Gréoux Research

Enabling the transition to a low-carbon future

Generations:

Understanding Deep Geological Repository Stakeholders through Large Language Model Personas

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Contents

Introduction

Live survey applications are now commonplace in schools, meeting rooms, and conferences. These apps offer various question formats, enabling the collection of data through multiple-choice polls, open-ended questions, and rankings, promoting active participation, and allowing presenters to tailor their communication based on real-time audience insights.

Interactive.li is a live survey platform tailored to the needs of training and communication professionals. It uses generative AI to automatically summarise and analyse audience feedback, helping to overcome cultural and language barriers while providing real-time insights. The platform also features gamification and model-based simulation, allowing participants to learn by doing in a safe, structured environment - and to enjoy the process along the way (Figure 1).

Gamification transforms passive learning into an active, engaging, and enjoyable experience.

Discuss

Experiment

Let's figure out what happened!

Visualize

Debrief

Simulation helps participants understand trade-offs - decide, see the outcome!

Generative AI breaks cultural and language barriers and analyses feedback in real time.
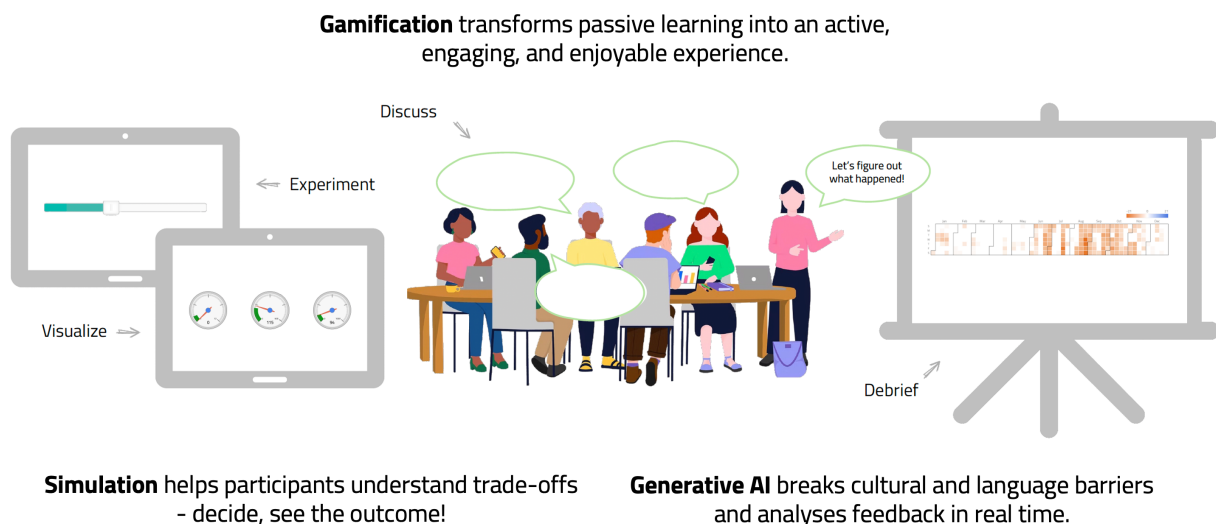
Figure 1: Interactive.li Platform Building-Blocks

These innovative features significantly improve the user experience for both instructors and participants, ultimately leading to more effective training workshops and communication campaigns.

This report provides a technical description of *Generations*, an Interactive.li-based serious game aimed at exploring and understanding stakeholder roles in deep geological repository (DGR) siting with Large Language Model (LLM) personas. In the game, participants assume the role of a policymaker, making decisions at key stages of the programme and receiving feedback from simulated stakeholder groups. Stakeholder responses are generated by an LLM trained on contextual information, government

policies and strategies, as well as each group's specific interests, expectations, and legal responsibilities.

The aim of the game is not to identify optimal stakeholder engagement strategies, but to raise awareness of the complexity involved in long-term governance, the need for trade-offs, and the importance of aligning diverse perspectives.

Generations was designed to spark dialogue, promote critical thinking, and encourage reflection on how decisions are framed and negotiated. To enhance the realism and relevance of the simulation, the game is grounded in the Swiss context and publicly available sources. Switzerland's participatory approach in radioactive waste governance provides a compelling example for exploring stakeholder dynamics in depth.

The learning experience is also intended to be playful and engaging. As they progress through different stages of the game, players collect points based on how well their decisions are received by different stakeholders. The winner is the player with the highest score at the end. However, players must also avoid getting a stakeholder veto, which results in an immediate "game over".

Caution: Simulated Feedback - For Educational Purposes Only

The stakeholder personas featured in *Generations* are fictional representations created for educational and illustrative purposes. They are based on publicly available information and are not affiliated with, endorsed by, or intended to represent the official positions of any real-world institutions, including the Swiss Federal Office of Energy (SFOE), the Swiss Federal Nuclear Safety Inspectorate (ENSI), the National Cooperative for the Disposal of Radioactive Waste (NAGRA), or other named bodies. All AI-generated responses used in this game are simulations and should not be interpreted as factual statements, policy recommendations, or official communications.

LLMs can sometimes "hallucinate" - that is, generate inaccurate or misleading information - because they rely on predicting patterns rather than retrieving verified facts. While care has been taken to ensure the content reflects known legal and institutional frameworks, no guarantee is given regarding its accuracy or completeness.

Context and Relevance

Introduction to Deep Geological Repositories (DGR)

DGRs are internationally recognised as the most suitable solution for the final disposal of high-level radioactive waste. By storing waste in stable geological formations hundreds of metres below the Earth's surface, these facilities are designed to provide long-term containment and isolation without reliance on active human oversight. Table 1 provides an overview of DGR projects worldwide and their status as of mid-2025.

In Switzerland, the repository programme follows a stepwise, participatory approach, ensuring that scientific, technical, and societal factors are fully accounted for. The goal is to safeguard people and the environment over geological timescales, respecting both current and future generations.

Importance of Long-term Governance in the Swiss Context

Switzerland's governance of radioactive waste is shaped by its federal structure, strong democratic traditions, and commitment to intergenerational responsibility. The Sectoral Plan for Deep Geological Repositories, led by the Swiss Federal Office of Energy (SFOE), establishes a legally binding, multi-decade framework for repository development. Transparent decision-making, inclusive stakeholder participation, and adherence to international conventions (such as the Espoo Convention) are essential for building and maintaining public trust. Long-term governance ensures not only technical safety but also the legitimacy and resilience of decisions across generations.

Role of Legal, Ethical, and Societal Frameworks

Legal, ethical, and societal considerations are central to the success of a DGR. Swiss law requires that long-term safety be demonstrated and that decisions respect the principles of fairness, transparency, and public accountability. Ethical imperatives - such as protecting future generations and preserving societal memory - are embedded in the regulatory framework. Societal dialogue, particularly through mechanisms like Regional Conferences and cross-border consultations, ensures that diverse perspectives inform the process. Together, these frameworks reinforce the legitimacy and sustainability of the repository system in a democratic context.

Country	Project Name	Geology	Waste Type	Status
Finland	Onkalo (Posiva Oy)	Crystalline granite, bentonite buffer (~430 m)	Spent nuclear fuel	Construction complete; first disposal expected in the mid-2020s.
Sweden	Forsmark (SKB)	Granite, bentonite buffer (~500 m)	Spent nuclear fuel	Licensed in 2022; construction started; full operation expected between 2030 and 2040.
France	Cigéo (Andra)	Callovo-Oxfordian clay (~500 m)	High-level and intermediate-level radioactive waste from reprocessing	Construction licence submitted in 2023; pilot industrial phase expected between 2025 and 2027.
Switzerland	Nördlich Lägern (Nagra)	Opalinus Clay (~500 m)	Spent nuclear fuel and other high-level radioactive waste	Site selected in 2022; federal approval pending; operation expected between 2050 and 2060.
Canada	NWMO DGR (Ignace/South Bruce)	Crystalline rock (~500 m)	Spent nuclear fuel	Site selected in 2024; licensing process ongoing.
China	Beishan URL (future DGR)	Granite (~560 m)	Spent nuclear fuel	Underground research laboratory under construction; repository not yet licensed. Research phase expected to continue until approximately 2040.
USA	Yucca Mountain (DOE)	Volcanic tuff (~600 m)	Spent nuclear fuel and other high-level radioactive waste (proposed)	Federally licensed but suspended; future uncertain.
USA	WIPP (New Mexico)	Bedded salt (~660 m)	Long-lived transuranic waste from defence-related activities (not high-level waste)	Operational since 1999; used exclusively for long-lived transuranic waste from military programmes.

Table 1: Global Deep Geological Repository (DGR) Projects for High-Level Radioactive Waste (HLW) Status as of Mid-2025

The Stakeholder Landscape

Switzerland's DGR programme involves a wide range of stakeholder groups, each bringing distinct responsibilities, interests, and perspectives. At the federal level, the Swiss Federal Office of Energy (SFOE) coordinates the siting process and ensures transparency and compliance under the Sectoral Plan. The waste implementer NAGRA is responsible for technical planning and safety assessments, while ENSI, the independent regulatory authority, evaluates compliance with national and international safety standards. Political oversight is exercised by the Swiss Parliament and cantonal governments, who assess the legitimacy, feasibility, and fairness of the programme. Regional Conferences enable municipalities and civil society groups in potential host regions to participate meaningfully, while German authorities engage through formal cross-border consultation under the Espoo Convention[1]. Finally, the Swiss public and future generations are considered key stakeholders, as the programme carries significant intergenerational implications.

A full list of stakeholder groups represented in *Generations* is included in Appendix 1.

Why Stakeholder Understanding is Essential

Understanding the different views and concerns of all stakeholder groups is crucial to building trust and ensuring the long-term success of Switzerland's DGR programme. As outlined in the Sectoral Plan and OECD NEA guidance, each group has its own expectations and conditions for how it should be involved, shaped by legal duties, ethical values, and political or social context (Appendix 1).

If these perspectives are poorly handled, it can lead to a breakdown of trust, public resistance, or even legal disputes, especially at key moments such as choosing the site, granting licences, or starting construction. Taking the time to understand what matters to each group helps make the decision-making process more open and respectful. It also encourages shared responsibility, helping to build long-term public support and confidence in how radioactive waste is managed over time.

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[1] The Espoo Convention, formally known as the Convention on Environmental Impact Assessment in a Transboundary Context, is a multilateral agreement that seeks to prevent environmental harm before it occurs. It requires parties to carry out environmental impact assessments for projects that may cause significant effects across national borders. The Convention also obliges countries to notify and consult with potentially affected states about such projects, promoting transparency and international cooperation in environmental decision-making.

Generations: Understanding DGR Stakeholders through LLM Personas

Purpose of the Serious Game

Generations is a serious game that simulates how various stakeholders (Appendix 1) might respond to decisions made within the framework of a deep geological repository (DGR) programme. As part of the game, players assume the role of the Swiss Federal Council and advance through a series of key policy stages (Appendix 2), making strategic decisions and observing the simulated responses of stakeholder groups. The game is designed to explore how these decisions interact with the diverse interests, responsibilities, and expectations of eight key stakeholder groups. *Generations* highlights the complexity of long-term governance, the necessity of compromise, and the critical importance of fostering alignment among a wide range of actors.

Educational and Policy Relevance

The game serves both as an educational resource and a policy simulation tool. For educators, it offers a structured, interactive method to explore themes such as intergenerational justice, stakeholder legitimacy, and regulatory credibility. For policy practitioners and researchers, it provides an opportunity to examine the framing and perception of decisions across different stakeholder groups. Built on Swiss legal and institutional frameworks, the game allows for a grounded understanding of DGR governance and invites reflection on the broader challenges of sustainable decision-making in high-stakes, long-term infrastructure projects.

Gamification Approach

Generations is based on the principles of discovery-based learning. During the interactive session, players are invited to make strategic decisions at key stages in the DGR siting process. Each decision triggers dynamic feedback from simulated stakeholder personas, powered by LLMs, allowing participants to get a sense of what could be the political, legal, and societal implications of their choices.

The game integrates eight distinct stakeholder personas, reflecting the key actors in a typical DGR governance landscape: the Swiss Federal Office of Energy (SFOE), NAGRA, ENSI, the Swiss Parliament, cantonal authorities, Regional Conferences, cross-border stakeholders, and the general public and future generations (Appendix 1). Each persona

represents not only an institutional role but also a set of expectations, concerns, and priorities grounded in law, ethics, and public discourse.

Stakeholder responses are generated by LLM personas that have been instructed to simulate reactions based on two factors: (1) the government's decision at each stage, and (2) the group's identity, role, interests, core concerns, and non-negotiable positions. The goal is not to predict real-world behaviour, but to reflect the reasoning, concerns, and communication styles of actual stakeholders.

Feedback is structured using a layered system that combines visual, quantitative, and qualitative elements. A traffic-light visualisation provides immediate signals: Green Light indicates strong support, Wait suggests conditional or cautious agreement, and Full Stop reflects clear opposition (Figure 2).

Green Light

Full Support

Wait

Conditional or Partial Approval
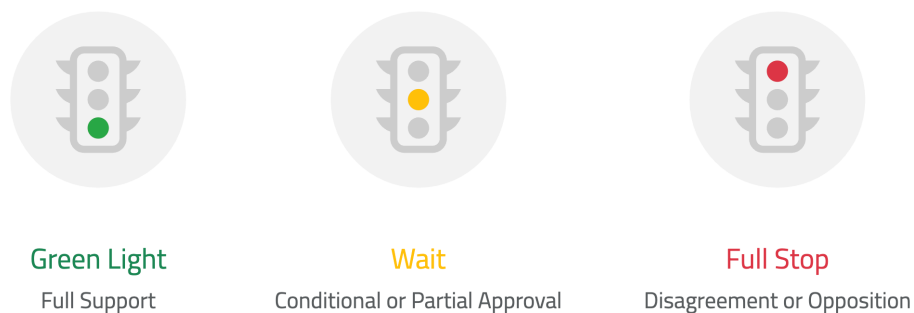
Full Stop

Disagreement or Opposition

Figure 2: Traffic Light Signals

Each response is accompanied by a satisfaction index, rated from 0 to 10, which measures how well the participant's decision aligns with the stakeholder's expectations. As the game progresses, players accumulate points based on these scores, which ultimately help determine the winner (Figure 3).

Figure 3: Score Build-up Example

The stakeholder feedback also includes concise, tailored explanations in the form of bullet points marked with ✓ if supportive, ✗ if critical, or 💡 if offering a suggestion for improvement (Figure 4).

The game is structured across four stages reflecting the real-world progression of the Swiss repository programme:

1. Legal Foundations, where the legal and ethical frameworks are established.
2. Regional Selection, where geologically suitable areas are assessed with stakeholder input.
3. Final Siting and Licensing, where technical, political, and public acceptance converge around a preferred site.
4. Implementation and Memory, where construction, emplacement, and intergenerational stewardship are addressed.

Each stage presents realistic policy dilemmas and forces participants to weigh trade-offs in safety, participation, and fairness. Annex 2 provides a detailed overview of each stage, including participant briefings, contextual background, and decision-making options.

Figure 4: Stakeholder Feedback Example

Appendices

Appendix 1: Key Stakeholders

SFOE

Federal coordinator of repository programme and environmental supervision

The Swiss Federal Office of Energy (SFOE) leads the national deep geological repository programme, coordinating actors across federal, cantonal, and local levels. It ensures procedural integrity, transparency, and compliance with legal obligations under the Sectoral Plan. SFOE is also responsible for overseeing environmental assessments in collaboration with the Federal Office for the Environment (FOEN), particularly regarding Switzerland's obligations under the Espoo Convention. Its core concerns include democratic legitimacy, international credibility, and the alignment of the repository process with national energy strategy.

NAGRA

Swiss waste management implementer

The National Cooperative for the Disposal of Radioactive Waste (NAGRA) is mandated by waste producers to design and propose repository concepts based on scientific and technical feasibility. It prepares siting proposals, safety analyses, and general licence applications for review by regulatory authorities. NAGRA operates under regulatory oversight and maintains close collaboration with host regions. Its non-negotiables include geological suitability, long-term safety, and maintaining project credibility through consistent technical standards and public engagement.

ENSI

Independent Swiss nuclear safety regulator

The Swiss Federal Nuclear Safety Inspectorate (ENSI) is the independent federal authority responsible for supervising nuclear safety and radiation protection. It reviews all technical documents submitted by NAGRA, evaluates safety cases, and ensures compliance with Swiss legislation and international best practices. ENSI's priorities are scientific rigour, transparency, and independence from political or economic pressures. It expects unrestricted access to data and decision-making free from stakeholder influence to guarantee long-term repository safety.

Swiss Parliament

Legislative authority overseeing national licensing decisions

The Swiss Federal Assembly, composed of the National Council and the Council of States, is responsible for reviewing and approving the general licence for the repository. Parliament ensures that the licensing process reflects constitutional principles, budgetary responsibility, and democratic accountability. It serves as a safeguard for national cohesion and federal balance and retains the power to trigger or respond to a facultative national referendum. Key concerns include legal robustness, procedural fairness, and public acceptance.

Swiss Cantons

Sovereign regional authorities with a joint advisory platform

The Swiss cantons hold planning sovereignty within their territories and play a decisive role in spatial development. Through the Commission of Cantons (KdK), they coordinate their input on repository siting, safety, and infrastructure. Cantons are involved in regional conferences, legal consultations, and political oversight. Their core expectations include early and binding involvement, respect for local priorities, and access to independent assessments. They seek clarity on long-term responsibilities and equitable treatment across regions.

Regional Conferences

Local stakeholder platforms for participation and oversight

Regional Conferences are formally established forums comprising municipalities, civil society actors, and local institutions from potential siting regions. They serve as advisory bodies to ensure community perspectives influence siting criteria, repository design, and transport planning. Grounded in the Sectoral Plan, they demand meaningful participation, not symbolic consultation. Key interests include regional development, long-term safety, social equity, and transparent communication. They expect financial resources to support independent studies and ongoing dialogue.

Cross-Border Stakeholders

German authorities and international environmental contact points

District-level authorities in neighbouring countries, particularly in southern Germany, are formally entitled to participate in the repository process under the Espoo Convention. They are supported in this role by the Swiss Federal Office for the Environment (FOEN), which manages transboundary consultation and notification. Cross-border stakeholders seek environmental protection, early warning systems, and diplomatic transparency. Their core concerns include shared groundwater resources, monitoring mechanisms, and the recognition of their legal consultation rights.

Swiss Public and Future Generations

Citizens, youth, and long-term stewards of the repository legacy

The Swiss public, empowered by direct democratic instruments such as referenda and objections, plays a fundamental role in shaping repository legitimacy. Citizens expect transparency, access to data, and credible communication throughout the process. This group also represents the ethical interests of future generations, with growing participation by youth organisations and education networks. Core values include intergenerational fairness, environmental protection, and the reversibility of decisions. Public trust depends on inclusive procedures and long-term accountability.

Appendix 2: Serious Game Levels

Stage 1: Legal Foundations - Setting the Rules for the Long Haul

Briefing

> You stand at the inception of Switzerland's national repository programme. The 2005 Nuclear Energy Act has established the legal mandate - but essential principles and mechanisms remain to be embedded in law.

> As the Swiss Federal Council, you must set the foundational rules: who bears responsibility, how decisions are made, and how long-term safety is interpreted. These legal choices will shape trust, legitimacy, and resilience across generations.

Elements of Context

> Switzerland is launching a multi-generational programme to ensure the safe, final disposal of radioactive waste in a deep geological repository. This foundational stage is pivotal in setting the strategic and legal framework for the decades ahead. Decisions will define guiding principles (e.g. safety, justice, reversibility), funding models (e.g. polluter pays), and commitments to transparency, institutional oversight, and ethical responsibility.

> Choices made here will influence public trust, stakeholder confidence, and international scrutiny. The framing of fairness, adaptability, and accountability now will determine the programme's resilience - or vulnerability - over the long term.

1. Enshrine a Core Principle in Law (Choose one)

> Which guiding value will underpin the Swiss repository programme?

> ⭕ Prioritise long-term geological safety above all other concerns

> ⭕ Centre the process on procedural justice and public participation

     ⭕ Emphasise adaptability through reversibility and monitoring rights

     ⭕ Balance all pillars - safety, justice, and intergenerational fairness

2. Define the 'Polluter Pays' Rule (Choose one)

How will financial responsibility for waste management be structured?

     ⭕ One-off payment into a sovereign public trust

     ⭕ Indexed annual payments linked to reactor risk profiles

     ⭕ Shared-cost model with future taxpayers for intergenerational fairness

     ⭕ Performance-based contracts with scheduled reviews every decade

3. Guarantee Participation Rights (Choose all that apply)

Which public and stakeholder rights should be enshrined in law?

     ☑ Legal foundation for regional conferences with advisory status

     ☑ Public right to access safety data and siting assessments

     ☑ Optional national referendum on final licensing decision

     ☑ Guaranteed cross-border consultation under the Espoo Convention

4. Define 'Long-Term Safety' in Law (Slider: 1-10)

On a scale from 1 to 10, how stringent should the legally defined safety timeframe be?

     🔘 1 = Minimum 10,000 years (baseline international standard)

     🔘 10 = At least 1 million years, aligned with Swiss modelling scenarios

Stage 2: Regional Selection - Building Trust on the Map

Briefing

With the legal framework in place, you now advance to site selection. Nagra has proposed six geologically suitable regions.

Your challenge is to decide how many to formally carry forward, how to present this to the public, and how to structure meaningful regional engagement. These decisions will determine whether the process is perceived as inclusive - or imposed.

Elements of Context

This stage marks the transition to politically sensitive territory. The Swiss Federal Council must balance scientific assessment with democratic legitimacy. Regional

Conferences are active, youth and civil society actors demand substantive roles, and perceptions of procedural fairness are under scrutiny.

The process must demonstrate that regional participation matters - that input affects outcomes. Failure to do so could erode public confidence and provoke contestation. At stake is not just the selection of sites, but the credibility of the entire programme.

1. Select Candidate Regions to Advance (Choose one)

Which siting strategy will you adopt?

○ Maintain all six regions for full assessment

○ Narrow to three regions, with optional reserve sites

○ Reopen the process to allow new regional proposals

○ Launch a national reassessment with public and cantonal input

2. Frame the Public Communication Strategy (Choose one)

Choose the primary message you wish to convey to the public and media.

○ Emphasise scientific integrity and independent assessment

○ Reassure that no final decisions are being made

○ Highlight national solidarity and shared responsibility

○ Present the process as a step towards sustainable innovation

3. Early Regional Engagement Measures (Choose all that apply)

Which support and dialogue mechanisms do you initiate?

☑ Fund municipalities to commission independent studies

☑ Launch youth engagement platforms and education initiatives

☑ Offer seed funding for community cultural projects

☑ Appoint regional mediators to support local dialogue

4. Depth of Regional Dialogue Commitment (Slider: 1-10)

To what extent do you commit to inclusive consultation in this phase?

◉ 1 = Informational briefings only

◉ 10 = Deep co-design of siting criteria and regional participation

Stage 3: Final Siting & Licensing - Decision Under the Microscope

Briefing

Nagra has identified two preferred sites. ENSI has delivered its safety assessment. You must now launch the federal review and manage the political process - including the possibility of a national referendum.

Your leadership will shape whether the final decision is sustained - or challenged.

Elements of Context

This is the legal and political apex of the repository process. The general licence application has been submitted; now Parliament and potentially the public must decide. Strategic coordination is essential - not to eliminate dissent, but to secure legitimacy.

You must also address fairness to the host region: is it a duty of solidarity or compensation for assumed risk? The outcome will hinge not just on technical quality, but on perceptions of democratic maturity and procedural justice.

1. Launch the Federal Review Process (Choose one)

What starting point will you adopt for reviewing Nagra's proposal?

- ○ Accept the shortlist and begin federal licensing immediately
- ○ Delay pending final feedback from regional conferences
- ○ Launch parallel public, NGO, and cross-border consultations
- ○ Commission a final independent ethics and trust assessment

2. Parliamentary Framing of the Licence (Choose one)

Choose the main narrative to frame the licence proposal.

- ○ As the result of a robust scientific and participatory process
- ○ As a technical step aligned with international best practice
- ○ As a national act of responsibility to future generations
- ○ As a provisional step in a supervised adaptive system

3. Referendum Risk Preparation (Choose all that apply)

What proactive steps do you take to manage the risk of a national vote?

- ☑ Launch a national awareness and information campaign
- ☑ Secure public endorsements from cantonal and regional leaders
- ☑ Invite key NGOs to roundtable dialogue on process legitimacy
- ☑ Include youth councils and regional panels in messaging

4. Perceived Referendum Risk Level (Slider: 1-10)

Based on your current pathway, how likely is a referendum?

◉ 1 = Broad consensus - low mobilisation risk

◉ 10 = High contention - significant risk of public rejection

Stage 4: Implementation & Memory - Building Across Generations

Briefing

The general licence is now in force. You enter the implementation phase: construction, emplacement, and long-term stewardship.

Your decisions will shape how future generations monitor, understand, and remember the repository - and how your legacy is judged.

Elements of Context

This phase is no longer purely technical. It is social, ethical, and cultural. You must define strategies for reversibility, real-time monitoring, and intergenerational knowledge transfer. Memory - not just safety - becomes a policy challenge.

Partnerships with schools, museums, universities, and citizen platforms may offer long-term resilience - but only if planned with intent. Your decisions now will define whether the repository becomes a symbol of responsibility - or a forgotten hazard.

1. Define Construction and Emplacement Strategy (Choose one)

How do you phase physical implementation?

⭕ Full construction and gradual waste emplacement

⭕ Pilot repository with a 10-year observational period

⭕ Delay waste emplacement until real-time monitoring systems are validated

⭕ Build infrastructure but postpone any emplacement for now

2. Design the Memory Preservation Approach (Choose one)

Select the principal memory preservation strategy to initiate.

⭕ Construct symbolic monuments and multilingual markers

⭕ Develop a digital "time capsule" and memory archive

⭕ Embed nuclear literacy into national education systems

⭕ Combine all measures under a UNESCO heritage strategy

3. Long-Term Engagement Measures (Choose all that apply)

Which societal connections will you institutionalise?

☑ National education programme on nuclear legacies

☑ Citizen science and monitoring initiatives

☑ Annual intergenerational events and remembrance festivals

☑ Partnerships with museums and universities to steward knowledge

4. Legacy Trust Index (Slider: 1-10)

How confident are you that future generations will understand and sustain the repository system?

◉ 1 = Low confidence - memory likely to fade or be lost

◉ 10 = Strong safeguards and cultural anchors in place

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In the interest of transparency, we acknowledge that generative AI tools (primarily ChatGPT) were used extensively throughout this project. This included support for brainstorming ideas, drafting content, developing game logic, and preparing this report and other supporting materials.

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