- a disposal facility (geological repository).

The timing (period of time) for design and construction of each facility should be known from the last National Programme. It is recommended that the costs be estimated as 'overnight' costs at the most recent year of the National Programme (e.g. EUR 2015) [94] to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

[94] Please note that EUR 2015 refers to the year to which the current value relates. In this case, it would be an amount that reflects the current value in the year 2015.

It is recommended that HLW be kept for a sufficient time in the storage facilities (10 years minimum) to allow a strong decrease in their thermal emissions before disposal in a geological repository.

Notes/considerations:

We recommend that the costs of searching for a site for a long-term storage facility or for the geological repository be included in this section.

These facilities are of utmost importance for Member States. They necessarily know the figures of these costs. Except for reprocessing facilities where information could be commercially confidential, there is no reason for Member States not to communicate these costs to the European Commission or even to the public.

Example of Member State practices:

While Member States normally have these costs, not all report them entirely and in a clear manner, and very few report them per waste stream. For example, Bulgaria reports on these costs but does not differentiate completely between waste streams. The country is building a storage facility for the long-term storage of HLW from the reprocessing of SNF, HA SIR and ILW-LL. For this activity, the Bulgarian authorities have set 2025 as a deadline and expect to invest around EUR 60 million.[95]

Transport costs

Recommended calculation method:

The basic scope for calculation should include the transport costs of HLW:

- from the reprocessing workshops to the reprocessing site storage facilities,
- from the reprocessing site storage facilities to the long-term storage facility or to the disposal facility (geological repository),
- the design and construction of transport containers.

The timing (period of time) for transportation of HLW should be known from the last National Programme. It is recommended that the costs be estimated as 'overnight' costs at the most recent year of the National Programme (e.g. EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

There is no specific recommendation regarding the timing of transport.

Notes/considerations:

Transportation of HLW is of utmost importance for the concerned Member States. They necessarily know the figures of these costs. However, as there is a competition for the transportation of HLW, the information is commercially confidential and the Member States will probably be reluctant to communicate these costs to European Commission or to the public.

Example of Member State practices:

[95] In addition, Bulgaria is also building a National Disposal Facility for the disposal of low and intermediate level short-lived RAW.

While all Member States transport their radioactive waste for management purposes, very few report on these costs, especially not by waste stream. For example, Sweden does report on these but does not differentiate between waste streams. The Swedish nuclear fuel and waste management company's own ship, Sigrid, transports NPP waste to RAW and SF management facilities located at Oskarhamn and Forsmark, which entails a total cost of EUR 302 million.

Operational personnel

Recommended calculation method:

The basic scope for calculation should include the costs of operational personnel for:

- packaging and storing the HLW in the storage facilities (on the NPP site or on a dedicated site or on the reprocessing site),
- operating the storage facilities,
- operating the reprocessing facilities,
- operating the long-term storage facility (if any) or the disposal facility (geological repository).

The timing (period of time) for operation of each facility should be known from the last National Programme. It is recommended that the costs be estimated as 'overnight' costs at the most recent year of the National Programme (e.g. EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

There is no specific recommendation regarding the timing of operational personnel.

Notes/considerations:

Personnel are not the only quantity-related operational cost; consumable fluids and materials are also quantity-related. However, for the sake of simplicity and because personnel costs are clearly individualised in the accounting systems, we only consider personnel costs in the approximation.

Management of HLW is of utmost importance for the relevant Member States. They necessarily know the figures of these costs; this information is not commercially confidential and there is no reason for Member States not to communicate these costs to the European Commission or even to the public.

Example of Member State practices:

While all Member States have these costs, not all report them in a clear manner and very few reports on them per waste stream. Denmark is an example of a Member State, which reports on operational costs related to staff, by presenting three scenarios of potential prices of these costs, but does not clearly differentiate between waste streams. Denmark's estimations for the long-term storage facility are in the following table:

Table 15 – Estimates of long-term facility costs (operational staff), Denmark

Type of cost	Most likely price DKK million	Minimum price DKK million	Maximum price DKK million
Operational costs related to staff	82.5 (EUR 11.06 million)	55.0 (EUR 7.37 million)	110.0 (EUR 14.75 million)

Decommissioning costs (storage facilities)

Recommended calculation method:

We consider that the (very limited) stream of HLW coming from the decommissioning of NPPs is in no way different from the HLW mainstream, and is thus included in it. We have only to take into account the decommissioning costs of the facilities utilised for the HLW mainstream; there is no rational reason to apply it to the disposal decommissioning which has no time horizon. Only the decommissioning costs of the storage facilities remain (which are themselves by nature very long-term costs). The timing (period of time) for decommissioning HLW storage facilities should be known from the last National Programme. It is recommended that these costs be estimated as ‘overnight’ costs at the most recent year of the National Programme (e.g. EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

There is no specific recommendation regarding the timing of decommissioning costs.

Notes/considerations:

Decommissioning HLW storage facilities is a far-future operation for the Member States concerned. They probably have an estimate of these costs; this information is not commercially confidential and there is no reason for Member States not to communicate these costs to European Commission or even to the public.

Example of Member State practices:

While Member States have normally estimated these costs, not all report them entirely and in a clear manner, and very few report them per waste stream. Hungary, for example, reports on the estimated costs for the National Radioactive Waste Repository (EUR 64 million) and the Radioactive Waste Treatment and Disposal Facility (EUR 44 million), although it does not differentiate the correspondence between the costs and the waste streams.

2. Management of Low Intermediate-Level Waste –Long Lived (LILW-LL)

Relevant quantities

- Quantity of stored LILW-LL (cubic metres) and /or LL radioactive sources
- Quantity of disposed LILW-LL (cubic metres) and /or LL radioactive sources.

Design and construction costs

Recommended calculation method:

The basic scope for calculation should include the design and construction costs of:

- new storage facilities (on the NPP site or fuel cycle facility site on a dedicated site),
- the extension or upgrading of existing storage facilities,
- the design and construction of a specific disposal facility or of a dedicated part in a geological repository.

The timing (period of time) for design and construction of each facility should be known from the last National Programme. It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g. EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

It is recommended that the final disposal of this waste stream be defined simultaneously with the design of HLW or spent fuel geological repository to optimise the global cost.

Notes/considerations:

We recommend that the costs of searching for a site for a specific disposal facility be included in this section.

These facilities are of utmost importance for Member States but they probably have not yet defined which solution they will use between a dedicated disposal and a dedicated part of a geological repository. They probably have figures of these costs for the two solutions. This information is not commercially confidential and there is no reason for Member States not to communicate these costs to European Commission or even to the public.

Example of Member State practices:

While Member States normally have these costs, not all report them entirely and in a clear manner, and very few report them per waste stream. For example, Poland reports on the costs of both its NSRWR (PLN 243 million) and DRWR (PLN 40 million) until 2025. And while the DRWR is intended for final disposal of long-lived radioactive waste, the NSRWR is intended for both LL and SL LILW and does not differentiate the cost per stream.

Transport costs

Recommended calculation method:

The basic scope for calculation should include the transport costs of LILW-LL:

- from the sites of NPPs under decommissioning to the storage facilities,
- from the sites of fuel cycle or research facilities to the storage facilities,
- from the locations of LL radioactive sources to the storage facilities,
- from the storage facilities to the dedicated disposal facility or geological repository,
- the design and construction of transport containers.

The timing (period of time) for transportation of LILW-LL should be known from the last National Programme. It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g. EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

Adapted containers must be available, on time and in sufficient quantities, when the need for transportation is imperative.

Notes/considerations:

The volume of these waste sis relatively small and the costs of transportation perhaps not yet estimated. In addition, as there is competition for transportation, the information may be considered commercially confidential and the Member States may be reluctant to communicate these costs to the European Commission and even more to the public.

Example of Member State practices:

While Member States have normally estimated these costs, not all report them entirely and in a clear manner, and very few report them per waste stream. No example is available for this type of waste stream.

Operational personnel

Recommended calculation method:

The basic scope for calculation shall include the costs of operational personnel for:

- packaging and storing the LILW-LL in the storage facilities (on the NPP site or on a dedicated site),
- operating the storage facilities,
- operating the dedicated disposal facility or part of the geological repository.

The timing (period of time) for operation of each facility should be known from the last National Programme. It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g. EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

There is no specific recommendation regarding the timing of operational personnel.

Notes/considerations:

Management of LILW-LL is of utmost importance for the Member States concerned. They necessarily know the figures of these costs; this information is not commercially confidential and there is no reason for Member States not to communicate these costs to the European Commission or even to the public.

Example of Member State practices:

While Member States have normally estimated these costs, not all report them entirely and in a clear manner, and very few report them per waste stream. The United Kingdom, for example, reports on the amount of staff costs for the NDA in 2016/17 (GBP 25 million) but without differentiating between waste streams.

Decommissioning costs (storage facilities)

Recommended calculation method:

We consider that the stream of LILW-LL coming from the decommissioning of NPPs (mainly graphite-gas) is in no way different from the LILW-LL mainstream, and consequently is included in it. We have only to take into account the decommissioning costs of the facilities utilized for LILW-LL mainstream; there is no rational reason to apply it to the disposal decommissioning which has no time horizon. Only the decommissioning costs of the storage facilities remain (which are themselves by nature very long-term costs). The timing (period of time) for decommissioning LILW-LL storage facilities should be known from the last National Programme. It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g. EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

There is no specific recommendation regarding the timing of decommissioning costs.

Notes/considerations:

Decommissioning LILW-LL storage facilities is a far-future operation for the Member States concerned. They probably have an estimate of these costs; this information is not commercially confidential and there is no reason for Member States not to communicate these costs to European Commission or even to the public.

Example of Member State practices:

While Member States have normally estimated these costs, not all report them entirely and in a clear manner, and very few report them per waste stream. Germany, for example, reports only on the estimated costs for the disposal facilities (EUR 1.9 billion) but not for other management facilities and without differentiating between waste streams.

3. Management of Low Intermediate-Level Waste - Short-Lived (LILW-SL)

Relevant quantities

- Quantity of stored LILW-SL (cubic metres),
- Quantity of disposed LILW-SL (cubic metres).

Design and construction costs

Recommended calculation method:

The basic scope for calculation should include the design and construction costs of:

- new storage facilities (on the NPP sites or fuel cycle or research facilities sites or on a dedicated site),
- the extension or upgrading of existing storage facilities,
- the design and construction of a disposal facility, one shot or through modular extensions.

The timing (period of time) for design and construction of each facility should be known from the last National Programme. It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g. EUR 2015) but the short or mid-term horizons of these facilities can legitimate an estimate at nominal costs with plausible escalation rates.

Recommended precision of the timing:

The quantities of LILW-SL and the years when they are generated are predictable and the disposal facilities are generally modular. Thus, there are no special constraints on the precision of the timing.

Notes/considerations:

We recommend that the costs of searching for a site for a disposal facility be included in this section.

The LILW-SL and the associated facilities are the core of the waste management system of a Member State. It involves different operators: electricity utilities, nuclear research centres and the dedicated nuclear waste agency. Each has an estimate of these costs and that means consolidation by the Member State is possible. This information is not commercially confidential but private actors could consider it as confidential if they want to ensure there is strong competition for their construction tenders.

Example of Member State practices:

While Member States normally have these costs, not all report them entirely and in a clear manner, and very few report them per waste stream. Estonia, for example, estimates a EUR 40 million expenditure on the planning and construction of their final disposal site from 2016 to 2050, but no other information is available.

Transport costs

Recommended calculation method:

The basic scope for calculation should include the transport costs of LILW-SL:
- from the sites of NPPs or fuel cycle or research facilities to the storage facilities,
- from the storage facilities to the disposal facility,
- the design and construction of transport containers.

The timing (period of time) for transportation of LILW-SL should be known from the last National Programme. It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g. EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

Adapted containers must be available, on time and in sufficient quantities, when the need for transportation is imperative.

Notes/considerations:

The volume of these wastes is significant and the costs of transportation well estimated as Member States can rely on decades of return of experience. This information is not commercially confidential and there is no reason for Member States not to communicate these costs to European Commission or even to the public.

Example of Member State practices:

While Member States have normally estimated these costs, not all report them entirely and in a clear manner, and very few report them per waste stream. No example is available for this type of waste stream.

Operational personnel

Recommended calculation method:

The basic scope for calculation should include the costs of operational personnel for:
- packaging and storing the LILW-SL in the storage facilities (on the NPP sites or on the fuel cycle or research facilities sites, or on a dedicated site),
- operating the storage facilities,
- operating the disposal facility.

The timing (period of time) for operation of each facility should be known from the last National Programme. It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g. EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

There is no specific recommendation regarding the timing of operational personnel costs.

Notes/considerations:

The LILW-SL and the associated facilities are the core of the waste management system of a Member State. It involves different operators: electricity utilities, nuclear research centres and the dedicated nuclear waste agency. Each has an estimate of these costs and that means consolidation by the Member State is possible. This information is not commercially confidential and there is no reason for Member States not to communicate these costs to European Commission or even to the public.

Example of Member State practices:

While Member States have normally estimated these costs, not all report them entirely and in a clear manner, and very few report them per waste stream. In Italy, for example, the costs related to personnel were estimated at about EUR 1.6 billion in 2014, but these are not presented per waste stream.

Decommissioning costs (storage facilities)

Recommended calculation method:

We consider that the stream of LILW-SL coming from the decommissioning of NPPs is in no way different from the LILW-SL mainstream, and consequently is included in it. We have only to take into account the decommissioning costs of the facilities utilised for LILW-SL mainstream; there is no rational reason to apply it to the decommissioning of the disposal facility which has a very-long-term time horizon. Only the decommissioning costs of the storage facilities remain (which are themselves by nature long-term costs). The timing (period of time) for decommissioning of LILW-SL storage facilities should be known from the last National Programme. It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g. EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

There is no specific recommendation regarding the timing of decommissioning costs.

Notes/considerations:

Decommissioning LILW-SL storage facilities are mid- and long-term operations for the actors concerned. They probably have an estimate of these costs; this information is not commercially confidential and there is no reason for Member States not to communicate these costs to European Commission or even to the public.

Example of Member State practices:

While Member States have normally estimated these costs, not all report them entirely and in a clear manner, and very few report them per waste stream. Lithuania, for example, reports only the expected decommissioning costs of Maišiagala (EUR 4 million), but no information is available for the other facilities, nor per waste stream.

4. Management of Very Low Level Waste (VLLW)

Relevant quantities

- Quantity of stored VLLW (cubic metres),
- Quantity of disposed VLLW (cubic metres).

Design and construction costs

Recommended calculation method:

The basic scope for calculation should include the design and construction costs of:

- new storage facilities (on the NPP sites or fuel cycle or research facilities sites),
- the extension or upgrading of existing storage facilities,
- the design and construction of one or several disposal facilities, one shot or through modular extensions.

The timing (period of time) for design and construction of each facility should be known from the last National Programme. It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g. EUR 2015) but the short- or mid-term horizons of these facilities can legitimate an estimate at nominal costs with plausible escalation rates.

Recommended precision of the timing:

The management of VLLW can encounter a bottleneck in countries where there is no exemption threshold as the volumes of VLLW created by decommissioning operations are very important. Thus the timing for making the facilities available needs to be coherent with the timing of the decommissioning operations (NPPs, research reactors, fuel cycle and other facilities).

Notes/considerations:

We recommend that the costs of searching for a site for a disposal facility be included in this section.

The VLLW and the associated facilities are a simple but voluminous part of the waste management system of a Member State. They involve different operators: electricity utilities, nuclear research centres and the dedicated nuclear waste agency. Each has an estimate of these costs and that means consolidation by the Member State is possible. This information is not commercially confidential but private actors could consider it as confidential if they if they want to ensure there is strong competition for their construction tenders.

Example of Member State practices:

While Member States normally have these costs, not all report them entirely and in a clear manner, and very few report them per waste stream. France, for example, only makes available the costs of investment in the future deep geological disposal, which amount to EUR

25 billion (EUR 2011), but information on other construction costs and the differentiation per waste stream are not available.[96]

Transport costs

Recommended calculation method:

The basic scope for calculation shall include the transport costs of VLLW:

- from the sites of NPPs or fuel cycle or research facilities under decommissioning to the storage facilities,
- from the storage facilities to the disposal facilities,
- the design and construction of transport containers.

Recommended precision of the timing:

Adapted containers must be available, on time and in sufficient quantities, when the need for transportation is imperative.

Notes/considerations:

The volume of these waste is very important and the costs of transportation well estimated as concerned Member States can rely on at least a decade of return of experience. This information is not commercially confidential and there is no reason for Member States not to communicate these costs to European Commission or even to the public.

Example of Member State practices:

While Member States have normally estimated these costs, not all report them entirely and in a clear manner, and very few report them per waste stream. No example is available for this type of waste stream.

Operational personnel

Recommended calculation method:

The basic scope for calculation shall include the costs of operational personnel for:

- packaging and storing the VLLW in the storage facilities (on the NPP sites or on the fuel cycle or research facilities sites),
- operating the storage facilities,
- operating the disposal facilities when any.

[96] The Member State has more recent data which it has not been possible to integrate to ensure a consistent and timely analysis, such as:

- Total RW (including RW resulting from SNF reprocessing) management costs are around EUR 48.6 billion (EUR 2017)
- Total SF management costs are around EUR 24.9 billion (EUR 2017)
- Total decommissioning costs are around EUR 47.7 billion (EUR 2017)
- VLLW disposal costs are around 500€/m3 (1200 €/m3 including processing and transportation) and the expected VLLW volumes (including VLLW created by decommissioning operations) are around 2200000 m3.

The timing (period of time) for operation of each facility should be known from the last National Programme. It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g. EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

There is no specific recommendation regarding the timing of decommissioning costs.

Notes/considerations:

The VLLW and the associated facilities are a simple but voluminous part of the waste management system of a Member State. They involve different operators: electricity utilities, nuclear research centres and the dedicated nuclear waste agency. Each has an estimate of these personnel costs and that means consolidation by the Member State is possible. This information is not commercially confidential and there is no reason for Member States not to communicate these costs to European Commission or even to the public.

Example of Member State practices:

While Member States have normally estimated these costs, not all report them entirely and in a clear manner, and very few report them per waste stream. No example is available for this type of waste stream.

Decommissioning costs (storage facilities)

There is no need to decommission VLLW storage or disposal facilities.

5. Management of spent fuel (SF)

Relevant quantities

- Quantity of stored spent fuel (tHM)
- Quantity of disposed spent fuel (tHM)

Design and construction costs

Recommended calculation method:

The basic scope for calculation should include the design and construction costs of:

- new wet storage facilities (on the NPP sites or on nuclear research centres or on the reprocessing site),
- new dry storage facilities (on the NPP sites or on nuclear research centres),
- the extension or upgrading of existing storage facilities,
- the creation or extension of reprocessing facilities,
- the design and construction of a long-term storage facility (if any),
- the design and construction of a disposal facility (geological repository).

The timing (period of time) for design and construction of each facility should be known from the last National Programme. It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g. EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

The clogging of the pools close to the NPPs is the main danger in spent fuel management. However, the evolution of the quantity of spent fuel is fully predictable. Therefore the timing of the construction of new storage capacities (on NPP sites or centralised) need to be coherent with this evolution. From a long-term perspective decisions on the construction of a geological repository are less constrained by the management of spent fuel but political orientations and public acceptance are of major importance.

Notes/considerations:

We recommend that the costs of searching for a site for a long-term storage facility or for the geological repository be included in this section, if not in the HLW section.

These facilities are of utmost importance for Member States. They involve different operators: electricity utilities, nuclear research centres and the dedicated nuclear waste agency. Each has an estimate of these costs and that means consolidation by the Member State is possible. Except for reprocessing facilities where information could be commercially confidential, there is no reason for Member States not to communicate these costs to European Commission or even to the public.

Example of Member State practices:

While Member States normally have these costs, not all report them entirely and in a clear manner, and very few report them per waste stream. Poland reports on the estimated costs of construction of the repository of high-level radioactive waste and spent nuclear fuel (PLN 4 640 million) but does differentiate between HLW and SF.

Transport costs

Recommended calculation method:

The basic scope for calculation should include the transport costs of spent fuel:

In the event of reprocessing:

- from the NPP or research reactor sites to the reprocessing facilities,
- from the reprocessing workshops to the reprocessing site storage facilities,
- from the reprocessing site storage facilities to the long-term storage facility or to the disposal facility (geological repository),
- the design and construction of transport containers,
- the costs of reprocessing if it is done in a foreign country.

In the event of no reprocessing:

- from the NPP or research reactor sites to the storage facilities,
- from the storage facilities to the long-term storage facility or to the disposal facility (geological repository),
- the design and construction of transport containers.

The timing for transportation of spent fuel should be known from the last National Programme. It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (ex: EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

Suitable containers must be available, on time and in sufficient quantities, when the need for transportation is imperative.

Notes/considerations:

Transportation of spent fuel is of utmost importance for the Member States concerned. They necessarily know the figures of these costs. However, as there is a competition for the transportation of spent fuel, the information is commercially confidential and the Member States will probably be reluctant to communicate these costs to European Commission or to the public.

Example of Member State practices:

While all Member States transport their radioactive waste for management purposes, very few report on these costs, and in particular do not differentiate them by waste stream. However, detailed information on spent fuel is more frequently reported on. For example, Slovakia reports in detail the costs for transporting spent fuel from the different nuclear power plants to the interim storage facility in Jaslovské Bohunice. The table below shows these detailed costs:

SNF transport costs							
	2015	2016	2017	2018	2019	2020	After 2020
V2 NPP - 40-year operation							
Transport cost - 2014 prices (EUR thousand)	525.87	262.93	525.87	394.40	394.40	262.93	3 944.01
Transport cost - nominal prices (EUR thousand)	536.39	273.56	558.06	426.91	435.45	296.11	4 885.38
EM012 - 40-year operation							
Transport cost - 2014 prices (EUR thousand)	362.93	494.40	494.40	494.40	362.93	231.47	14 085.89
Transport cost - nominal prices (EUR thousand)	370.19	514.37	524.66	535.16	400.71	260.67	20 366.32
EM034 - 40-year operation							
Transport cost - 2014 prices (EUR thousand)							19 450.17
Transport cost - nominal prices (EUR thousand)							32 899.18

SNF transport costs							
	2015	2016	2017	2018	2019	2020	After 2020
TOTAL in 2014 prices (EUR thousand)	888.80	757.34	1 020.27	888.80	757.34	494.40	37 480.08
TOTAL in nominal prices (EUR thousand)	906.58	787.93	1 082.72	962.07	836.16	556.78	58 480.08

Source: National policy and national programme strategy (Slovakia) – p.72 of the national programme

Operational personnel

Recommended calculation method:

The basic scope for calculation should include the costs of operational personnel for:

- storing the spent fuel in the storage facilities (on the NPP site or on a dedicated site or on the reprocessing site),
- operating the storage facilities,
- operating the reprocessing facilities,
- operating the long-term storage facility (if any) or the disposal facility (geological repository).

The timing (period of time) for operation of each facility should be known from the last National Programme. It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (ex: EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

There is no specific recommendation regarding the timing of personnel costs.

Notes/considerations:

Personnel are not the only quantity-related operational cost; consumable fluids and materials are also quantity-related. However, for the sake of simplicity and because personnel costs are clearly individualised in the accounting systems, we will only use them as an approximation.

Management of spent fuel is of utmost importance for the Member States concerned. They necessarily know the figures of these costs; this information is not commercially confidential and there is no reason for Member States not to communicate these costs to European Commission or even to the public.

Example of Member State practices:

While Member States have normally estimated these costs, not all report them entirely and in a clear manner, and very few report them per waste stream. No example is available for this type of waste stream.

Decommissioning costs (storage facilities)

Recommended calculation method:

The basic scope for calculation should include the costs of decommissioning for:

- the storage facilities of spent fuel (on the NPP sites or on the research reactor sites or on the reprocessing site),
- the reprocessing facilities (if any),
- the long-term storage facility (if any).

The timing (period of time) for the decommissioning of each facility should be known from the last National Programme. It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (ex: EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

There is no specific recommendation regarding the timing of personnel costs.

Notes/considerations:

Decommissioning the storage facilities of spent fuel is a far-future operation for the concerned Member States. Decommissioning the reprocessing facilities needs to receive specific consideration as the strategy may differ between France and the UK. However the reprocessing operators have an estimate of these costs; this information is not commercially confidential and there is no reason for Member States not to communicate these costs to European Commission or even to the public.

Example of Member State practices:

While Member States have normally estimated these costs, not all report them entirely and in a clear manner, and very few report them per waste stream. Denmark, for example, estimates three potential price scenarios for the establishment of a final disposal facility (with a likely price of EUR 4.03 million, minimum price of EUR 2.01 million, and maximum price of EUR 8.06 million), but does not provide a breakdown per waste stream, nor the costs for the long-term intermediate storage facility.

6. Management of NORM waste, exempt waste and materials

In addition to the waste classes mentioned above, the IAEA GSG-1 classification system defines:

- Exempt waste with concentrations of radionuclides small enough not to require provisions for radiation protection. Such material can be cleared from regulatory control and does not require any further consideration from a regulatory control perspective.
- Very short-lived waste containing only very short half-life radionuclides, thus such waste can be stored until the activity has fallen beneath the levels of clearance, allowing the cleared waste to be managed as conventional waste.

The latter two waste classes do not require future long-term management or disposal as radioactive waste due to their short lifetime and/or levels allowing the exemption or clearance from regulatory control. Accordingly, exempt waste and very short-lived waste are in most cases not reported by Member States. Thus, these waste classes have not been used for data aggregation in the Commission's SWD 159 document[97] and we also consider that there is no merit in including them in the definition of Cost Assessment Indicators.

Waste containing naturally occurring radioactive material – NORM (e.g. from uranium mining and milling) is not categorised as radioactive waste in some Member States, although a few Member States declare this waste within the scope of their National Programmes. Considering the huge volume of this waste where it exists, and the non-negligible sensitivity of the local public to its acceptance, we think that it could be useful to set up a minimum of Cost Assessment Indicators for this category of waste.

These CAIs could be reduced to:

- Design and construction costs
- Operational costs

Relevant quantities

- Quantity of disposed NORM waste (cubic metres)

Design and construction costs

Recommended calculation method:

The timing (period of time) for design and construction of each facility should be known from the last National Programme. It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (ex: EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

There is no specific recommendation regarding the timing of personnel costs.

Notes/considerations:

These facilities involve different operators (nuclear fuel cycle companies, oil and industrial companies) and the national nuclear waste agency in charge of establishing the inventory. Each has an estimate of these costs and that means consolidation by the Member State is possible. There is no reason for Member States not to communicate these costs to European Commission or even to the public.

[97] https://ec.europa.eu/energy/sites/ener/files/documents/staff_working_document_progress_of_implementation_of_council_directive_201170euratom_swd2017_159_final.pdf

Operational personnel

Recommended calculation method:

For this category of waste it is not worthwhile to have a detailed granulometry as the figures probably do not exist in the corporate accounting of the operator. This is why the most pertinent indicator shall globally cover the operational costs as a whole. The timing for operating should be known from the last National Programme. It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g. EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

There is no specific recommendation regarding the timing of operational personnel costs.

Notes/considerations:

Different operators (nuclear fuel cycle companies, oil and industrial companies) and the national nuclear waste agency in charge of establishing the inventory are involved. Each has an estimate of these costs and that means consolidation by the Member State is possible. There is no reason for Member States not to communicate these costs to European Commission or even to the public.

Non-quantity related costs

Other types of cost linked to radioactive waste and spent fuel management are invariant to quantity and type of radioactive waste. Four types of costs correspond to this category and are detailed hereunder. These are:

- Allowances for unspecified items are an allocation that added to the cost estimations to cover items that are not considered in the calculations from the start, but that experience shows should be accounted for. This allowance is not to be mistaken for that of unforeseen factors and risks, which concerns circumstances that could take place and could have a financial impact, but for which there is no certainty.
- Operational costs are those costs that are linked to the resources necessary to keep facilities running. Contrary to the operational personnel costs referred to under the quantity-related costs section, these costs are fixed and do not vary on the basis of the degree of waste.
- Compensation to authorities are allowances negotiated with local governments to compensate for establishing nuclear (management) facilities in their area. In some Member States such compensation represents a significant part of the cost, which makes it a crucial category to report on.
- Research and development costs are linked to activities generating the necessary capabilities (in terms of know-how and technologies) to improve and guarantee the performance of the management of waste.

1. Management of High-Level Waste (HLW)

Allowance for unspecified items

Recommended calculation method:

The scope should include at least:

- The uncertainties in the cost of construction projects, depending on the stage of the project (basic design, etc.) and as calibrated in the PMBOK (Project Management Book of Knowledge),
- An allowance to cover delays due to unexpected changes in regulations or political decisions.

It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g. EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

The timing should follow the timing for design and construction of each facility which itself should be known from the last National Programme.

Notes/considerations:

Other than for rare exceptions, these allowances do not officially exist. However, a good approximation of the risks they cover can be given by the calibrated range of uncertainties in the construction projects depending on the stage of design and construction.

Example of Member State practices:

While Member States may have these allowances, none have reported them.

Operational costs

Recommended calculation method:

The scope should include:

- The expenses related to the operations, excluding personnel and transport, e.g.: materials, fluids and other consumables, sub-contracting, small equipment,
- The expenses related to safety and security of operations; radioprotection, environmental surveillance and monitoring, control of access.

It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (ex: EUR 2015).

Recommended precision of the timing:

There is no specific recommendation regarding the timing of operational costs.

Notes/considerations:

As safety and security are intrinsically linked to the operations, it is preferable to take into account the cost of these in the operational costs rather than in overhead costs. In fact, expenses for consumables are partially quantity-related. The decision has been made keep them in this item for the sake of simplicity.

These facilities are of utmost importance for Member States. They necessarily know the figures of these costs. Except for reprocessing facilities where information could be commercially confidential, there is no reason for Member States not to communicate these costs to European Commission or even to the public.

Example of Member State practices:

While Member States have normally estimated these costs, not all report them in a clear manner and very few report on them per waste stream. For example, Poland reports on their costs for operations from 2021-2141 (PLN 30.7 million), but do not differentiate between waste streams.

Compensation to authorities

Recommended calculation method:

The scope should include:

- The financial support provided by the operators or the national waste agency to the local authorities and population to prepare and support the setting up of a reprocessing, or storage or disposal facility, and especially a geological repository. This support can be set by law and/or on a voluntary basis.
- The financial support provided by the operators or the national waste agency to the local authorities and population all along the operations of a reprocessing, or storage or disposal facility. This support can be set by law and/or on an voluntary basis

It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (ex: EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future

Recommended precision of the timing:

The timing should anticipate the construction of the facilities and start as soon as the conceptual design of the project. The compensation will last, with variable funding levels, as long as the facility is in operation, including decommissioning (if any).

Notes/considerations:

Some of these costs are public because they are based on law and regulations. Others are borne by the operators but there is no confidential aspect; therefore, consolidation by the Member State is possible.

Example of Member State practices:

While Member States normally have these costs, not all report them entirely and in a clear manner, and very few report them per waste stream. In the case of Spain, compensation to authorities is not broken down per individual waste stream, but by groups of waste stream. For instance, SF, HLW and ILW are reported together for 2005, and Spain also estimates the costs for 2006, 2007 to 2010 and from 2011 until the expected end of the programme. The table below depicts this approach.

Table 16 – Compensation costs: Spain

EUR	Actual as of 31/12/2005	Estimated 2006	Budget 2007-2010	Estimated 2011-2070	Total
Assignments to town councils	322 552	17 981	72 951	418 242	831 726

Research and development costs

Recommended calculation method:

The scope should include:

- The R&D activities implemented by national research organisations to develop new technologies for treatment, processing and storage, as well as to estimate the impact of the HLW on environment.
- The R&D activities implemented by the national waste agency related to the geological repository.

It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g. EUR 2015).

Recommended precision of the timing:

The timing should significantly anticipate the design of the facilities and last as long as the basic design of the project. Technology improvements related to treatment and processing are continuous.

Notes/considerations:

These costs are well known and can easily be provided by the Member States

Example of Member State practices:

While Member States normally have these costs, not all report them entirely and in a clear manner, and very few report them per waste stream. Belgium reports on its costs for research, development and demonstration (RD&D) activities related to geological disposal, including the costs for their laboratory HADES, but does not differentiate between waste streams. They calculate their expenditures from 1974 to 2014 at approximately EUR 360 million (€2008), more or less EUR 9 million (€2008) per year.

2. Management of Low Intermediate-Level Waste – Long-Lived (LILW-LL)

Allowance for unspecified items

Recommended calculation method:

The scope should include at least:

- The uncertainties in the costs of construction projects, depending on the stage of the project (basic design , etc.) and as calibrated in the PMBOK,

- An allowance to cover delays due to unexpected changes in regulations or political decisions.

It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (ex: EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

The timing should follow the timing for design and construction of each facility which itself should be known from the last National Programme

Notes/considerations:

Other than for rare exceptions, these allowances do not officially exist. However, a good approximation of the risks they cover can be given by the calibrated range of uncertainties in the construction projects depending on the stage of design and construction.

Operational costs

Recommended calculation method:

The scope should include:

- The expenses related to the operations, excluding personnel and transport, e.g.: materials, fluids and other consumables, sub-contracting, small equipment,
- The expenses related to safety and security of operations; radioprotection, environmental surveillance and monitoring, control of access.

It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g. EUR 2015).

Recommended precision of the timing:

There is no specific recommendation regarding the timing of operational costs.

Notes/considerations:

As safety and security are intrinsically linked to the operations, it is preferable to take into account the cost of these in the operational costs than in overhead costs. In fact, expenses for consumables are partially quantity-related. It has been decided to keep them in the current item for the sake of simplicity.

These facilities are of utmost importance for Member States. They necessarily know the figures of these costs. There is no reason for Member States not to communicate these costs to European Commission or even to the public.

Example of Member State practices:

While Member States have normally estimated these costs, not all report them in a clear manner and very few report on them per waste stream. The Czech Republic reports on their yearly operational costs for their for LLW and ILW disposal facilities (Dukovany, Richard, Bratstvi), which amount to CZK 65-75 million.

Compensation to authorities

Recommended calculation method:

The scope should include:

- The financial support provided by the operators or the national waste agency to the local authorities and population to prepare and support the setting up of a specific disposal facility, or of the geological repository. This support can be set by law and/or on a voluntary basis,
- The financial support provided by the operators or the national waste agency to the local authorities and population all along the operations of a disposal facility. This support can be set by law and/or on a voluntary basis.

It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (ex: EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

The timing should anticipate the construction of the facilities and start as soon as the conceptual design of the project. The compensation will last, with variable funding levels, as long as the operation of the facility, including decommissioning (if any).

Notes/considerations:

Some of these costs are public because they are based on law and regulations. Others are borne only by the operators but there is no confidential aspect; therefore, consolidation by the Member State is possible.

Example of Member State practices:

While Member States normally have these costs, not all report them entirely and in a clear manner, and very few report them per waste stream. Slovenia pays compensation to the local communities of Brežice, Krško and Sevnica for the use of space for the storage of LILW (EUR 2.331 million) and reports on it, but it does not specify if the LILW is long-lived or short-lived.

Research and development costs

Recommended calculation method:

The scope should include:

- The R&D activities implemented by the national research organisations to develop new technologies for treatment, processing, storage as well as to estimate the impact of the LILW-LL on the environment,
- The R&D activities implemented by the national waste agency related to a specific disposal or to the geological repository.

It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g. EUR 2015).

Recommended precision of the timing:

The timing should significantly anticipate the design of the facilities and last as long as the basic design of the project. Technology improvements related to treatment and processing are continuous.

Notes/considerations:

These costs are well known and can easily be provided by the Member States.

Example of Member State practices:

While Member States normally have these costs, not all report them entirely and in a clear manner, and very few report them per waste stream. The Netherlands, for example, reports on its costs for the research programmes on geological disposal for high-level waste and long-lived waste, but does not differentiate between both waste streams. The costs reported by the Netherlands for its research programmes are:

- The OPLA (Land Storage) programme costs amounted to EUR 31 million from 1985 to 1993,
- The CORA (Committee on the Disposal of Radioactive Waste) programme costs amounted to EUR 3.5 million from 1996 to 2000, and
- The OPERA (Research Programme Disposal Radioactive Waste) programme costs amounted to EUR 10 million from 2011 to 2016.

3. Management of Low Intermediate-Level Waste – Short-Lived (LILW-SL)

Allowance for unspecified items

Recommended calculation method:

The scope should include at least:

- The uncertainties in the costs of construction projects, depending on the stage of the project (basic design, etc...) and as calibrated in the PMBOK
- An allowance to cover delays due to unexpected changes in regulations or political decisions

It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g. EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

The timing should follow the timing for design and construction of each facility which itself should be known from the last National Programme

Notes/considerations:

Other than for rare exceptions, these allowances do not officially exist. However, a good approximation of the risks they cover can be given by the calibrated range of uncertainties in the construction projects depending on the stage of design and construction.

Example of Member State practices:

While Member States may have these allowances, none have reported them.

Operational costs

Recommended calculation method:

The scope should include:

- The expenses related to the operations, excluding personnel and transport, e.g.: materials, fluids and other consumables, sub-contracting, small equipment,
- The expenses related to safety and security of operations; radioprotection, environmental surveillance and monitoring, control of access.

It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (ex: EUR 2015).

Recommended precision of the timing:

There is no specific recommendation regarding the timing of operational costs.

Notes/considerations:

As safety and security are intrinsically linked to the operations, it is preferable to take into account the cost of these in the operational costs than in overhead costs. In fact, expenses for consumables are partially quantity-related. It has been decided to keep them in the current item for the sake of simplicity.

These facilities are of utmost importance for Member States. They necessarily know the figures of these costs. There is no reason for Member States not to communicate these costs to European Commission or even to the public.

Example of Member State practices:

While Member States have normally estimated these costs, not all report them in a clear manner and very few report on them per waste stream. For example, Poland reports on its costs for operations from 2021-2141 (PLN 30.7 million), but does not differentiate between waste streams.

Compensation to authorities

Recommended calculation method:

The scope should include:

- The financial support provided by the operators or the national waste agency to the local authorities and population to prepare and support the setting up of a disposal facility, or of the geological repository. This support can be set by law and/or on a voluntary basis,
- The financial support provided by the national waste agency to the local authorities and population all along the operations of a disposal facility. This support can be set by law and/or on a voluntary basis.

It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g.: EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

The timing should anticipate the construction of the facilities and start as soon as the conceptual design of the project. The compensation will last, with variable funding levels, as long as the operation of the facility, including decommissioning (if any).

Notes/considerations:

Some of these costs are public because they are based on law and regulations. Others are borne only by the operators but there is no confidential aspect; therefore, consolidation by the Member State is possible.

Example of Member State practices:

While Member States normally have these costs, not all report them entirely and in a clear manner, and very few report them per waste stream. Latvia provided information on the compensation reserved to the municipality holding the facility storing the RAW (Baldone), which was EUR 14 229 annually EUR in 2004-2008, but did not differentiate between waste streams..

Research and development costs

Recommended calculation method:

The scope should include:

- The R&D activities implemented by the national research organisations to develop new technologies for treatment, processing, storage as well as to estimate the impact of the LILW-SL on the environment,
- The R&D activities implemented by the national waste agency related to a disposal.

It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g.: EUR 2015).

Recommended precision of the timing:

The timing should significantly anticipate the design of the facilities and last as long as the basic design of the project. Technology improvements related to treatment and processing are continuous.

Notes/considerations:

These costs are well known and can easily be provided by the Member States.

Example of Member State practices:

While Member States normally have these costs, not all report them entirely and in a clear manner, and very few report them per waste stream. Spain, for example, reports on its R&D expenses for 2005, and its estimates for 2006, 2007 to 2010 and from 2011 until the expected end of the programme, but does not differentiate between waste streams. The table below depicts this approach.

Table 17 – R&D costs: Spain

EUR thousand	Actual as of 31/12/2009	Actual 2010-2011	Forecast 2012	Budget 2013-2016	Estimated from 2017	Total
R&D costs	205 616	8 011	5 736	21 050	167 650	408 063

4. Management of Very Low-Level Waste (VLLW)

Allowance for unspecified items

Recommended calculation method:

The scope should include at least:

- The uncertainties in the costs of construction projects, depending on the stage of the project (basic design , etc.) and as calibrated in the PMBOK;
- An allowance to cover delays due to unexpected changes in regulations or political decisions.

It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g.: EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

The timing should follow the timing for design and construction of each facility which itself should be known from the last National Programme.

Notes/considerations:

Other than for rare exceptions, these allowances do not officially exist. However, a good approximation of the risks they cover can be given by the calibrated range of uncertainties in the construction projects depending on the stage of design and construction.

Example of Member State practices:

While Member States may have these allowances, none have reported them.

Operational costs

Recommended calculation method:

The scope should include:

- The expenses related to the operations, excluding personnel and transport, e.g.: materials, fluids and other consumables, sub-contracting, small equipment,
- The expenses related to safety and security of operations; radioprotection, environmental surveillance and monitoring, control of access.

It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g.: EUR 2015).

Recommended precision of the timing:

There is no specific recommendation regarding the timing of operational costs.

Notes/considerations:

As safety and security are intrinsically linked to the operations, it is preferable to take into account the cost of these in the operational costs rather than in overhead costs. In fact, expenses for consumables are partially quantity-related. It has been decided to keep them in the current item for the sake of simplicity.

The VLLW and the associated facilities are a simple but voluminous part of the waste management system of a Member State. They involve different operators: electricity utilities, nuclear research centres and the dedicated nuclear waste agency. Each has an estimate of these costs and that means consolidation by the Member State is possible. This information is not commercially confidential but private actors could consider it as confidential if they want to ensure there is strong competition for their construction tenders.

Example of Member State practices:

While Member States have normally estimated these costs, not all report them in a clear manner and very few reports on them per waste stream. For example, Portugal reports on its costs for operations of its PRR storage facility, which amount to EUR 150 000 to EUR 200 000 per year, but do not differentiate between waste streams.

Compensation to authorities

Recommended calculation method:

The scope should include:

- The financial support provided by the operators or the national waste agency to the local authorities and population to prepare and support the setting up of a disposal facility. This support can be set by law and/or on a voluntary basis,
- The financial support provided by the national waste agency to the local authorities and population all along the operations of a disposal facility. This support can be set by law and/or on a voluntary basis.

It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g. EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

The timing should anticipate the construction of the facilities and start as soon as the conceptual design of the project. The compensation will last, with variable funding levels, as long as the operation of the facility, including decommissioning (if any).

Notes/considerations:

Some of these costs are public because they are based on law and regulations. Others are borne only by the operators but there is no confidential aspect; therefore, consolidation by the Member State is possible.

Example of Member State practices:

While Member States have normally estimated these costs, not all report them in a clear manner and very few reports on them per waste stream. In the case of VLLW, no Member State specifically reports on the compensation to authorities for this waste stream.

Research and development costs

Recommended calculation method:

The scope should include:

- The R&D activities implemented by the national research organisations to develop new technologies for treatment, processing, storage as well as to estimate the impact of the VLLW on the environment,
- The R&D activities implemented by the national waste agency related to a disposal.

It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g.: EUR 2015).

Recommended precision of the timing:

The timing should significantly anticipate the design of the facilities and last as long as the basic design of the project. Technology improvements related to treatment and processing are continuous.

Notes/considerations:

These costs are well known and can easily be provided by the Member States.

Example of Member State practices:

While Member States normally have these costs, not all report them entirely and in a clear manner, and very few report them per waste stream. Italy, for example, reports on its R&D expenses from 2007 to 2017 (around EUR 5 million) and for the period of 2017 to 2025 (a comparable figure), as well as for the development of the National Repository (EUR 1 billion). However, the data do not differentiate between waste streams.

5. Management of spent fuel (SF)

Allowance for unspecified items

Recommended calculation method:

The scope should include at least:

- The uncertainties in the costs of construction projects, depending on the stage of the project (basic design , etc.) and as calibrated in the PMBOK,
- An allowance to cover delays due to unexpected changes in regulations or political decisions.

It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g. EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

The timing should follow the timing for design and construction of each facility which itself should be known from the last National Programme.

Notes/considerations:

Other than for rare exceptions, these allowances do not officially exist. However, a good approximation of the risks they cover can be given by the calibrated range of uncertainties in the construction projects depending on the stage of design and construction.

Example of Member State practices:

While Member States may have these allowances, none have reported them.

Operational costs

Recommended calculation method:

The scope should include:

- The expenses related to the operations, excluding personnel and transport, e.g.: materials, fluids and other consumables, sub-contracting, small equipment,
- The expenses related to safety and security of operations; radioprotection, environmental surveillance and monitoring, control of access.

It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g.: EUR 2015).

Recommended precision of the timing:

There is no specific recommendation regarding the timing of operational costs.

Notes/considerations:

As safety and security are intrinsically linked to the operations, it is preferable to take into account their costs in the operational costs than in overhead costs. In fact, expenses for consumables are partially quantity-related. It has been decided to keep them in the current item for the sake of simplicity.

These facilities are of utmost importance for Member States. They necessarily know the figures of these costs. Except for reprocessing facilities where information could be commercially confidential, there is no reason for Member States not to communicate these costs to European Commission or even to the public.

Example of Member State practices:

While Member States have normally estimated these costs, not all report them in a clear manner and very few report on them per waste stream. However, detailed information on spent fuel is more frequently reported on. In Lithuania’s case, spent fuel related operational costs for its dry spent fuel interim storage facilities (DSFSF & ISFSF B1) are available and reported on. They amount to EUR 0.33 million per year.

Compensation to authorities

Recommended calculation method:

The scope should include:

- The financial support provided by the operators or the national waste agency to the local authorities and population to prepare and support the setting up of a reprocessing, or storage or disposal facility, and especially a geological repository. This support can be set by law and/or on a voluntary basis,
- The financial support provided by the operators or the national waste agency to the local authorities and population all along the operations of a storage or disposal facility. This support can be set by law and/or on a voluntary basis.

It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g. EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

The timing should anticipate the construction of the facilities and start as soon as the conceptual design of the project. The compensation will last, with variable funding levels, as long as the facility operates, including decommissioning (if any).

Notes/considerations:

Some of these costs are public because they are based on law and regulations. Others are borne only by the operators but there is no confidential aspect; therefore, consolidation by the Member State is possible.

Example of Member State practices:

While Member States have normally estimated these costs, not all report them in a clear manner and very few report on them per waste stream. However, detailed information on spent fuel is more frequently reported on. Croatia estimates its compensation to local communities for the disposal of SF to amount to EUR 66 million from 2043 to 2095.

Research and development costs

Recommended calculation method:

The scope should include:

- The R&D activities implemented by the national research organisations to develop new technologies for processing and storage as well as to estimate the impact of the spent fuel on environment,
- The R&D activities implemented by the national research organisations to develop new technologies for partitioning and transmutation of the HLW in the reprocessing of spent fuel,
- The R&D activities implemented by the national waste agency related to the geological repository.

It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g. EUR 2015).

Recommended precision of the timing:

The timing should significantly anticipate the design of the facilities and last as long as the basic design of the project. Technology improvements related to treatment and processing are continuous.

Notes/considerations:

These costs are well known and can easily be provided by the Member States.

Example of Member State practices:

While Member States normally have these costs, not all report them entirely and in a clear manner, and very few report them per waste stream. Sweden, for example, reports on the expenses for its research laboratories (EUR 562.7 million until the end of their nuclear programme), but does not differentiate between waste streams.

6. Management of NORM waste, exempt waste and materials

Allowance for unspecified items

Recommended calculation method:

The scope should include:

- The uncertainties in the costs of construction projects if any, depending on the stage of the project (basic design, etc.) and as calibrated in the PMBOK,
- An allowance to cover delays due to unexpected changes in regulations or political decisions.

It is recommended that these costs be estimated as overnight costs at the most recent year of the National Programme (e.g. EUR 2015).

Recommended precision of the timing:

The timing should follow the timing for design and construction of each facility if any which itself should be known from the last National Programme.

Notes/considerations:

Other than for rare exceptions, these allowances do not officially exist. However, a good approximation of the risks they cover can be given by the calibrated range of uncertainties in the construction projects depending on the stage of design and construction.

Operational costs

See § 1.5.1.6. above.

Compensation to authorities

Recommended calculation method:

The scope should include:

- The financial support provided by the operators or the national waste agency to the local authorities and population to prepare and support the setting up of a disposal facility. This support can be set by law and/or on a voluntary basis,
- The financial support provided by the national waste agency to the local authorities and population all along the operations of a disposal facility. This support can be set by law and/or on a voluntary basis.

It is recommended that these costs be estimated as overnight costs at the most recent year of the national programme (e.g. EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

The timing should anticipate the construction of the facilities and start as soon as the conceptual design of the project. The compensation will last, with variable funding levels, as long as the facility operates.

Notes/considerations:

Some of these costs are public because they are based on law and regulations. Others are borne only by the operators but there is no confidential aspect; therefore, consolidation by the Member State is possible.

Research and development costs

There are no research costs related to this waste stream.

Overhead costs

When establishing such a cost classification, the costs are mainly classified in the quantity-related and non-quantity related categories. Therefore, only the costs that cannot be clearly allocated to one of the six waste streams will be classified as overhead costs.

Administration costs

Definition:

Administration or administrative costs are those related to general costs necessary to provide for a company and the maintenance of its business, but are not directly linked to a concrete department (e.g. corporate administration and administration of the research centres).

Recommended calculation method:

The scope should include:

- The administration costs of the nuclear operators, which can be allocated to waste and spent fuel management,
- The administration costs of the research institutes, which can be allocated to waste and spent fuel management,
- The administration costs of the national waste agency (or of the several if it is the case),

- The costs of the government departments in charge of consolidation and follow up of waste streams.

It is recommended that these costs be estimated as overnight costs at the most recent year of the national programme (e.g.: EUR 2015).

Recommended precision of the timing:

No need.

Notes/considerations:

Member States can easily obtain and consolidate these costs.

Example of Member State practices:

Most Member States do not seem to report these costs in a distinct manner. The United Kingdom, however, reports on the administration costs as part of the Authority's administration expenditure. This amounted to GBP 15 million in 2015 and GBP 19 million in 2014.

Procurement costs

Definition:

Procurement costs are those costs incurred in the acquisition of the necessary resources to carry out the management of radioactive wastes.

Recommended calculation method:

The scope should include:

- The procurement costs of the nuclear operators which can be allocated to waste and spent fuel management,
- The procurement costs of the research institutes which can be allocated to waste and spent fuel management,
- The procurement costs of the national waste agency (or of several if such is the case).

It is recommended that these costs be estimated as overnight costs at the most recent year of the national programme (e.g.: EUR 2015).

Recommended precision of the timing:

No need.

Notes/considerations:

The Member States can easily obtain and consolidate these costs.

Project management

Definition:

Project management costs are those linked to the everyday management of specific projects.

Recommended calculation method:

The scope should include:

- The costs of the programme management teams of nuclear operators dedicated to waste and spent fuel management and of associated owner engineer teams (if any),
- The costs of the programme management teams of research institutes dedicated to waste and spent fuel management and of associated owner engineer teams (if any),
- The costs of the programme management teams of the national waste agency (or of several where that is the case) and of associated owner engineer teams.

It is recommended that these costs be estimated as overnight costs at the most recent past year of the national programme (e.g.: EUR 2015).

Recommended precision of the timing:

No need.

Notes/considerations:

The Member States can easily obtain and consolidate these costs.

Training/qualification of personnel

Definition:

Training/qualification costs are linked to those activities aimed at passing on knowledge and guidance to the personnel in order to guarantee and/or improve the performance of the management of waste.

Recommended calculation method:

The scope should include:

- The costs of training/qualification of all personnel of nuclear operators dedicated to waste and spent fuel management,
- The costs of training/qualification of all personnel of research institutes dedicated to waste and spent fuel management,
- The costs of training/qualification of all personnel of the national waste agency (or of several if such is the case).

It is recommended that these costs be estimated as overnight costs at the most recent year of the national programme (e.g.: EUR 2015).

Recommended precision of the timing:

No need.

Notes/considerations:

These figures are not broken down in the accounting systems of operators and research institutes; therefore it is not really feasible to require provision of such costs to Member States.

Consultants and expert activities

Definition:

This category includes all expenses dedicated to external experts and consultants contracted for concrete activities or tasks in the management of radioactive waste.

Notes/considerations:

There is no need to require information on these costs as almost all that are relevant to waste management are included in other items (owner engineer services, project management, and procurement costs).

Licensing costs

Definition:

All fees paid to the competent authority to obtain the approval of a licence to undertake the necessary activities to manage radioactive waste. This might include construction permits, operating permits, etc.

Notes/considerations:

There is no need to require provision of these costs as almost all that are relevant to waste management are included in other items (design and construction costs, personnel costs, administrative costs).

Environmental monitoring

Definition:

Environmental monitoring costs include all costs linked to the assessment and supervision to ensure compliance with environmental requirements.

Notes/considerations:

There is no need to require provision of these costs as almost all that are relevant with waste management are included in other items (design and construction costs, personnel costs, administrative costs).

Consumable goods

Definition:

Costs for consumable goods are those linked to products that are frequently used and are worn out after use. In the case of radioactive waste management, these are mainly water, industrial gases, small equipment, detectors, gloves, etc.

Notes/considerations:

There is no need to require provision of these costs as almost all that are relevant to waste management are included in other items (operational costs, administrative costs).

Utilities

Definition:

Utility costs are those costs incurred for water, gas, and electricity, etc., to run the facilities. Contrary to the utility costs under the quantity-related costs, the utility costs under overhead costs are those that will remain regardless of the amount of radioactive waste.

Recommended calculation method:

The scope should include:

- The share of utility costs of nuclear operators that can be allocated to waste and spent fuel management and is not included in the operational costs,
- The share of utility costs of research institutes that can be allocated to waste and spent fuel management and is not included in the operational costs,
- The share of utility costs of the national waste agency (or of the several if it is the case) that is not included in the operational costs.

It is recommended that these costs be estimated as overnight costs at the most recent year of the national programme (e.g. EUR 2015).

Recommended precision of the timing:

No need.

Notes/considerations:

These figures are not broken down in the accounting systems of operators and research institutes; therefore, it is not really feasible to require provision of such costs to Member States.

Data management and preservation of knowledge

Definition:

Data management and preservation of knowledge costs include all costs related to data collection, storage, access, preservation, security, availability and reuse. These can be both employee- and technology-related.

Recommended calculation method:

The scope should include:

- The data management and preservation of knowledge costs of nuclear operators related to legacy waste, and storage and disposal facilities,
- The data management and preservation of knowledge costs of research institutes related to legacy waste and storage and disposal facilities,
- The data management and preservation of knowledge costs of the national waste agency (or of the several if it is the case) related to legacy waste and storage and disposal facilities.

It is recommended that these costs be estimated as overnight costs at the most recent year of the national programme (e.g. EUR 2015) to limit the effect of uncertainties on the escalation rate over a long time and in a far future.

Recommended precision of the timing:

As soon as possible if not yet in place.

Notes/considerations:

These costs are probably not yet broken down in the accounting systems of the waste management actors. However, it is worth to doing this as it is a major issue for long-term storage or disposal facilities.

Example of Member State practices:

While some Member States report that they carry out these activities, none seems to report on the costs, at least separately.

Regulatory costs

Definition:

Regulatory costs refer to those costs incurred to ensure regulatory compliance.

Recommended calculation method:

The scope should include:

- The costs of the Safety Authority and of the Security Authority (if any) that can be allocated to the regulation of waste management,
- The share of the costs of the Technical Support Organisations that can be allocated to the regulation of waste management.

It is recommended that these costs be estimated as overnight costs at the most recent year of the national programme (e.g. EUR 2015).

Recommended precision of the timing:

No need.

Notes/considerations:

The Member States can easily obtain and consolidate these costs.

Example of Member State practices:

While Member States may know these costs, none has reported them.

Rates used for capturing cost escalation and inflation, and discount rates

Inflation rate

Definition:

The inflation rate captures the level at which prices of goods and services increase and consequent purchasing power.

Recommended calculation method (or rate):

The average inflation rate in the Member State during the last three years seems to be the best estimate of the escalation rate during the next 10 years. Beyond that period, the average inflation rate forecast for the EU (e.g. 2%) looks more appropriate. However, it is recommended that the calculation be updated every 3 or 5 years.

Recommended precision of the timing:

No need.

Notes/considerations:

There is no difficulty in obtaining these assumptions from the Member States, as they are the same for all the Member State's actors.

Example of Member State practices:

While Member States normally estimate these rates, not all report them entirely and in a clear manner. In line with the rate forecast for the EU, Bulgaria uses an annual inflation rate of 2 %.

Discount rate

Definition:

The discount rate represents an interest rate to determine the present value of a specific amount of money.

Recommended calculation method (or rate):

When a reference exists in terms of interest earned by the Waste Fund of the Member State during the last three years, the difference between this reference rate and the inflation rate over the same period is the best basis for estimating the discount rate for future years. Experience show that these figures are in the range 1%-2.5%.

Without a point of reference or to remain prudent, we recommend a discount rate of inflation plus 1% (percentage point).

Recommended precision of the timing:

No need.

Notes/considerations:

There is no difficulty in obtaining these assumptions from the Member States, as they are the same for all the Member State's actors.

Example of Member State practices:

While Member States normally estimate these rates, not all report them entirely and in a clear manner. Some examples of discount rates include Hungary's 2.5%, Spain's 1.4% and Slovakia's 1.1%.

Rates for unforeseen factors and risks

Contingency rate

Definition:

The contingency rate is an allowance to account for unforeseeable circumstances and events.

Recommended calculation method (or rate):

There is no single dedicated calculation method for the contingency rate of unforeseen factors and risks. We recommend leaning on well-known engineering cost assessment methodologies (see table below from AACE international) to have an estimate of the unforeseen factors and risks. They are de facto similar to the uncertainties classically taken into account at a specific stage of a project/programme. In the present case we consider that the accuracy of the estimates provided by the Member States generally is around the level of the beginning of class 4 to end of class 3, i.e. -30% to + 30%.

Figure 27 – Comparison of Classification Practices

INCREASING PROJECT DEFINITION

AACE Classification Standard	ANSI Standard Z94.0	AACE Pre-1972	Association of Cost Engineers (UK) ACostE	Norwegian Project Management Association (NFP)	American Society of Professional Estimators (ASPE)
Class 5	Order of Magnitude Estimate -30/+50	Order of Magnitude Estimate	Order of Magnitude Estimate Class IV -30/+30	Concession Estimate Exploration Estimate Feasibility Estimate	Level 1
Class 4	Budget Estimate 15/+30	Study Estimate	Study Estimate Class III -20/+20	Authorization Estimate	Level 2
Class 3		Preliminary Estimate	Budget Estimate Class II -10/+10	Master Control Estimate	Level 3
Class 2	Definitive Estimate -5/+15	Definitive Estimate	Definitive Estimate Class I -5/+5	Current Control Estimate	Level 4
Class 1		Detailed Estimate			Level 5 Level 6

Source: AACE International Recommended Practice No. 18R-97, "Cost estimate classification system – as applied in engineering, procurement, and construction for the process industries".

Example of Member State practices:

While Member States normally account for these rates, not all report them entirely and in a clear manner. In Bulgaria's case, the contingency costs for the main groups of activities in the decommissioning of its units 1 to 4 are reported for the period 2003-2030; however, those for the other units are not. The following table depicts this reporting:

Table 18 – Contingency costs for main activity groups: Bulgaria[98]

Code	Activity	Contingency (EUR million)
01	Decommissioning preparatory activities	376
02	Activities at the time of closure	1 910
03	Supply of equipment and materials	1 689
04	Dismantling activities	13 972

[98] The Member State has more recent data which has not been possible to integrate to ensure a consistent and timely analysis.

Code	Activity	Contingency (EUR million)
05	RAM and RAW treatment and delivery for disposal	21 055
06	Site management and maintenance	10 089
07	Project management and engineering	1 491
08	Fuel and nuclear materials management	0
	TOTAL	50 206

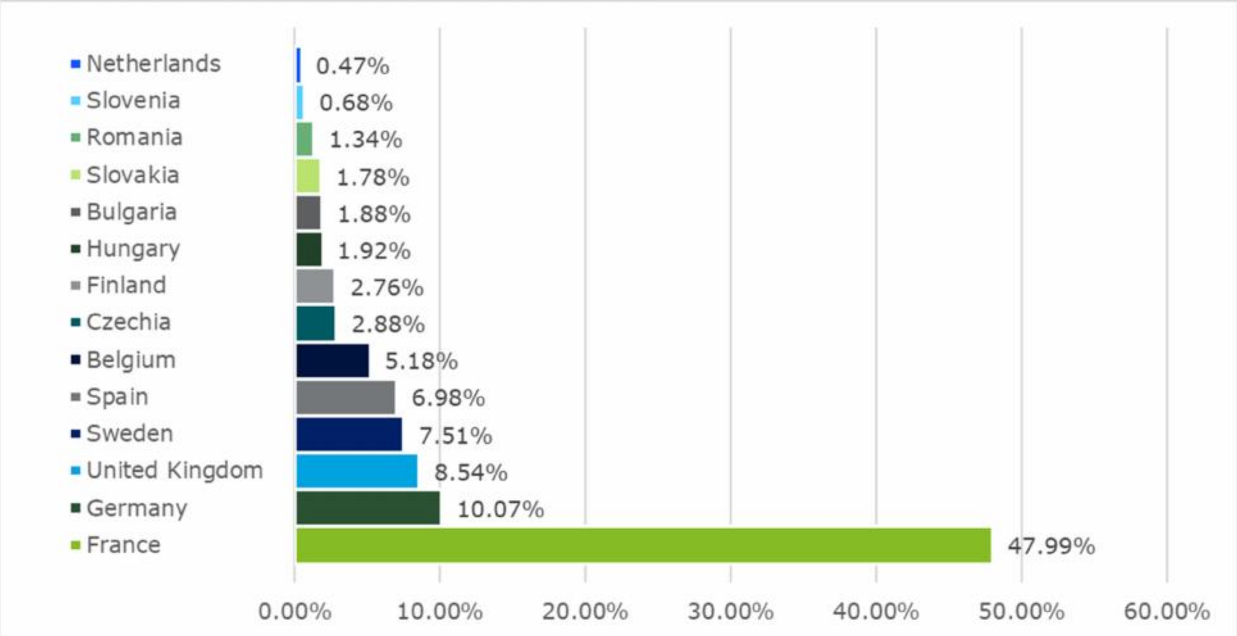
Appendix 4: Overview of the nuclear industry, including radioactive waste and spent fuel

This section provides high-level information on the situation of the nuclear industry in the EU. It also includes indicative figures on radioactive waste and spent fuel storage and disposal in the EU, well as the costs and funding.

The nuclear energy sector in the EU

With 129 nuclear power plants (NPPs) operating in the EU[99], the EU's nuclear fleet is currently the largest in the world. The average age was 29 years. Figure 28 shows that France's 58 NPPs represent the bulk of the EU's nuclear energy output – totalling 48% of total nuclear energy produced in the EU – followed by Germany and the United Kingdom.

Figure 28– Member States' share of total EU nuclear energy generation, 2016



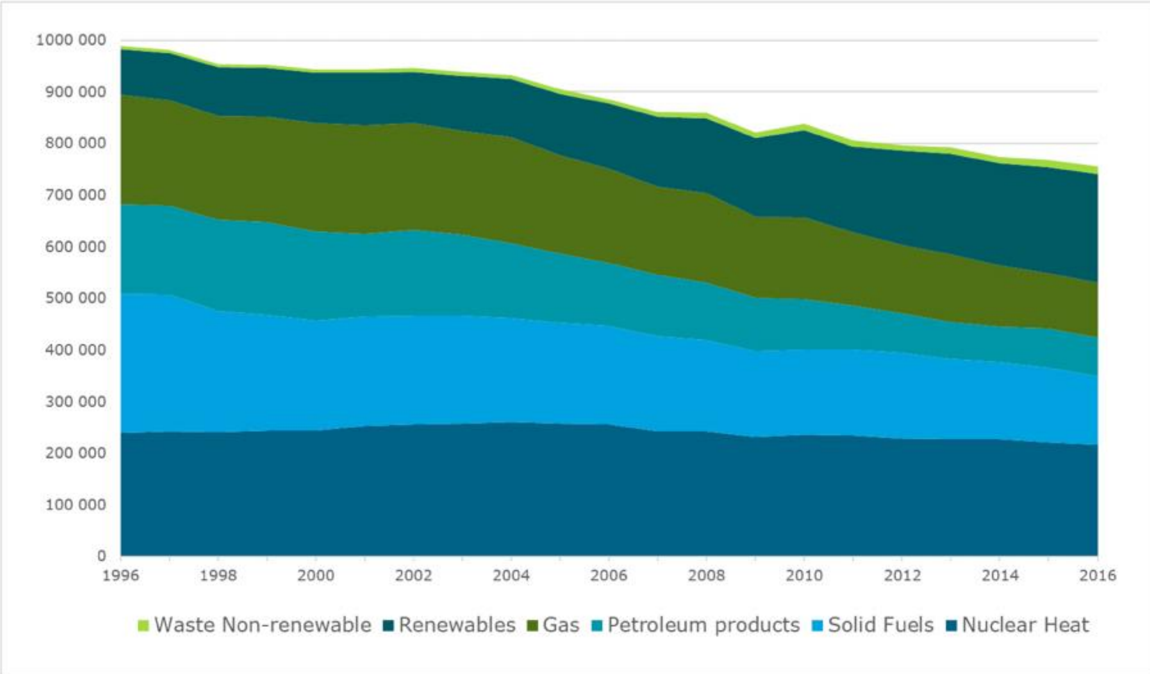
Source: Authors from Eurostat, Energy Statistics – http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_100a&lang=en

The nuclear energy sector is characterised by a medium-term trend of decreasing levels of nuclear energy in the EU. While Eurostat numbers show that the share of primary nuclear energy in the EU's total energy output has remained relatively stable in the last decade – at around 28% of the total – the downward trend can be observed by looking at the data on nuclear heat, this can be explained because total energy output is going down. As shown in

[99] https://ec.europa.eu/energy/sites/ener/files/documents/pinc_staff_working_document_.pdf

Figure 29, nuclear heat consumption peaked in 2004 before decreasing. This dynamic can be explained by several factors, including the shutdown at the time of the 2004 EU enlargement of the EU of eight Soviet-design nuclear power units in Bulgaria, Lithuania and Slovakia, and the policy of some Member States of moving gradually away from nuclear energy (e.g. Belgium and Germany). On the other hand, there are also Member States with a growing share of nuclear energy in their total energy generation.

Figure 29 – Energy mix over time



Source: Authors from Eurostat, Energy Statistics – http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_100a&lang=en

Despite the observed decline in European nuclear energy, the Commission's 2017 Communication on a Nuclear Illustrative Programme (PINC)[100] predicts that the trend will be reversed after 2030. This reversal will reflect both the construction of new nuclear power plants and the extension of the lifetime of others.

The age of the EU's nuclear plants creates a structural need for investment, and the Commission's prediction of a future increase in the output of the nuclear energy sector is accompanied by a call for substantial long-term investment programmes. Estimates from

[100] Commission Staff Working Document accompanying the document "Communication from the Commission on Nuclear Illustrative Programme Presented under Article 40 of the Euratom Treaty - Final (after opinion of EESC)", SWD(2017) 158 final, 12 May 2017; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52017SC0158

2016 suggest that the projected investments in new nuclear capacity from 2015 to 2050 will range between EUR 349 billion and EUR 455 billion[101].

The sources of radioactive waste and spent fuels are mainly:

- Nuclear power plants in operation,
- Fuel cycle facilities,
- Research centres,
- Facilities being decommissioned,
- Storage and disposal facilities,
- Waste treatment and packaging centres,
- Mining/milling tailings,
- Legacy waste,
- A wide range of radioactive sources,
- Hospitals, conventional industries and research activities.

The different phases in the life of nuclear facilities, including nuclear reactors, are broadly the same: publication of the regulatory measure authorising creation of the facility, operational phase, final shutdown, decommissioning phase, de-licensing.

During the operation of a reactor, different types of LLW and ILW are generated. This waste must be conditioned, packaged and stored prior to its disposal. Most of this waste (by volume) has low levels of radioactivity.

At the end of the operating life, a reactor is shut down and eventually dismantled. During dismantling, contaminated and activated components are separated, treated and if necessary managed as radioactive waste; the largest volumes generated are in the VLLW or LLW classes. Smaller volumes of ILW are also generated. Most of the waste (by volume) from dismantling is, however, not radioactive and can be handled as industrial waste, in accordance with national regulations.

Following its use in a reactor, spent fuel is highly radioactive, and is typically transferred to a fuel pool for several years. After this period (sometimes referred to as decay storage), spent fuel is safer and easier to handle and can be transferred to interim storage facilities. Some States reprocess spent fuel, resulting in the reuse of the uranium and plutonium in new fuel, as well as the separation of waste products. Otherwise spent fuels are considered high level radioactive waste (HLW).

[101] These figures comprise both the investment in new capacity and the replacement of shut-downs post-2050. Please note that, in the latter case, “the projection considers that after 2050 the contribution of nuclear energy to the total generation of electricity will remain stable. To achieve that, the construction of several reactors will have to begin before 2050 in order to be connected to the grid after the cut-off date of 2050.” Commission Staff Working Document accompanying the document “Communication from the Commission on Nuclear Illustrative Programme Presented under Article 40 of the Euratom Treaty - Final (after opinion of EESC)”, SWD(2017) 158 final, 12 May 2017; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52017SC0158.

Radioactive waste and spent fuel in the EU

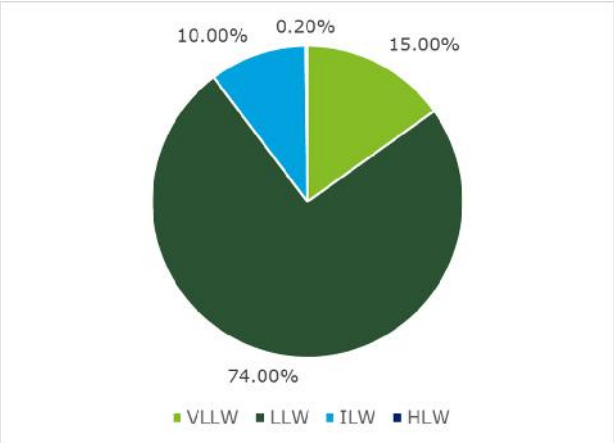
It is currently estimated that 122 000 m³ of radioactive waste is generated every year in the EU from the regular activities of the NPPs, as well as from non-power related uses[102]. The figures in Table 2 below show that over the 2004-2013 period, an average of 66 400 m³ of radioactive waste, excluding spent fuel, was generated each year, corresponding to a 25% increase in the inventory of radioactive wastes over the 10 years. The bulk of this waste is LLW (74%) although VLLW (15%) and ILW (10%) also account for a significant part of the mix.

Table 19 – Radioactive waste inventories (in thousands of m³)

Waste Category	2004	2007	2010	2013
VLLW	210	280	414	516
LLW	2228	2435	2356	2453
ILW	206	288	321	338
HLW	5	4	5	6
Total	2649	3007	3096	3313

Source: Authors from data in Commission Staff Working Document 161 Final, 15 May 2017

Figure 30 – Waste inventory per waste category, end-2013

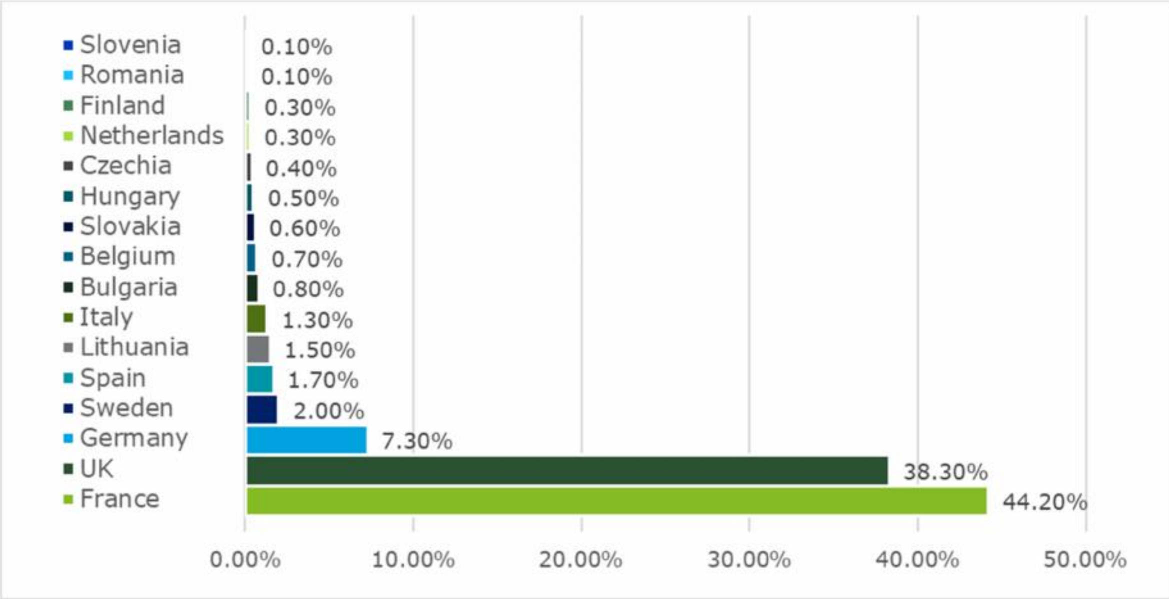


[102] Commission Staff Working Document accompanying the document "Communication from the Commission on Nuclear Illustrative Programme Presented under Article 40 of the Euratom Treaty - Final (after opinion of EESC)", SWD(2017) 158 final, 12 May 2017; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52017SC0158

Source: Authors from data in Commission Staff Working Document 161 Final, 15 May 2017[103]

This radioactive waste is mostly the result of the nuclear energy sector's activity, from regular operations to decommissioning, and has largely been generated by those Member States that operate or have operated NPPs. The 16 Group I Member States account for 99.7% of the EU's radioactive waste inventory. Figure 31 below gives a more precise picture, revealing that the waste generated mainly comes from France (44.2%) and the UK (38.3%), in correlation with the size of those two countries' respective nuclear energy systems.

Figure 31 – Waste inventory per country (among nuclear industry possessing Member States), end-2013



Source: Authors from data in Commission Staff Working Document 161 Final, 15 May 2017

Radioactive waste and spent fuel management in the EU

As shown in Table 20 and Figure 32, 2 316 000m³ of radioactive waste was in disposal by end-2013, around 70% of the total waste inventory. The level of the total inventory of and of waste in disposal has been trending upwards at a similar rate over the 2004-2013 period (by around 25% for each). Thus, waste disposal has managed to keep pace with total waste generation. The bulk of the waste disposed of is LLW, which represents 87% of all waste in disposal.

[103] Commission Staff Working Document Inventory of radioactive waste and spent fuel present in the Community's territory and the future prospects Accompanying the document Report from The Commission to the Council and the European Parliament on progress of implementation of Council Directive 2011/70/EURATOM and an inventory of radioactive waste and spent fuel present in the Community's territory and the future prospectshttps://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52017SC0161

Table 20 – Radioactive waste in disposal (in thousands m³), 2004-2013

Waste Category	2004	2007	2010	2013
VLLW	34	105	197	279
LLW	1817	1940	1991	2025
ILW	0	0	0	12
HLW	0	0	0	0
Total	1851	2045	2188	2316

Source: Authors from data in Commission Staff Working Document 161 Final, 15 May 2017

Figure 32 – Radioactive waste in disposal by type relative to the total inventory (%), 2004-2013

Source: Authors from data in Commission Staff Working Document 161 Final, 15 May 2017

As of end-2013, 54 300 tonnes of Heavy Metal (tHM) of spent fuel were stored in the EU, up around 2% since 2010.

Table 21 – Spent Fuel in storage (in tHM³ thousands)

2004	2007	2010	2013
38.1	44.9	53.3	54.3

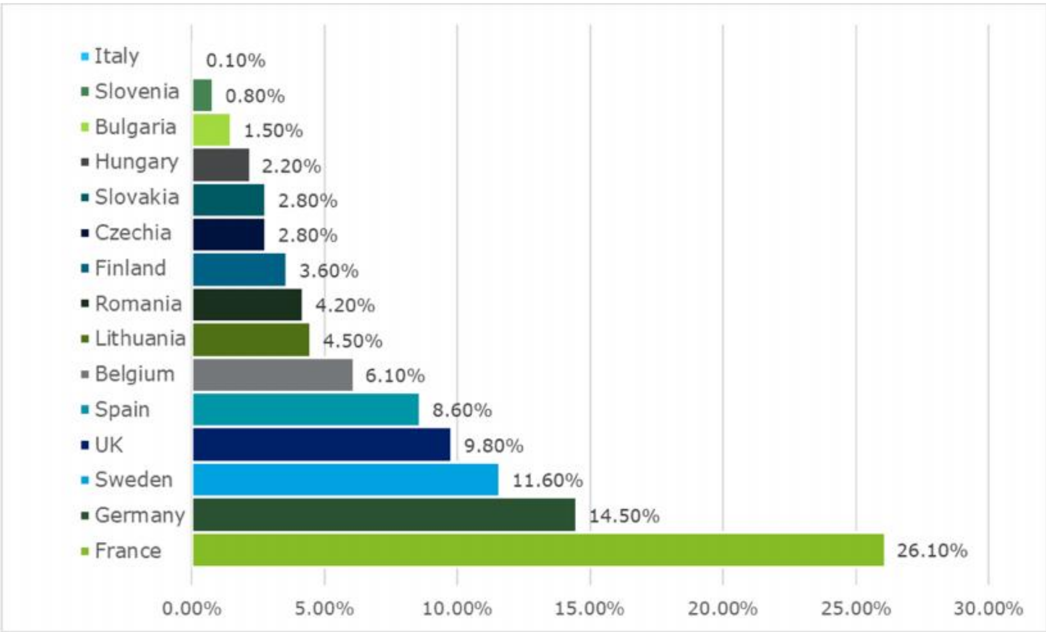
Source: Authors from data in Commission Staff Working Document 161 Final, 15 May 2017

Similar to radioactive waste generation, the biggest generator of spent fuel is France which currently accounts for 26.1% of the inventory, with Germany following at 14.5%. Two “visions” of the management of spent fuel currently exist, namely open cycle systems (which treat it as a waste and therefore store it until disposal) and closed cycle systems (which on try to reprocess spent fuel for future use in energy-producing operations). Countries that adhere strictly to the former approach are Finland and Sweden. France is at the other end of the spectrum. It recycles all its spent fuel before treating the radioactive waste generated in the process.

Member States have always exported their spent fuel outside the EU for reprocessing – around 1.5% of their total inventory in 2013 or 800tHM - or to the Member States that possess reprocessing facilities. For instance, Belgium, Germany, Italy, Spain and Sweden used to export their spent fuel to France for reprocessing. The Netherlands is the only Member State which still does so. Bulgaria sends its spent fuel to Russia. However, as spent fuel reprocessing generates radioactive waste of its own, such radioactive waste is usually returned to the country of origin.

Finally, as with ILW and HLW, spent fuel requires special accommodation in the form of deep geological disposal (given the technology currently available). With around 3 200 heavy metal tons (tHM) of spent nuclear fuel generated every year, spent fuel is expected to keep accumulating in storage until the first disposal facilities become operational[104].

Figure 33 – Member States' share of the overall spent fuel inventory in the EU, end-2013



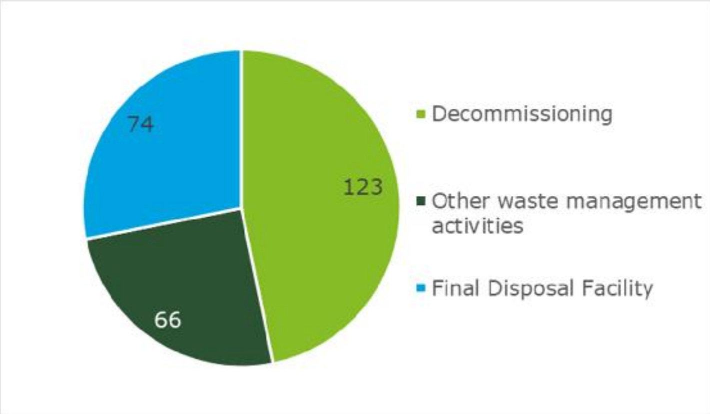
Source: Authors from data in Commission Staff Working Document 161 Final, 15 May 2017

[104] Commission Staff Working Document accompanying the document "Communication from the Commission on Nuclear Illustrative Programme Presented under Article 40 of the Euratom Treaty - Final (after opinion of EESC)", SWD(2017) 158 final, 12 May 2017; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52017SC0158

Cost and funding

Back-end activities in the nuclear fuel cycle (decommissioning, and management of radioactive waste and spent fuel) include a wide range of operations that all incur different costs. Figure 34 shows that the largest cost element in the back-end activities is construction of the final disposal facilities, estimated at around EUR 74 billion for the EU. However, the multiplicity of categories, the cost assumptions and several uncertainties make it particularly difficult to obtain a clear picture of the overall cost of radioactive and spent fuel management.

Figure 34 – Overall cost by main category (projections to 2050, EUR billion)



Source: Authors from data in Commission Staff Working Document (2017) 158 Final, 12 May 2017[105]

In order to finance the costs related to radioactive waste management, Member States often impose a fixed contribution on power generators based on the electricity produced by the power plants concerned. They use three types of funds, namely:

- Segregated internal funds: directly managed by operators in separate budgets specifically dedicated to decommissioning and waste management purposes, under the control of competent regulatory authorities. Funds of this type exist in France and Belgium.
- Non-segregated internal funds: directly managed by operators in one general budget. Funds of this kind exist in Germany (for decommissioning activities only), where power companies are required by law to build up reserves in their balance sheets for back-end operations.
- Segregated external fund: management is external to the operators. The funds can either be external to the State budget, as is the case in Finland and Sweden, or they can be within the State budget, e.g. Bulgaria, Hungary, Romania and Slovakia.

[105] Commission Staff Working Document accompanying the document "Communication from the Commission on Nuclear Illustrative Programme Presented under Article 40 of the Euratom Treaty - Final (after opinion of EESC)", SWD(2017) 158 final, 12 May 2017; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52017SC0158

In 2014 (Figure 34), it was estimated that EUR 263 billion would be needed by 2050 to cover the costs relating to nuclear decommissioning and radioactive waste management. At that time, Member States affirmed that around EUR 133 billion was currently available in the form of asset-backed funds, covering approximately 51% of the needs[106].

[106] Communication for the Commission, Nuclear Illustrative Programme presented under Article 40 of the Euratom Treaty, SWD (2017) 158 final, 12 May 2017 https://ec.europa.eu/energy/sites/ener/files/documents/nuclear_illustrative_programme_pinc_-_may_2017_en.pdf.

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