2.1.3 DI Technology Selection

Domain Insight with EURAD Roadmap

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This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945098.

Remark

The DI document on Technology selection was produced in collaboration with:

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Outline

- Technology selection is an **important part of the planning process** when setting up a **waste management programme**
- Critical part in the planning process for a waste management programme
- Assessment of the **feasibility of technologies for processing, storage, and monitoring**, taking economic constraints into account and considering subsequent stages in the waste management lifecycle, including final disposal
- Crucial during implementation of a programme to evaluate if suitable technologies are being implemented.
- EURAD Pre-disposal theme overview, domain 2.1.3, Technology Selection, part of the sub-theme “Planning pre-disposal management of radioactive waste in close cooperation with waste generators” (Planning) and of the broader theme 2 “Pre-disposal Activities prior to geological disposal” (Pre-disposal).

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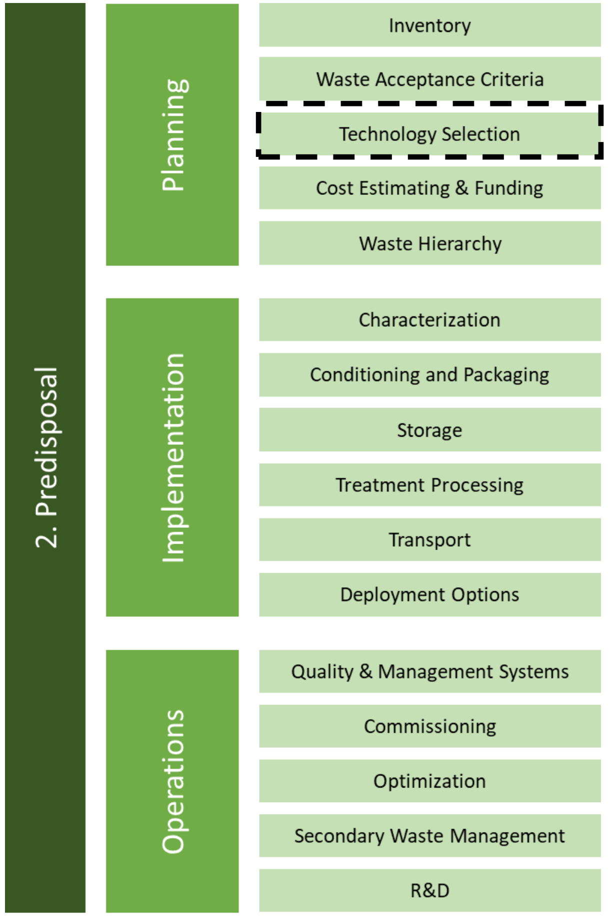
Introduction to DI Technology Selection

What is Technology Selection?

- Assessment and selection of technologies for implementation during various phases of the waste management lifecycle

Takes into account

- Cost-benefit ratio
- Availability
- Legislation
- Safety



PREDIS

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Introduction to DI Technology Selection

According to the EURAD Theme 2 Overview, the process of technology selection includes:

- Comparison of pre-disposal processing technology options with respect to economic and environmental lifecycle parameters.
- Evaluation of spent fuel reprocessing options as well as free release and recycling opportunities for very low radioactivity materials to avoid disposal altogether in accordance with the waste hierarchy.
- Understanding of regulatory requirements for both pre-disposal and disposal aspects.

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Introduction to DI Technology Selection

EURAD Theme 2 Overview also notes:

- numerous mature technologies and services available in the international market reflecting, including pre-disposal waste management.
- Some countries and companies operating pre-disposal waste management facilities for decades, including interim storage, final disposal, etc.

But:

- Availability of pre-disposal waste management technologies and market offerings highly dependent on the type of waste and its geographical location
- Significant market opportunities for new companies to provide innovative technologies and services in the pre-disposal field

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Typical overall goals and activities in the domain (Based on EURAD Roadmap GBS)

Domain Goals:

- Assess the feasibility of technologies
  - taking economic constraints into account
  - considering subsequent stages in the waste management lifecycle, including final disposal
- based on
  - the waste inventory that has been generated
  - planned waste stream composition
  - or the evolution over time of waste packages that result from storing fractions of the waste stream according to the regulations or procedures.

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Typical overall goals and activities in the domain (Based on EURAD Roadmap GBS)

Domain Activities

Phase 1: Planning and programme Initiation	Gather detailed information on the waste stream and available technologies. Compile and scale boundary conditions, regulations and other decision criteria. Match technology parameters vs. decision criteria, then decide.
Phase 2: Programme Implementation	Continuously monitor the selected technology for performance, upgrades, and alternatives as well as changes in regulation, and optimize the procedures and their descriptions, whenever new opportunities arise.

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Typical overall goals and activities in the domain (Based on EURAD Roadmap GBS)

Domain Activities

Phase 3: Programme Operation and Optimisation	Continue monitoring as in phase 2
Phase 4: Closure	Final evaluation of the technology, documentation, and compilation of “lessons learned”.

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International Legislation

To the best of the authors’ knowledge:

No **international legislation** specifically on Technology Selection.

However:

Relevant national and international legislation and standards must be considered in the Technology Selection process. This includes considerations related to radiation safety, environmental safety, occupational health and safety, as well as national nuclear policies.

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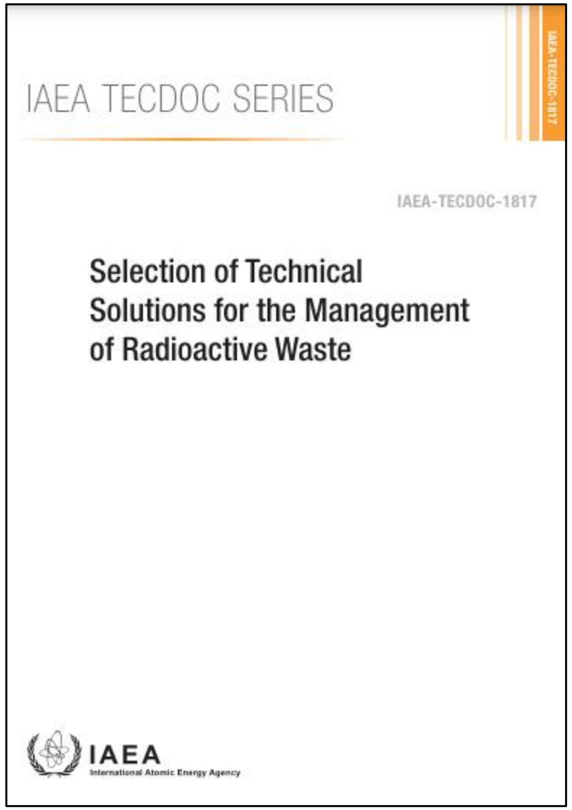
International Legislation

IAEA issued guidance on Technology selection:

- IAEA, 2017. Selection of Technical Solutions for the Management of Radioactive Waste. IAEA Tecdoc-1817, Vienna.
- IAEA, 1999. Review of the factors affecting the selection and implementation of waste management technologies. IAEA TecDoc-1096, Vienna.



PREDIS

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IAEA Tecdoc-1817 – Factors to be adressed

- Political and socioeconomic criteria
    - Compliance with regulations – Will the technology gain regulatory approval?
    - Financial resources – Can funding be secured for both investments and ongoing operations?
    - Manpower and personnel competence – is the right personnel available or can they be acquired?
    - Physical infrastructure – Does the technology seamlessly integrate with existing infrastructure?
    - Research and development – Is there capacity to advance emerging technologies to maturity?
    - Public involvement and political acceptance – Is there sufficient political support, and can the safety of the technology be effectively communicated to the public?
    - Facility location - Have all relevant factors, such as transportation, been considered in selecting an appropriate facility location?
    - Opportunity for international cooperation – Should collaboration with other entities be sought to share the workload and expertise?

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IAEA Tecdoc-1817 – Methods

Linear Decision Tree Approach:

- Advantages: Provides a structured framework for decision-making.
- Limitations: Constrained by multiple, non-linear objectives and dependencies of criteria/factors.

Cost-Based Approach with Work Breakdown Structure:

- Advantages: Utilises a systematic breakdown for cost evaluation.
- Limitations: May prioritise cost and speed over the quality and safety of the technology, especially in complex environments.

Multi-Attribute Analysis:

- Advantages: Offers transparency and accommodates the complexity and interdependence of criteria.
- Limitations: Time-intensive, requiring a comprehensive evaluation due to its consideration of multiple attributes.

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Multi-Attribute Analysis

Option	Feasibility of method		Availability of technology		Cost		Possibility for clearance or authorized discharge		Availability of technology for treatment and conditioning of secondary waste		Public acceptance		Final score
	Weight (%)	Score	Weight (%)	Score	Weight (%)	Score	Weight (%)	Score	Weight (%)	Score	Weight (%)	Score	Score
Chemical precipitation	A_1	B_1	C_1	D_1	E_1	F_1	G_1	H_1	I_1	J_1	K_1	L_1	Σ_1
Ion exchange	A_2	B_2	C_2	D_2	E_2	F_2	G_2	H_2	I_2	J_2	K_2	L_2	Σ_2
Evaporation	A_3	B_3	C_3	D_3	E_3	F_3	G_3	H_3	I_3	J_3	K_3	L_3	Σ_3
Membrane processes	A_4	B_4	C_4	D_4	E_4	F_4	G_4	H_4	I_4	J_4	K_4	L_4	Σ_4
Biotechnological processes	A_5	B_5	C_5	D_5	E_5	F_5	G_5	H_5	I_5	J_5	K_5	L_5	Σ_5
Electrochemical processes	A_6	B_6	C_6	D_6	E_6	F_6	G_6	H_6	I_6	J_6	K_6	L_6	Σ_6
Combination of evaporation and membrane processes	A_7	B_7	C_7	D_7	E_7	F_7	G_7	H_7	I_7	J_7	K_7	L_7	Σ_7
Combination of chemical precipitation and ion exchange	A_8	B_8	C_8	D_8	E_8	F_8	G_8	H_8	I_8	J_8	K_8	L_8	Σ_8

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Multi-Attribute Analysis

Option	Feasibility of method		Availability of technology		Cost		Possibility for clearance or authorized discharge		Availability of technology for treatment and conditioning of secondary waste		Public acceptance		Final score
	Weight (%)	Score	Weight (%)	Score	Weight (%)	Score	Weight (%)	Score	Weight (%)	Score	Weight (%)	Score	Score
Chemical precipitation	A_1	B_1	C_1	D_1	E_1	F_1	G_1	H_1	I_1	J_1	K_1	L_1	Σ_1
Ion exchange	A_2	B_2	C_2	D_2	E_2	F_2	G_2	H_2	I_2	J_2	K_2	L_2	Σ_2
Evaporation	A_3	B_3	C_3	D_3	E_3	F_3	G_3	H_3	I_3	J_3	K_3	L_3	Σ_3

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Assessment

- Assessment of the “**What-is**” situation (Existing waste streams, regulations, stakeholders, technologies already implemented, existing storage facilities, etc.)
- Assessment of the “**What will be**” situation (upcoming waste streams, expected changes in regulations, etc.)
- Assessment of “**What is available**” (technologies available on the market, potential partners/contractors, etc.)
- Assessment of “**What is missing**” (technology gaps, R&D needs, etc.)
- Assessment of “**Can we to do ourselves**” (e.g., can a certain part of waste management be done by a consultant/contractor/service provider, potentially in other countries)

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Assessment Tools

- Feasibility Study, technology selection and concept design: This consists of evaluation of existing techniques and selection of mature techniques that have been successfully applied for similar purposes. Where there are no common practices, a new approach and new dedicated solutions may be investigated.
- HAzard and OPerability analysis (HAZOP): This is a methodical and rigorous tool to proactively identify potential issues by scrutinising safety aspects in designs and reassessing ongoing processes within the nuclear industry.
- A detailed project report: This outlines the selected technology, characteristics of the materials to be treated with the chosen technology, and the complex process defined to produce the final waste packages.

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Critical issues, information, data or knowledge in the domain of Technology Selection

The most critical generic issues in the process of Technology Selection are:

- **Precision in criteria and relative importance:** Ensuring accurate selection criteria and their respective weightings
- **Inclusive engagement with regulators and stakeholders:** Actively involving regulators and relevant stakeholders throughout the selection process

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Critical issues, information, data or knowledge in the domain of Technology Selection

The most critical generic issues in the process of Technology Selection are (cont.):

- **Comprehensive insight into technologies:** Gaining a comprehensive understanding of available and emerging technologies, considering their maturity levels.
- **Periodic re-evaluation:** Regularly reassessing technologies to incorporate the latest data, experiences, research, and legislative updates.

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Critical issues, information, data or knowledge in the domain of Technology Selection

Further Thoughts (1):

Technology Selection criteria and weights to be applied will depend on several factors such as the waste stream of interest, country context, envisaged disposal type, etc. Therefore, it is important to select these appropriately for the specific application scenario. This can be done based on guidance provided earlier, which aligns with recommendations from the IAEA. **Involving regulators and relevant stakeholders** is crucial to gaining acceptance for the selected technology.

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Critical issues, information, data or knowledge in the domain of Technology Selection

Further Thoughts (2):

To ensure an optimal solution in Technology Selection, a **comprehensive overview of available and emerging technologies**, including potential limitations and level of maturity, is required. This insight can be gained through existing institutional knowledge, national and international research programmes, documents from relevant organisations, and participation in conferences and trade fairs within the domain.

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Critical issues, information, data or knowledge in the domain of Technology Selection

Further Thoughts (3):

It is anticipated that during the lifetime of pre-disposal waste handling facilities, **new technologies may come onto the market**. These should be evaluated for relevance and return-on-investment potential before implementing the technology in practice. In instances where information on a promising technology is lacking or trust is insufficient, initiating R&D projects and/or conducting demonstrations on a realistic scale in authentic environments becomes imperative. For instance, the EC PREDIS project has tested specific wireless technologies within an actual facility in the context of waste package

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Critical issues, information, data or knowledge in the domain of Technology Selection

Further Thoughts (3 cont.):

However, it is crucial to acknowledge the **inherent risk associated with immature technologies** as they may prove non-optimal after evaluation, resulting in a loss of both time and budget.

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Critical issues, information, data or knowledge in the domain of Technology Selection

Further Thoughts (4):

Technology Selection extends **beyond programme implementation and the start of operation**. Periodic re-evaluation is necessary to align technologies with new experiences, emerging technologies, and changes in boundary conditions such as legislation, WAC, and the availability of final disposal sites.

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Future advances

Emerging tools within Technology Selection **that are being implemented or could be applicable** and have relevance in the radioactive waste domain encompass

- Value Assessment,
- Life Cycle Assessment (LCA), and
- Life Cycle Costing (LCC).

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Future advances

Value Assessment is a crucial tool utilised in decision-making processes to evaluate the performance of various options against multiple attributes or criteria. In the realm of radioactive waste management, Value Assessment provides a structured approach to assessing the 'value' associated with a chosen waste management / treatment / monitoring technology. The term 'value' is defined as the realisable benefit in terms of safety, monetary aspects, and environmental outcomes resulting from the implementation of a specific option at a designated time. This assessment comprehensively considers benefits and challenges across all stages of the waste management lifecycle.

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Future advances

Value Assessment was used in the Theramin project!

Attribute	Data Category	Assessment considerations					
		Construction	Pre-treatment	Treatment operations	Post-treatment	Storage and Disposal	Decommissioning
Operational and Transport Safety	Facility construction and decommissioning						
	Waste pre-treatment requirements (conventional and radiological safety implications)						
	Waste post-treatment requirements (conventional and radiological safety implications)						
	Waste operational safety issues (e.g., ease of providing shielding during operation)						
	Transport safety issues						
Environmental Impact	Material requirements						
	Energy requirements						
	Secondary waste and gaseous/liquid discharges generated						
	Nuisance						
Impact on disposability / long-term safety	Ability to meet waste acceptance criteria						
	Disposability of secondary waste						
Implementation	Indicative lifetime feed						
	Ease of achieving required throughput for process (full-scale facility) (m^3/year)						
	Potential to treat a wide range of waste groups (flexibility) including problematic and orphan wastes						
	Impact on waste management strategy						
Timescale	Design, construction and active commissioning timescale						
	Lifetime operating timescale						
	Decommissioning timescale						
Technical Readiness	Maturity of technology						
Strategic Cost Impact	Costs of construction, operation and decommissioning						
	Impact on disposal costs (total packaged waste volume, disposal route, and required storage and disposal capacity)						

theramin

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Future advances

Life Cycle Assessment (LCA) and **Life Cycle Costing (LCC)** are used to assess the potential environmental impacts and related costs of a product or process throughout its entire life cycle. In the field of radioactive waste management, this concept is relatively new, but its application may lead to identification of approaches to mitigate harmful impacts and reduce costs. The methodologies are established for LCA and LCC when comparing a new technology to an existing option as a basis for decision making. The input boundary conditions, both upstream and downstream, over the lifetime of the material, product or technique must be clearly defined.

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Future (optimization) challenge

- Challenges exist with some technologies because there can be a limited number of facilities or commercial companies offering related services.
- The feasibility of utilising certain technologies may be hindered by factors such as the unsuitability of local facilities, necessitating the transport of waste to other processing facilities.
- Some technologies may be constrained in their applicability due to handling only specific types of waste (i.e., liquids but not solids).
- Lack of spare parts, lack of operators, emissions that do not meet local regulations, etc.
- Some technologies may become rapidly obsolete or encounter scale-up issues.
- There may be challenges associated with transport of waste across international borders to access specialised facilities, emphasising the need for mobile or transportable facilities that can bring technological tools to areas with local needs.

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Innovation needs

- **Update guidance documents** to include new selection methods and recent experience
- **Collect and share best practices** in this field, suggesting a potential avenue for creating a database or case studies to guide users towards best practices.

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Past R&D projects on Technology Selection

Previous projects funded by the IAEA and/or the European Commission that have addressed aspects of Technology Selection include:

- Pre-disposal management of radioactive waste (PREDIS).
- Thermal treatment for radioactive waste minimization and hazard reduction (THERAMIN)
- Innovative and Adaptive Technologies in Decommissioning of Nuclear Facilities, IAEA CRP 2004-2008
- Development and try-out of an on-site process for sharing knowledge created in the frame of the nuclear decommissioning assistance programme. Project N° ENER/D2/2020-273

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Uncertainties

Uncertainties directly related to the technology:

- Is the technology performing as promised?
- Is the technology robust in the face of changing boundary conditions outside the tested range?
- Is the technology available for the long term (e. g., considering the possibility of providers going bankrupt)?
- Will the necessary personnel be available over the long term?
- If the technology is not fully mature, will the required R&D result in the necessary progress?
- Can the development costs be reasonably anticipated?

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Uncertainties

Uncertainties related to the boundary conditions:

- Will there be changes in legislation or standards affecting the selected technology?
- Will there be a final disposal facility available when needed?
- Will there be changes in WAC for final disposal?
- Will the required funding be available throughout the lifespan of the technology?
- Will the transport between facilities, and potentially across countries, be possible?
- Will there be public acceptance for the selected technology?

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Guidance, training and communities of practice

Guidance
• IAEA, 2017. Selection of Technical Solutions for the Management of Radioactive Waste. IAEA Tecdoc-1817, Vienna [1] • IAEA Integrated Review Service for Radioactive Waste and Spent Fuel Management, Decommissioning and Remediation (ARTEMIS), https://www.iaea.org/services/review-missions/integrated-review-service-for-radioactive-waste-and-spent-fuel-management-decommissioning-and-remediation-artemis
Training
• There is no specific training on Technology Selection to our knowledge available yet. However, some aspects are included in the IAEA Nuclear Energy Management School and some of the online IAEA Spent Nuclear Fuel training courses available in Learning Management System: https://elearning.iaea.org/m2/course/index.php?categoryid=60

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Guidance, training and communities of practice

Active communities of practice and networks
• IAEA International Radioactive Waste Technical Committee (WATEC) https://www.iaea.org/resources/databases/watec • Western European Nuclear Regulators Association (WENRA), working group on waste and decommissioning (WGWD) (https://www.wenra.eu/wgwd)

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Key competencies required in Technology Selection

- General background in waste management, treatment and storage options
- Understanding of relevant legislation and the safety principles underlying it
- knowledge in the relevant engineering domains (mechanical, processing, materials science, building materials, etc.) and chemistry
- experience in risk assessment and cost-benefit analysis
- generic competences in stakeholder involvement, project management, teamwork and economics.

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Additional references and future reading

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2. Bychkov, A., Drace, Z., Ojovan, M.I., 2013. Technical solutions for the management of radioactive waste (RAW): overview and methods of selection, in: Radioactive Waste Management and Contaminated Site Clean-Up. Elsevier, pp. 115–144. https://doi.org/10.1533/9780857097446.1.115
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Poll question 1

Technology selection is important in the planning process only!

□ yes

□ no

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Poll question 1

Technology selection is important in the planning process only!

□ **yes**

X no

Technology Selection is important in all phases. The selected technologies have to be monitored and optimised during the entire process, new technologies might become available or boundary conditions can change.

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Poll question 2

The following groups have to be involved in the Technology selection process:

□ **Waste producers**

□ **Technology providers**

□ **Regulators**

□ **Public stakeholders**

□ **All of them**

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Poll question 2

The following groups have to be involved in the Technology selection process:

□ **Waste producers**

□ **Technology providers**

□ **Regulators**

□ **Public stakeholders**

X All of them

Not taking everybody relevant on board can kill a technology!

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Poll question 3

The Technology selection process is internationally thoroughly regulated!

□ yes

□ no

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Poll question 3

The Technology selection process is internationally thoroughly regulated!

□ **yes**

X no

There is no international legislation or standards, just an IAEA guideline. However, tons of national laws and rules will influence the process.

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Poll question 4

Waste producers can delegate the Technology selection process to a service or technology provider!

□ yes

□ no

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Poll question 4

Waste producers and regulators can delegate the Technology selection process fully to a service provider!

□ **yes**

X no

Even if a service provider (who shouldn't be a technology provider at the same time) can be of significant help in organization, assessment and reporting, the basic questions (What do we need? What do we want? What is important and how much?) have to be answered by waste producers and regulators. This is a lot of work!

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