Deliverable 17.5:
Enhanced system understanding, multi-party dialogue.

Work Package 17 MODATS

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Executive Summary

This document aims to present how the complex underlying socio-technical dimensions involved in monitoring system of a geological disposal of radioactive waste were addressed thanks to an experimental methodology of multi-party dialogue, which was developed and tested in the frame of the sub-task 2.5 of the European Joint Programme on Radioactive Waste Management (EURAD) MODATS work package.

The work of sub-task 2.5 proposed pathways for appropriate interactions between researchers and members of civil society. The experimental method used for building such pathways is based on the general framework given in EURAD interactions with civil society (ICS), relying on the implementation of the Aarhus Convention, notably through European Directives 2003/4/EC and 2003/35/EC (access of civil society to information, participation, justice) and acknowledges the work already done in other programmes. The framework of ICS in EURAD already gave in other WPs different initiatives and fruitful methods of interactions with civil society, enabling the finding of an appropriate room for civil society in such research programme.

In the frame of MODATS, two multi-stakeholders' workshops were organized in Nancy in April 2023 and Paris in October 2023. The organisation of the workshops 1°) enabled to discussed key topics related to monitoring and data management and 2°) contributed to confirm the validity of experimental methodological processes: discussions based on practical cases and elaboration of a specific version of a PEP tool. The PEP methodology enabled discussion on a same footing and the specific version of PEP on monitoring and digitalisation is a promising tool that could be used in future research involving multi-stakeholders. Members of the public can bring a different way of thinking that would be useful to consider in a comprehensive approach: including members of the public in face-to-face discussions can help build trust, and it may lead to technical experts improving the way that they explain their concepts. This demands a certain reflexivity on governance, in the spirit of a shared safety culture and mutual understanding.

The workshops organised in the frame of MODATS sub-task 2.5 highlighted 6 major outcomes regarding monitoring: the definition of the major concepts, the questions about data, models and digital twins, the knowledge management challenges, the long-term issues, the core concepts of confidence and trust and the link with civil society. These outcomes which emerged in multi-party dialogues, helped to lay the foundations for a socio-technical interpretation of monitoring, that could be used for the organisation of other socio-technical exchanges related to GDF monitoring, and opened axis of future activities.

This report presents the proposed methodological approach and its associated feedback, as well as the main outcomes of the discussions. It also proposes an interpretation of the way the socio-technical complexity of the monitoring system for a geological disposal facility can be addressed between research partners and civil society members.

Figure 1. Participants of MODATS sub-task 2.5 Workshop n°2 - October 2023, Paris

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Acronyms

CSO	Civil Society Organisation
GDF	Geological Disposal Facility
ICS	Interactions with Civil Society
MODATS	MOnitoring equipment and DAta Treatment for Safe repository operation and staged closure
MoDeRn	EU-FP7 project "Monitoring Developments for Safe Repository Operation and Staged Closure"
Modern2020	Horizon2020 - project “Development and Demonstration of Monitoring Strategies and Technologies for Geological Disposal”
NTW	Nuclear Transparency Watch
PEP	Pathway Evaluation Process
RE	Research Entity
RWM	Radioactive Waste Management
SOTA	State-of-the-Art
TECDOC	IAEA Technical Document
URL	Underground Research Laboratory
WMO	Waste Management Organisation
WP	Work Package

1. Introduction

Today, almost no industrial facility can operate without an associated monitoring system to control its operation or evolution. These systems traditionally help to gather online information to assist in decision-making, regarding the operational management of the facility.

Envisaged industrial solutions for managing high-level and long-lived radioactive waste on the long term involve disposal in deep geological formations. This disposal serves two main purposes: first, isolating the waste from environment, and second, confining the waste as long as possible away from potential groundwater flow, which could transport radionuclides to the surface.

Depending on the country and particularly on constraints related to the subsurface resources of each, the type of rock considered can vary significantly (primarily crystalline and clayey rocks). The concept of geological disposal is then based on safety functions, which vary from one country to another, with some considering the rock as the main component of the confinement, others considering the package or engineered barrier system as providing the main part of the confinement.

In such a context, it is relatively easy to understand that safety cases can vary from one country to another, as well as the objectives and thus the way of implementing a surveillance system. In addition, there are certain inherent characteristics of deep geological storage facilities. Indeed, the installation of a large number of sensors, along with cable pathways that themselves may affect safety functions (of the rock, seals, packages, etc.), makes establishing a surveillance strategy complex. Furthermore, the long-term durations to consider for issues such as sensor maintenance pose a colossal technical challenge. Finally, questions regarding the management of data derived from this surveillance over the very long term are also a challenge that must be considered.

The safety of deep geological disposal of radioactive waste cannot rely solely on monitoring system. Indeed, given the very long timescales involved in the life of a repository (several hundreds to thousands of years), modelling remains an essential component in demonstrating long-term safety. Furthermore, given the constraints involved in installing and maintaining sensors within a repository, as well as the detriment they can cause to the watertightness of the host rock, a monitoring system cannot be considered on its own as an element in demonstrating safety. Nevertheless, it is essential to acquire information from such a facility to support model predictions, to support decision-making in the event of an incident, to provide transparency (a guarantee of trust for society) and to ensure memory until the repository is closed, notably to refine the safety argument. Monitoring is also relevant to support in the transition between disposal phases (operational, closure, etc.). These elements highlight how tricky could be a common and shared understanding of what is a surveillance system of a repository, between experts and non-experts.

For years, researchers have been exploring monitoring technologies for geological repositories, previous international collaborative RD&D activities, such as the European Thematic Network (ETN; 2001-2004)[1], the Geneva Workshop (2007)[2], the MoDeRn and Modern2020 (2015-2019) projects, and relevant publications from intergovernmental organisations (including the Nuclear Energy Agency (NEA) and the IAEA) and national waste management programmes.

More specifically, the Modern2020 project, funded by the Euratom research and training program from 2015 to 2019, provided guidance on designing monitoring programs. It also created a "Stakeholder guide" aimed at explaining geological disposals and the associated monitoring to a broad audience. This guide included detailed information on past and present discussions between Civil Society (CS) and various stakeholders, such as implementers and authorities.

[1] European Commission (2004). Thematic Network on the Role of Monitoring in a Phased Approach to Geological Disposal of Radioactive Waste, Final Report. EUR 21025 EN.

[2] E.J. Harvey and M.J. White (2007). Monitoring of Geological Repositories: Summary Note of an RWMC / Nirex Workshop. Geneva.

These studies are continuing under MODATS (Monitoring Equipment and Data Treatment for Safe Repository Operation and Staged Closure), a EURAD (European Joint Programme on Radioactive Waste Management) work package (WP), which is focusing on evaluating, developing, and describing monitoring methods and technologies. The MODATS work package aims to evaluate, develop and describe monitoring methods and technologies, and to provide the means to measure, treat, analyse and manage monitoring data in a consistent manner.

Activities in MODATS WP focuses on monitoring during the operational phase of repository programmes to build further confidence in the long-term safety case. The ambition of the MODATS WP is to address detailed questions regarding monitoring data that have been identified, but not resolved in previous international collaborative activities. For further details regarding the initial objectives and context of MODATS WP, see its SOTA document. [3]

In this scenario, there is a clear recognition of the necessity to engage society in conversations concerning research on monitoring. This is crucial due to the various implications it holds for society, such as preserving the memory of the operational phase and considering the intergenerational aspects related to the long-term existence of such facilities. From the perspective of civil society, grasping the significance of a monitoring system for experts and decision-makers in ensuring safety is paramount. This entails comprehending how monitoring outcomes contribute to refining the safety argument and guiding future decision-making procedures.

Therefore, it seemed imperative to seek effective methods for involving civil society in discussions regarding monitoring. Given the complexities surrounding GDFs, monitoring systems, safety cases, and their technical intricacies, alongside the unique nature of these facilities compared to other industrial installations, establishing a dialogue between experts and civil society members can prove challenging. Mutual understanding of the issues and technical subjects cannot always be guaranteed. This is precisely one of the major goals of this work which was developed through MODATS WP, to use methodology in order to create the good conditions to enable those discussions.

Furthermore, there is broad consensus among various countries regarding the importance of upholding the principles set forth in the Aarhus Convention. This commitment involves ensuring significant access to information, avenues for public engagement, and avenues for legal redress in all environmental matters, including scientific initiatives related to Geological Disposal Facilities (GDFs). EURAD plays a pivotal role in facilitating knowledge exchange and addressing conceptual divergences among European member states concerning deep geological disposal facility programs. Operating as a collaborative platform, EURAD promotes cooperation and dialogue among member states, facilitating the exchange of best practices, lessons learned, and diverse perspectives. By convening experts, policymakers, and stakeholders from diverse backgrounds, EURAD creates opportunities to bridge gaps in understanding and harmonize strategies for the safe and efficient management of radioactive waste. Through collective efforts, EURAD contributes to consensus-building, transparency promotion, and the enhancement of the combined capacity of European member states to tackle the complex challenges associated with deep geological disposal.

The governance structure of the interactions with civil society (ICS) within EURAD follows a "3+1" dialogue approach, wherein civil society is considered a legitimate participant but not with the same role as Waste Management Organizations (WMOs), Technical Support Organizations (TSOs), and Research Entities (REs). This setup allows for the involvement of ICS at a supranational level, fostering the development of new ideas that enrich the debate on geological disposal beyond national decision-making contexts, where ongoing interests and stakeholder positions may not necessarily foster fruitful interactions. The EURAD program includes interactions with civil society (CS) based on a "double-wing" model, which has been refined and tested through projects like SITEX II and JOPRAD, particularly in view of the EURAD proposal. The double-wing model is an operational model of interaction with civil

[3] Bertrand J., Haines, T., White, M. (2023): Initial state-of-the-art on monitoring in radioactive waste repositories in support of the long-term safety case. Final version as of 24.08.2023 of deliverable D17.1 of the HORIZON 2020 project EURAD. EC Grant agreement no: 847593.

society based on epistemic, moral and political principles described notably by Arnstein[4], Schon[5] or Cetina[6]. More details about these principles and the double-wing model itself can be found in the PMO deliverable D1.16 "Evaluation of the experimental model of interaction between EURAD participants and Civil Society".[7]

The double-wing model encompasses two categories of CS participants: the Civil Society Larger Group and the Civil Society Experts Group. The selection process for the CS Larger Group was developed by the Program Management Office (PMO) Task 8, validated by EURAD PMO and Bureau, and comprises 22 selected members from 15 countries. The group maintains a balanced representation between Western and Eastern countries, gender diversity, and various categories of stakeholders, including individuals, local stakeholders, and national or European associations. All CS members have committed to participating in the entire EURAD 1 ICS activities (2019-2024), supporting EURAD's vision and pledging constructive contributions in line with EURAD's objectives.

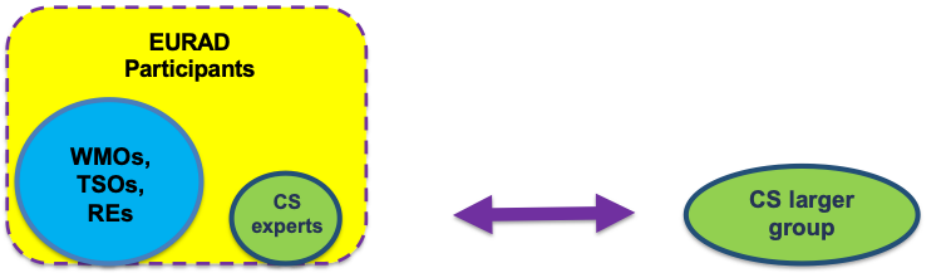


Figure 2. Double-Wing model of interactions with Civil Society in EURAD

The CS experts serve as a bridge between the EURAD participants and the larger CS group, facilitating the translation of technical findings into understandable language for a non-expert audience. They also facilitate mediation during dialogues between experts, researchers and CS representatives. Indeed, several scientists are working in the field of monitoring, researchers and experts, sometimes both involved in research programs or safety assessment. Depending on the role of each participant, it was noticed that language could vary from one to another, which can notably lead to different understanding from CS.

This mediation, conducted within the CS members, fosters trust in the dialogue process among the involved experts and CS representatives. The group of CS experts consists of 14 members from various European countries, operating under the umbrella of Nuclear Transparency Watch, a European network comprising 50 members (individuals and organizations) from twenty European countries, with the aim of fostering citizen vigilance regarding safety and transparency in nuclear matters.

The CS larger group comprises 22 members representing two categories of stakeholders: representatives of European and national associations, and local stakeholders (individuals or representatives of local communities with an interest in Radioactive Waste Management - RWM). In order to incorporate diverse perspectives on Radioactive Waste Management, the CS larger group intentionally includes members from European countries with both less and more advanced RWM programs, citizens from Western and Eastern Europe, individuals with various interests in fields related to RWM (such as health, environment, science, and energy), as well as people from diverse genders and generations. The detailed selection process of these members is outlined in EURAD D1.13 List of CS members.

[4] Arnstein, S. (1969): A ladder of citizen participation, *Journal of the American Institute of Planners*, vol. 35, n°4.
[5] Schon, D.A. (Ed.). (1963): Displacement of Concepts (1st ed.). Routledge. https://doi.org/10.4324/9781315014111
[6] Cetina, K. K. (1999): *Epistemic Cultures: How the Sciences Make Knowledge*. Harvard University Press. https://doi.org/10.2307/j.ctvxw3q7f
[7] Fontaine Gauthier, Geisler-Roblin Alexis, Lavelle Sylvain, Dewoghélaëre Julien. (2024): Evaluation of the ICS activities and experimental model of interaction between EURAD participants and Civil Society. Final version as of 16.05.2024 of deliverable D1.16 of the HORIZON 2020 project EURAD. EC Grant agreement no: 847593.

The ICS practices are rooted in innovative methodologies aimed at facilitating interactions on equal ground. Specifically, within the EURAD framework, ICS methodologies are openly employed during interactions involving contextualized case studies or dialogue tools such as the Pathway Evaluation Process (PEP) tool. These methodologies and tools were also utilized within the MODATS context, as part of sub-task 2.5

Within the MODATS work package, primarily focused on sensor and monitoring data management, sub-task 2.5 aimed to facilitate discussions between the three colleges of EURAD (WMOs, REs, TSOs) and members from EURAD civil society groups (CS experts and CS larger group) to tackle the intricate challenges associated with monitoring within surveillance systems.

The primary objectives were to cultivate mutual understanding and shared perspectives among participants, including research partners and civil society members, regarding key challenges and topics related to monitoring systems. Additionally, the task sought to gather opinions, questions, and expectations from participants to enhance socio-technical dialogues. In essence, the central inquiry of this work was: how to establish a suitable multi-party dialogue on issues linked to GDF monitoring?

This overarching question guided the following objectives of sub-task 2.5:

- Contribute to the development of mutual understanding and shared perspectives on key challenges and topics related to monitoring systems and data management.
- Collect civil society's expectations on monitoring.
- Introduce a socio-technical interpretation of monitoring systems.
- Contribute to research by identifying points of vigilance.

The initial step involved considering five main topics for discussion, encompassing structural problematization questions:

- Data provided by sensors.
- Information systems to collect, view, analyse, and understand transferred data.
- Traceability of knowledge.
- Digital twins as examples.
- Connection with the governance process, reliability, trust, and unexpected data.

Additionally, a cross-cutting topic addressed throughout was the various conceptual and operational relationships between monitoring and safety cases.

Following this, sub-task 2.5 of MODATS organized two workshops (held in Nancy in April 2023 and in Paris in October 2023) to facilitate productive interactions between MODATS experts and members of the EURAD civil society group. These workshops played a pivotal role in generating numerous methodological options. Insights gleaned from discussions informed assumptions regarding methodology and the dissemination of conclusions drawn from oral exchanges.

This report offers a comprehensive overview of the completed work, presenting various results in terms of methodology and content outcomes. Furthermore, it consolidates lessons learned that could guide the organization of future diverse interactions concerning monitoring systems and delineates potential avenues for further research.

2. Methodological process of the multi-party dialogue

The multi-party dialogue process undertaken in sub-task 2.5 was implemented in two phases. A preparatory phase aimed at defined terms, topics, and questions consistent for the multi-party dialogue on monitoring. This definition of topics started by a review on previous work done in Modern2020 related to public participation and at the end, the preparatory phase identified in a collective manner five main topics to be discussed. An implementation phase was then undertaken in two steps: a first workshop dedicated to three topics on monitoring with a methodology of dialogue based on practical cases, and a second workshop dedicated to digitalisation of monitoring and trust issues that used the PEP methodology. The governance topics was a cross-cutting issue that has been discussed during the two workshops. The organisation of the workshops enabled to test several methodological possibilities and gave interesting results on how to address monitoring issues in a multi-stakeholder framework.

2.1 Preparatory phase of the multi-party dialogue

2.1.1 Review of Modern2020 stakeholder guide

To ground its works on past results, the coordination team of sub-task 2.5 started by reviewing the deliverable D5.2 "Monitoring in geological disposal and public participation: a stakeholder guide[8]" of the Modern2020 project[9]. One objective of this project was to consider public stakeholder expectations (particularly those of local public stakeholders at (potential) disposal sites). In this perspective, researchers on monitoring and local citizens from Belgium, Finland, France and Sweden, with the support of social scientists from Antwerp University, thought about monitoring issues together: what is the role of monitoring in the frame of GDF and how to include public participation in the frame of RWM? Written as part of Modern2020 project, the Stakeholder Guide aimed to introduce the process of geological disposal and some of its challenges to a broader audience. Firstly, it presents the state-of-the-art of monitoring technologies and strategies for high-level radioactive waste repositories in an accessible way. Secondly, it is intended to serve as a source of inspiration for local stakeholders who are involved in the decision-making process regarding RWM.

The goal for the review of this stakeholder guide by MODATS sub-task 2.5 team was to identify in the results of this previous project interesting elements for elaborating fruitful interactions between researchers and civil society representatives in the frame of the multi-party dialog of MODATS. In order to perform this review, sub-task 2.5 team has undertaken a qualitative evaluation of its content, using a methodology developed in the frame of the evaluation of ICS activities[10].

First, this deliverable is recognized by sub-task 2.5 team as an effective tool for conveying technical topics to a broad audience, including key monitoring concepts and tools. It reflects a genuine commitment to transparently communicate foundational concepts related to geological disposal and monitoring systems to the public. Sub-task 2.5's evaluation also identified several important points:

- Monitoring can create a link between the disposal programme and people (experts and non-experts) and could play a supporting role for governance by supplying data to the safety case.
- Not only local stakeholders should be considered, but a dialogue also involving different types of CS stakeholders could enrich the discussions about monitoring. MODATS was the opportunity to include national and transnational public into the discussion.

[8] A. Meyermans, P. Cools & A Bergmans (2019), "Monitoring in geological disposal & public participation: a stakeholder guide", Deliverable D5.2 of the Modern2020 project (2015 – 2019), ISBN: 9789057286148, University of Antwerp

[9] For more information on Modern2020, see: http://www.modern2020.eu/

[10] For more detailed regarding the methodology, see A. Geisler-Roblin, S. Lavelle (2022), "Mid-term evaluation of the ICS activities and experimental model of interaction between EURAD participants and Civil Society", Final version as of 10.10.2022 of deliverable D1.14 of the HORIZON 2020 project EURAD. EC Grant agreement no:847593.

- In addition to this, there is a lack of focus on the meaning that the Modern2020 scientific results have for the public, at the local and national level, including data availability. Monitoring is a technical topic and there is a need to focus more in detail on the technical elements. MODATS multi-party dialogue tried to constitute a tool to bring technical knowledge into discussion with civil society in an understandable way, and a tool to frame monitoring technical questions regarding a CS perspective.
- The purpose is not to build stakeholder's confidence, because confidence is a result, not a goal itself. From sensors to public, transparency is one major key to create a reliable interaction about the system understanding by all stakeholders (including public).
- In the stakeholder guide document, there is an implicit picture of the governance that is relatively static in the approach of the different roles, by considering fixed through time the different categories of actors, and thus by not considering the timely evolutions of institutions and empowered populations. On the other hand, in EURAD CS is organised in the perspective of the Aarhus Convention, which is more dynamic, as it highlights the importance of the possible means for civil society to better contribute to decision-making though time and institutional changes.

All these elements presented here pointed out to the following conclusion: involvement of CS in RWM and in the specific context of monitoring could contribute to improve transparency, public participation, decision making process, in this specific long-term and multigenerational context of RWM. RWM can be understood as a long-term decision-making process in an uncertain environment. Therefore, governance should be dynamic in a long-term context, and the question of monitoring is a big challenge in that perspective.

2.1.2 Definition of topics for the multi-party dialogue

A meeting was organized in January 2022, gathering different partners from MODATS task 2[11], aiming at co-constructing the topics to be discussed in the multi-party dialogue. To ensure diversity of views, representatives of the different views of actors involved in MODATS (WMOs, TSO, RE and CS) attended the meeting. In order to connect the topics for the multi-party dialogue with the work achieved in MODATS, the meeting started by presentations on the different MODATS Task 2 activities: work on monitoring quality assurance and technology roadmaps[12], on data management, modelling and visualisation[13], on lessons learnt for repository monitoring from Underground Research Laboratory (URL) experiments[14] and work on development of digital twins in the context of GDF[15]. Then a discussion was engaged to define the topics to be discussed during the multi-party dialogue.

The results of the "Modern2020 stakeholder guide" review and the discussion with task 2 partners led to a proposal of five topics. For each topic a short title and description are given followed by some questions which illustrate the potential aspects to be discussed:

[11] the technical partners of MODATS task 2 were the following: ANDRA, SSTC NRS, PSI, EURIDICE and UFZ in addition to the sub-task 2.5 coordination team members: IRSN, Mutadis, EIMV and NTW

[12] the results of the work done are available in M. White, Y. Caniven, T. Haines, J. Verstricht, J. (2024): Guidance on Quality Assurance Programme Plans for Repository Monitoring Programmes. Final version of Deliverable D17.4 of the HORIZON 2020 project EURAD. EC Grant agreement no: 847593.

[13] The results of the work done are available in M.J. White, J. Bertrand, F. Chinesta, J. Cotton, N. Graebling, T.J. Haines, G. Hu, A. Laikari, E. Manukyan, D. Muñoz, W. Pfingsten, M. Schoenball, A.E. Thomas, J. Verstricht, C. Wetter (2024): Advancements in Monitoring Data Management, Modelling and Visualisation. Final version of deliverable D17.6 of the HORIZON 2020 project EURAD. EC Grant agreement no: 847593.

[14] The results of the work done are available in T. Haines and M. White. (2022): Lessons for Repository Monitoring from Underground Research Laboratory Experiments. Deliverable D17.3 of the HORIZON 2020 project EURAD. EC Grant agreement no: 847593

[15] The results of the work done are available in M.J. White *et al.* (2023): Position Paper: MODATS Opinion on Digital Twin. EC Grant agreement no: 847593.

1. **Data delivered by sensors:** issues related to the types of sensors envisioned for GDF monitoring like wireless data transmission, interactions between sensors and multi barriers repository system, etc.:
   - Which parameters/data will be collected?
   - When and how long?
   - Is the collected data complete?
   - What will be done if something goes wrong? e.g., no data, spurious data…
   - How to deal with big variabilities of data?
2. **Systems that allow to collect, view, analyse and understand the transferred data:** issues related to data management, to the integration of monitoring data and models, etc.:
   - How will the interpretation of data be organized?
   - Who will be involved?
   - What kind of peer review will be performed?
3. **Traceability of knowledge:** issues related to the transparency, access to data and traceability of data over time**:**
   - What is it meant by traceability?
   - What kind of knowledge?
   - Who will be involved?
   - How long will the traceability be assured?
4. **Data digitalisation and digital twin:** issues related to data digitalisation and the potential implementation of a digital twin for GDF:
   - What are they used for?
   - What will be included?
   - Is the model complete?
   - Does it provide information on the reality (uncertainties, real data, etc.) or on inferred phenomena (models)?
5. **Governance process:** issues related to governance of GDF monitoring and related models, involvement of different stakeholders and conditions for ensuring confidence**:**
   - How will it be organised?
   - Who will be involved?
   - For how long?
   - How would inputs from new data be provided?

The results of the discussion confirmed that the topics were relevant to engage a multi-party dialogue. One specific element was added to the envisioned topics. From a technical perspective, recent advances in battery technology and distributed fibre optic sensors enhance the possibilities of monitoring, including after closure. Such technology shows a potential to give long-term visibility on monitoring and increase confidence in long-term safety when institutional control ends post-closure. It was decided to include this information to feed the discussion of the workshops of sub-task 2.5.

2.2 Implementation phase: organisation of workshops and creation of the PEP tool on monitoring

2.2.1 A multi-party dialogue implemented in two steps

The multi-party dialogue was practically implemented in two steps: a first workshop held in Nancy (East of France) in 18-20 April 2023 and a second Workshop in Le Vésinet (first day) and Paris (second day) in 24-25 October 2023. Initially, this second workshop was planned to be online, but it was decided after the first workshop to change the online format to a physical one in order to preserve the good quality of the exchanges. Each time, the possibility for online connections for participants who could not join the meeting in person was nevertheless allowed.

The first workshop initiated the discussion between EURAD and CS representatives on the first three topics identified during the preparatory phase (see 2.1 above): data delivered by sensors, systems that

allow to collect, view, analyse and understand the transferred data, and traceability of knowledge. The questions related to monitoring's governance (identified topic n°5) were also tackled as cross-cutting issues. We organised the discussions as follows:

- An introductory discussion related to the definition of monitoring and its meaning for the different actors in the frame of the GDF implementation.
- A second discussion was organised in working groups around practical cases presenting different issues related to the three monitoring topics. The list of practical cases is available in appendix C of the report.
- A plenary session provided an opportunity to share and discuss the results of each group. The goal was to collect the views of the different actors to identify potential communalities and differences between them.
- A final discussion was structured around the link existing between monitoring and the safety case.

In the perspective of the continuation of the discussions initiated during the first workshop, the second workshop dealt with the topic of digitalisation (identified topic n°4) and governance issues (topic n°5). The link between monitoring, and trust and confidence in the context of geological disposal was also addressed. The main question structuring this second workshop was: "How digitalisation and monitoring systems in the different contexts of GDF projects can contribute to a larger strategy of uncertainty management enabling trust-building processes in all phases?" To answer this question, we implemented four pillars:

- The technical visit of Téléray Remote Monitoring Network, an IRSN facility located in Le Vésinet (France) dealing with environmental monitoring and that provides to the participants an interesting example of a surveillance system as a digital twin[16]" (see also 2.3)
- A test of the PEP tool dedicated to monitoring issues, aiming at facilitating multi-stakeholder's discussion on this topic.
- A session was dedicated to presentations of each type of actors' views on digitalisation of monitoring topic and the way it can help in decision making. A roundtable was then organised to exchange views between the different actors' visions.
- A discussion dedicated to the link between confidence, trust and monitoring, based on a presentation prepared by sub-task 2.5 gathering elements coming from IAEA TECDOC 1208 or SSG-31 (2014)[17], the sociologist Niklas Luhmann's theory on trust as a way to improve the stability of complex systems ("*trust is an […] effective form of reducing complexity"*)[18] , and two other workshops: ICS workshop n°4 held in Fontainebleau (near Paris) on 24-25 May 2023 and ICS workshop n°5 held in Brussels on 18-19 October 2023. These two workshops were organised in the frame of EURAD ICS activities and have gathered views from members of civil society on this specific topic of the contribution of monitoring to confidence.

The detailed agenda of the two workshops are available in Appendix A and B.

2.2.2 Audience of the two workshops

Regarding the audience of the two workshops, it was decided to invite MODATS sub-task 2.5 members, all interested MODATS partners (with priority to Task 2) and all members of CS involved in EURAD (either as CS experts or members of CS larger group[19]). The number of places was limited for financial reasons (provisioned budget allowing a participation of around 15 CS participants in addition to the MODATS sub-task 2.5 partners) and methodological ones (the implemented methodology of dialogue necessitated small groups of discussions with a limited number of facilitators). For the organizers, it was important to have diversity of participants: representatives from the different types of research actors in

[16] See the Téléray webpage: http://teleray.irsn.fr/

[17] IAEA Safety Standards Series No. SSG-31 (2014): Monitoring and surveillance of Radioactive waste disposal facilities, Specific Safety Guides

[18] N. Luhmann (1979): *Trust and Power*. Wiley, Chichester. Other authors could have been consulted as well (Weber, Habermas). It was a first step of discussion on this issue to provide inputs for MODATS issue on data confidence. As Luhmann's theory of complexity can describe well RWM, it was considered as an interesting author to start with. These discussions should be further developed and enriched with other references.

[19] See introduction for details on the two CS groups in EURAD

EURAD, local and national CS stakeholders coming from various countries (Eastern and Western Europe) with different GDF programmes (more and less advanced programmes).

At the end, the two workshops gathered approximatively 20 participants ensuring a certain diversity of views. The list of participants of the two workshops are available in Appendix A and B. Nevertheless, there are elements that could be improved in the composition of the audience: the representation of the eastern countries could have been better, as well as the number of local stakeholders. It could have been interesting to integrate also other type of stakeholders like regulators and public decision-makers to enrich the discussions. The composition of the PEP groups during the PEP session of the second workshop could have been improved also (see the section 2.3)

2.2.3 Creation of the PEP tool on monitoring issues

The PEP methodology is the core instrument that was used for implementing the multi-party dialogue in MODATS. This methodology has been developed within the SITEX II project (2015-2017). It is based on a "serious game[20]" enabling a multi-stakeholder's discussion on radioactive waste management issues. The main goal of the PEP is not to identify one solution as better than another. The objective is to facilitate discussions between different types of stakeholders to grasp the complexity of the issues involved in the management of radioactive waste in the short, medium and long term. It is also to better understand the views positions of the different categories of actors. The PEP objective is to identify and discuss issues, that are important to the various stakeholders (including civil society), in the context of the investigated RWM "Pathways" over a timescale of several generations. RWM is considered including waste already produced and potentially waste to be produced.

The PEP tools are composed of boards (representing different types of strategies or "pathways" to manage the waste until a "safe terminus": a safe situation that does not require human intervention) and cards. There are two sets of cards: the events cards describing events or/and uncertainties that could challenge the pathways and the evaluation criteria cards that are questions enabling to orient the discussions.

The PEP methodology invites the participants to frame the discussion by building their own practical cases (using one event card and two criteria cards). The discussion around a practical case is structured in two rounds of discussions. After the first round, the participant that suggested the practical case synthetised what he/she heard from the others. A second round of discussion is organised to let the possibility to all the participants to add additional comments and react to what they heard from the other participants. During the two rounds of discussions, every participant are invited to speak, one after the other, without being interrupted. The facilitator ensures an equal speaking time for each participant and also helps to reformulate views and opinions in order to make them clear for all the participants (without interfering with the opinion expressed).

As it is a quite demanding methodology (participants have to listen carefully what the others says and wait their turn to be able to express their views and react to the other viewpoints), the PEP methodology needs to be applied in small groups of 4-6 participants and animated by a facilitator accustomed with the methodology.

Several PEP tools already exist and are disseminated under the frame of the SITEX.Network[21]. A comprehensive presentation of this methodology is also available on the EURAD website: https://euradschool.eu/event/ll15/

[20] A **serious game** or **applied game** is a game designed for a primary purpose other than pure entertainment. Serious games are a subgenre of serious storytelling, where storytelling is applied "outside the context of entertainment, where the narration progresses as a sequence of patterns impressive in quality ... and is part of a thoughtful progress". See, https://en.wikipedia.org/wiki/Serious_game

[21] https://www.sitex.network/

In the frame of sub-task 2.5, it was decided to develop a dedicated PEP on monitoring issues. The main goals of this development were to:

- enable fruitful interactions between different participants of the MODATS sub-task 2.5 workshops (multi-party dialogue).
- collect views of the different participants in an original way.
- present results of sub-task 2.5 in a dynamic and innovative format.
- test the adaptation of PEP to a specific context (monitoring) using feedback from previous PEP sessions to provide a tool that could be used for future multi-stakeholders' interactions on monitoring.

This work on a PEP tool focusing on monitoring issues was initiated by MODATS sub-task 2.5 team with students from EM Nancy. Together with two members of NTW, the students developed thoughts on what could be a PEP focused on monitoring and preliminary PEP cards. This work was presented during the first MODATS workshop. The participants estimated that this work could provide a valuable input for multi-party dialogue. So, sub-task 2.5 decided to further develop the tool. A board and two sets of cards (events cards and evaluation criteria cards) were created and then tested during the second sub-task 2.5 workshop in Le Vésinet / Paris.

The board designed for the PEP tool on monitoring is presented in the figure 3 below:

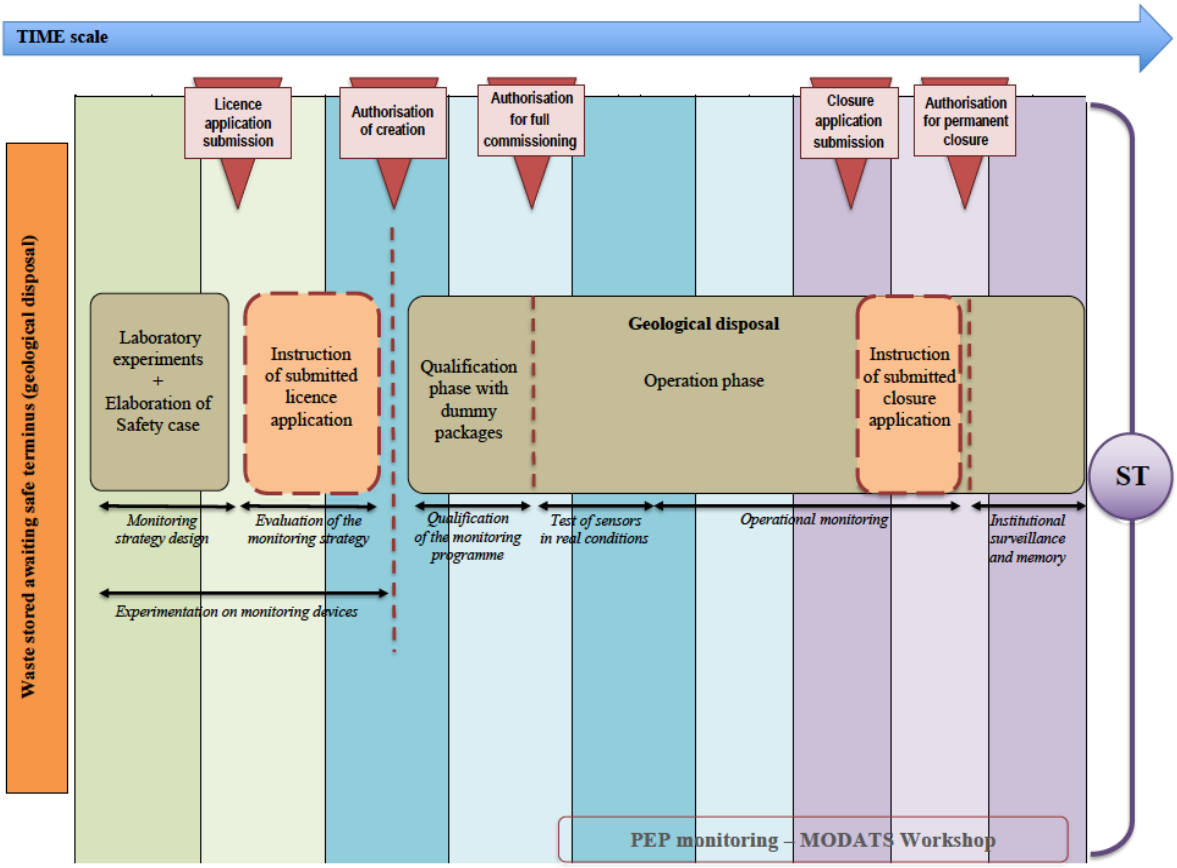


Figure 3. PEP Board - pathway on monitoring tested during the sub-task 2.5 workshop

The Board presents one generic strategy to deal with the waste inventory (the orange box on the left). The safe terminus for this strategy is the implementation of a GDF. The different steps of decisions are represented by red arrow (at the top of the board). At the middle of the board, there are the main facility implemented: laboratory + geological disposal and the important phase: instruction of the licence application, qualification phase, operation phase and instruction of closure application.

Below, we can find the different steps of the monitoring strategy (black arrows). Before the implementation of GDF, 3 elements are represented: monitoring strategy design, experimentation on

monitoring devices and evaluation of the monitoring strategy during the instruction of the licence application. At the beginning of GDF implementation, the board strategy plans a qualification of the monitoring programme. Then, tests of sensors in real conditions are planned during the beginning of the operation phase before to have operational monitoring until closure. After closure, the strategy plans institutional surveillance and elements for keeping memory of the site. All the elements are inspired of existing or planned strategies for implementing a GDF but remains sufficiently general in order to allow discussions of a various sets of situations participants could have in mind related to their national cases. This PEP board is not aiming at representing the best strategy for RWM and monitoring GDF. It is a basis for enabling participants to discuss monitoring issues.

Associated to the board, sub-task 2.5 developed two sets of cards:

- a set of "events cards on monitoring and digitalisation" illustrating situations that could occurred and challenged the strategy for monitoring.
- A set of "evaluation criteria cards" that are questions to orient the discussion on the situations presented by the participants.

21 events cards have been elaborated to help workshops participants creating challenging situations they wanted to discuss with the others, such as defective monitoring demonstrator, cyber-attack, data preservation issue, discrepancy between measurements and models, etc. Below is presented as an example, the PEP event card **M21 – Controversy on GDF digitalisation**.

Figure 4. Example of PEP event card on monitoring and digitalisation

An event card is composed of a title : "Controversey on GDF digitalisation", a generic text presenting the challenging situation " The massive use of digital tools to monitor geological disposal facility (GDF) generates scientific or/and societal discussion" and examples that can be used for illustrating more practically the situation: " 1) Scientific discussion on the real meaning of a GDF digital twin, 2) Societal controversy on the risks and benefits associated with the monitoring digitalization" A participant can of course illustrate a situation by a different example he has in mind. Examples are just here to help participants to create a situation to be discussed. If a participant is inspired by none of the card, he/she has the possibility to create its own card reflecting the situation he/she wants to discuss.

14 evaluation criteria cards have been created by sub-task 2.5 team. These cards are presenting questions to orient the discussion on a technical or more societal aspect according to the interest of the participant that frame the discussion: maintaining social trust in monitoring, continuous security of data,

adaptability of monitoring strategy, transparency and access to data, data traceability, etc. As example, the PEP criteria card **Q6 – Adaptability of monitoring strategy** is presented below:

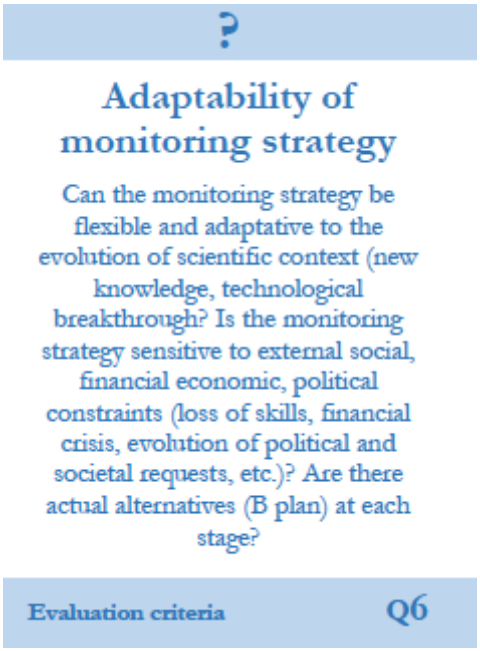


Figure 5. Example of PEP evaluation criteria card on monitoring and digitalisation

An evaluation criteria card is composed of a title “adaptability of monitoring strategy” and a set of questions related to this title: “Can the monitoring strategy be flexible and adaptative to the evolution of scientific context (new knowledge, technological breakthrough? Is the monitoring strategy sensitive to external social, financial economic, political constraints (loss of skills, financial crisis, evolution of political and societal requests, etc.)? Are there actual alternatives (B plan) at each stage?” The questions are here to focus the discussion on specific aspects that are interesting for the participant that is framing the discussion. Some participants are more interested by discussing technical aspects of the discussions, others will orient the discussion on transparency issue, etc... The questions written in the evaluation criteria cards are here for inspiration. It is not necessary to follow exactly the wording or to select all the questions present in the card (one participant could formulate the question on the same topic differently or could choose only one question on the card for orienting the discussion). If a participant is inspired by none of the card, he/she has the possibility to create its own card reflecting the question he/she wants to raise.

The detailed lists of the two sets of PEP cards on monitoring and digitalisation are available in appendix D.

Thanks to the elaboration of these elements (board and two sets of cards), a PEP session has been organised during the second sub-task 2.5 workshop. The participants were divided in three groups of 5-6 participants. The discussion in each group were ensured by a sub-task 2.5 member (NTW or IRSN). Each participant was invited to create a challenging situation to be discussed by the group following the PEP methodology. To create a situation, a participant had to select one event card and to associated with two evaluation criteria cards. The figure 6 below presents one example of a situation.

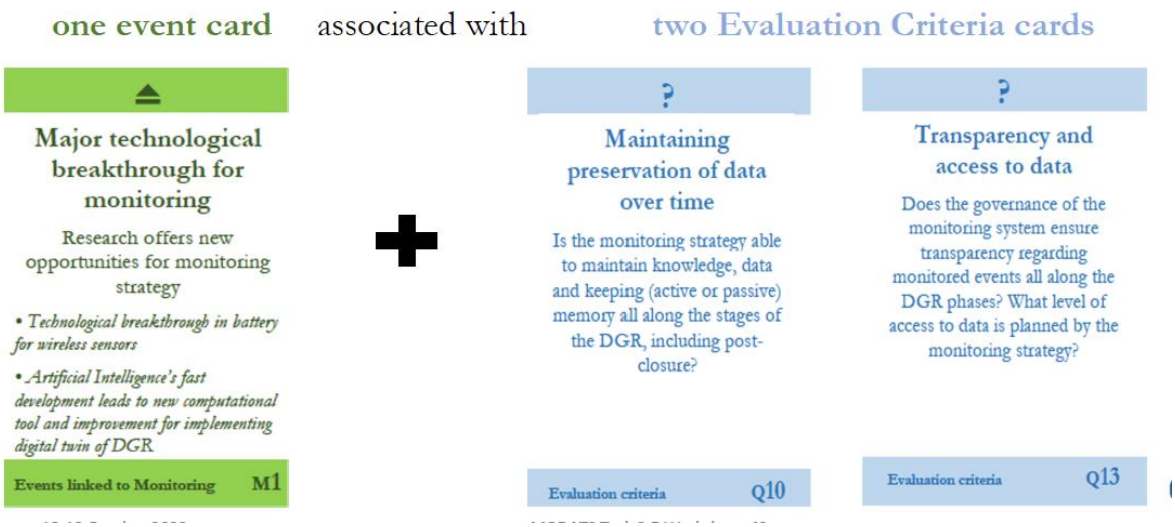


Figure 6. PEP mechanisms

Based on the text on the cards and with the support of the facilitator, each participant was invited to detail the challenging situation he/she elaborated: give details on the event to facilitate the discussion with others and explain the choice of the questions and the points he/she wanted to discuss in relation to the challenging situation. The participant had then to precise at what time the situation could occurred by locating the event card on the PEP board: the discussion is not the same if the event occur at the beginning of the pathway, during the operational phase, or near before the GDF closure. When all the details have been given, the facilitator started the two rounds of discussion letting each other participants gave their views on the challenging situation: they had to answer the questions of the evaluation criteria cards, giving their feelings on the realism of the situation (is it improbable or on the contrary a very probable situation) and on how the issue could be solved: what is robust in the strategy presented on the board, what should be adapted in order to solve the issue, etc... At the end of the first round of discussion, the participant that suggested the situation did a synthesis of what he/she heard from the others and gave potential additional elements according to the different answers given. Then, a second round of discussion started, enabling other participants to react on what the others said during the first round. After the second round of discussion, the facilitator closed the discussion and invited another participant to suggest a new challenging situation to be discussed. At the end of the PEP session, four of five situations were discussed by each group.

2.3 Methodological outcomes to address monitoring issues in a multi-stakeholder framework

This section presents the main lessons learnt during the experimental implementation of the multi-party dialogue: discussions around “practical cases” during the first workshop and test of the PEP tool during the second workshop. These lessons are related to the conditions needed to implement a fruitful dialogue on GDF monitoring between different types of actors and more precisely WMOs, TSO, RE and civil society. There are also elements related to the role of the technical visits associated with the workshops and specific elements related to the PEP session.

2.3.1 Conditions for enabling fruitful interactions within a multi-stakeholder audience

To implement the multi-party dialogue in MODATS, sub-task 2.5 followed rules that are important for ensuring the quality of the exchanges between the different types of actors involved.

Build a safe place for dialogue:

For ensuring good exchanges during the multi-party dialogue, it was needed to elaborate a space where the participants can exchange safely, with respect towards the other participants and without pressure

of any kind. In order to ensure such a safe space, the CS representatives involved in EURAD, and the experts involved in MODATS that participated to the workshops have accepted the rules to exchange in an opened manner with respect of the different positions. The goal of the multi-party dialogue was to collect the different views and to try building a mutual understanding on what could be monitoring of GD and what are the conditions for ensuring trust in the monitoring system for the different actors.

The discussion on practical cases and the PEP that were used during the workshops were based on rules that ensure a safe space. As it was described in the PEP methodology (see 2.2.3 above), each participant has to listen the others and has to express his/her views. It is quite demanding because some participants are at ease to express their views and share their knowledge and others are more reluctant or uncomfortable orally. It is why the role of mediator is essential in the PEP session. In EURAD and MODATS particularly, the double-wing model (see part 1) was used to generate this safe space: the CS experts were mediators between the researchers and civil society participants and helped facilitating the discussion. The different actors trusted them to ensure the safe space and they were accustomed with the PEP methodology.

It is also important to note that the actors are invited to speak freely, not as a member of an organisation but rather as a person concerned by the topics addressed. However, all the thoughts already shaped by the organisation are part of the participant's opinion, which is also has to be taken into consideration and why it is important to have equal balance between colleges in such interactions. The results of PEP sessions cannot be transferred to global or generic statements of what must be done, but they provide an input that helps the participants to better understand the other participants. It is the also reason why the collection of results of the multi-party dialogue do not bring verbatim with names associated to opinions that have been expressed. It ensures the anonymity of the data collected.

Co-construction of the dialogue frame:

A second important element is the co-construction of the dialogue frame. If the topics that could or could not be discussed are chosen before the discussion, it would lead to frustrations and risk to fail to build fruitful interactions. It is also not a way to ensure a fruitful contribution of civil society and multi-party dialogue to the research. It is important to let range for different views to be expressed and duly considered. The multi-party dialogue in MODATS was driven by this consideration.

The theme of discussion was obviously monitoring, and it was also decided to focus the discussion on five topics: (see 2.1 above). Nevertheless, the views of the different types of actors have been collected to define the 5 topics: views of MODATS actors have been collected during the January meeting (see 2.1) and views of CS participants during the ICS workshops (see 2.2.1). The PEP tool was designed by sub-task 2.5 team (composed of TSO and CS experts) but there are also "joker" cards enabling participants to create their own topics of discussion if they are not interested by the existing PEP cards.

During the preparation of the two workshops and during the discussions in the workshops, the mediation rule was to let all the actors speak freely, to have a frame as broad as possible and to include in the discussion elements that people wanted to discuss. For instance, the first workshop started with a discussion on the meaning of monitoring for the different actors. We started from the existing elements and definition established by experts in the field but put it into discussion to collect the different acceptation of the different actors of what should be monitoring.

Ensure the "global picture" - complex issue, socio-technical dimension, link to safety:

In the same perspective, the elaboration of the workshops' agenda, practical cases and PEP material was done keeping in mind the "global picture" of geological disposal. An interesting contribution of multi-party dialogue and inclusion of civil society in research is to decompartmentalise the technical discussions and to have a permanent link with safety (that is the goal of GDF). It forces to put technical results of research (on monitoring or other topics) in this more generic context of safety. To ensure this global picture, sub-task 2.5 methodology was to address the complex issues of data monitoring and digitalisation with a socio-technical perspective, including non-technical considerations (governance, financial, ethical, political issues) into the technical decisions. To consider GD monitoring in all the dimensions (and not only in silo of technical perspectives), to have embedded discussions is the better way to build a mutual understanding of the issues at stake. It is also a way to improve the quality of the

results by giving a real added value to the multi-party dialogue. The practical cases and PEP cards were elaborated to allow consideration of both technical and non-technical issues.

The first workshop also organised a session dedicated to the link between monitoring and the safety case. This discussion was based on a presentation made by IRSN as introduction to this very complex topic. It helps bringing first elements of understanding but there are still need for further discussions on the topic because safety and the safety case are a difficult topic for public stakeholders to understand.

Legitimacy of the ability to express different views, expression on the same footing:

Considering GDF monitoring in a global perspective requires establishing the legitimacy of expressing the different perspectives involved in the process. The PEP methodology allows participants to frame the discussion with the perspective to have expressions of different perspectives on the same footing. It does not mean that non-technicians are as well qualified as researchers in their field of research but that the different views are legitimate to be expressed. This rule is important to ensure the quality of dialogue. Having experts presenting their results from a podium is a passive way to exchange information. ICS methodology in EURAD and notably in MODATS tried to develop a more active and dynamic way. In addition to that, pluralism of views can let participants have new perspectives they did not have thought of before.

Interest of the practical cases:

Finally, a condition for having fruitful interactions during the multi-party dialogue is to have discussions based on practical illustrations of issues at stake. Having theoretical discussions without any contextualisation present the risk to not allow the non-technicians to enter the discussion at all. It could compromise the previous rule of letting people speak on the same footing and create frustrations for the non-specialists that will be excluded from the discussion. Contextualisation can also be a bias for the discussion, but we designed the practical cases to be as neutral as possible.

During the first workshop, the working group discussions were based on practical cases enabling to tackle key monitoring issues during interesting discussions where all actors where involved. For instance, the question related to the link between monitoring data and models is a technical issue that is difficult to enter in an abstract way or by a presentation of a model. Entering through a practical case facilitated the discussion with non-specialist's participants. sub-task 2.5 team prepared a practical case and questions (see Figure 7 below)

Practical case 1 - Inconsistency between data and models

The geological disposal has been licensed and is under operation. The waste packages are being transferred into cells that are monitored. The sensors provide for data in a way that seems reliable. However, people in charge of their analysis face some challenges: for example, in one cell, H2 concentration value is significantly higher from the other cells, without any obvious explanation, and is in conflict with the models. The H2 concentration values are still below the limit where explosion risks arise but since the phenomenon is not understood, there is no reason to believe that it will remain this way.

Questions

•What is the ideal balance between the risks posed by intervention (radiological exposure, explosion caused by air perturbation…or potential unknown situation at the time of intervention) and the drawbacks of staying in ignorance of the phenomena into play?

•Is it desirable to plan for a priori intervention thresholds, before operational phase, for any type of monitoring results? What organisations shall be implied in the definition of these thresholds?

•To what extent monitoring systems should be designed to be adaptable, flexible and easy to maintain?

Figure 7. Example of practical case discussed during Nancy's Workshop

All the practical that has been discussed are available in Appendix C. The choice of this methodology was also done because it was successfully tested in another EURAD project (UMAN seminar on uncertainty management[22])

During the second workshop, the PEP game allowed participants to address the specific issues related to monitoring they wanted to address.

2.3.2 Connecting dialogue with technical visits

In the perspective to have practical illustrations of the issues discussed during the multi-party dialogues, technical visits were organised during the two workshops. These visits were not considered as an annex event in a methodological point of view but as an integrated part of the workshop. This choice of sub-task 2.5 team of MODATS followed the example of MoDeRn during which visits of Mont-Terri and Grimsel were organised with stakeholders. For sub-task 2.5, it was a way to put monitoring topics into situation, a way to complement the practical cases discussed during the workshops, to illustrate theoretical discussions. In this perspective, a visit of Bure laboratory was organised by ANDRA in order to allow participants to discover this specific environment and all related issues connected with experiments and monitoring. A second technical visit was organised by IRSN in its Le Vésinet site where participants had a presentation of the early warning network called Téléray, dedicated to ambient dose equivalent rate monitoring, over French territory. This visit was organised during the meeting in Paris, following discussions which happened in Nancy, about IT systems and related database and support to decision making. It was interesting to establish a parallel about common problems about monitoring as spurious data, data validation process, alarm management, data publication, etc.

2.3.3 PEP methodology to the specific context of monitoring

One important result of sub-task 2.5 in a methodological perspective is the elaboration of the PEP game extension on monitoring. The material in appendices is a way to encapsulate important socio-technical issues related to GD monitoring and to put them into discussion with an audience composed of a diversity of stakeholders. The second workshop provided an opportunity to test this methodology and it was a success. All the participants took an active part in the discussions. There were active discussions observed by the facilitators. During the restitution session, participants expressed unanimously their interest for the tool and the need to test it with more participants. Events cards seems to constitute a framework with sufficient diversity to enable participants to elaborate practical cases they want to discuss; criteria cards seem to address questions participants wanted to raise; monitoring board allow a stimulating discussion in the three groups.

Successful implementation of the PEP monitoring

The test confirms the ideal number of participants for a PEP session is approximately 4-5. This number allows both a diversity of views and fluidity in the discussion. Participants have the appropriate time for expressing their ideas without the necessity to be interrupted by the moderator to leave time for the others to speak. Having less participants could bring to have less dynamic and rich discussions and having more could bring to quick exhaustion because they must wait too long before to speak and they receive too much information during the round of discussions. The test also confirms the possibility to have hybrid PEP session, but it requires good informatic conditions (internet connection, big screen, good audio, etc...).

As a way for improvement, we must underline that the test was done without having all types of actors involved in each PEP group as it was planned. Due to schedule's conflict, some of the registered participants could not attend the PEP session: WMO representatives were missing in 2 groups, RE representative in 1 group). For the second PEP group that was only constituted from CS and TSO

[22] The UMAN seminars gathered multi-stakeholders audience to discuss uncertainty management and the potential role of civil society in it. The results are presented in different deliverables D10.13, D10.14, D10.15, D10.16 and D10.17 that are available on EURAD website: https://www.ejp-eurad.eu/publications

participants, it was underlined during the restitution session that the inclusion of other types of actors' views (coming from WMOs or REs) could have enriched the discussions.

For avoiding any misunderstanding, it is important to underline that it is not necessary to have each type of EURAD actors in each PEP group to have fruitful discussions during a PEP session. We already mentioned above that the participants are invited to speak from a personal point of view and not to deliver the official position of their organisations, even if as said previously, we do not have to underestimate direct or indirect influence the organisation could have on the personal opinion. And we do not consider that one participant from one organisation will represent the diversity of views inside one organisation. In fact, with other PEP tools, PEP sessions were organised[23] in the frame of the same organisation or with the same type of actors and the discussions were fruitful as a way to exchange information between newcomers in the RWM field and more experienced participants for instance. PEP tools could be very effective training tools especially because it also allows people to change its opinion by introducing nuances after listening others..

The important point is to adapt the audience of the PEP session to the objective you want to achieve. In the perspective of the PEP session during the MODATS workshop, the goal was to test the new PEP tool on monitoring: Does the PEP material allow to discuss the different issues on monitoring? How could it be improved for a future use (modification of cards texts, addition of new cards or suppression of non-necessary cards, etc...). In this perspective, it would have been good to have all the types of actors' views in all the groups. In the same way, other tests should be conducted with member of a bigger diversity of countries (notably from Eastern Countries and less advanced programmes) to collect additional perspectives. Finally, the inclusion of more local CS representatives will be interesting to ensure the tool encapsulate a sufficient diversity of perspectives.

Way to collect views of the different actors and present results in a dynamic format

The PEP tool seems to be a way to collect views of diversity of issues (diversity of practical cases played and different type of questions raised). For instance, the redundancy of some issues that have been discussed during the game demonstrated a specific interest of the audience for these issues. In the three figures below are presented the different issues discussed by the participants from the three PEP groups. The column "type of actors" indicates who elaborated the case, the events card and criteria cards columns indicate the cards being played to elaborate the case, the "time occurrence" indicate the phase of the GD implementation where the event occurs, and the description of the event gives elements to precise the event.

[23] Training sessions were organised in the frame of the SITEX.Network (with TSO and CS members) and a session was organised internally to Andra. Different sessions have also been organised internally to IRSN. Each time, the diversity was organised in the group by having members coming from different units, with different level of experiences, taking also into account the gender.

Case	Type of actors	Events card	Criteria cards	Time occurrence	Description of the event
Case 01	WMO	M9 **Requirement of new data**	Q6 **Adaptability of monitoring strategy** Q11 **Resilience & Robustness of monitoring**	Operational phase	New generation of NPP, new type of waste with new fuels, SMRs for ex. Authorities accept waste in GDF, but with the requirement of additional monitoring systems. New parameter to monitor, such as new exhaust gas.
Case 02	RE	M20 **Discrepancy between measurements and models**	Q1 **Maintaining social trust in monitoring** Q9 **Uncertainty management**	Operational phase	Re-saturation of host rock: in favour of having impact on corrosion rate, and on the other hand the worst case would be to have somehow higher conductivity. Where does the water come from? Bad for “selling” monitoring programme, if such differences are observed.
Case 03	CS	M17 **Request for post-closure monitoring**	Q1 **Maintaining social trust in monitoring** Q5 **Robustness of monitoring to disruptive events**	Between closure application submission and authorization for permanent closure	Request for post-closure monitoring: why the future generations should suffer the risk of no monitoring? Burden for future generations.
Case 04	TSO	M1 **Defective monitoring demonstrator**	Q7 **Maintaining reversibility** Q13 **Transparency and access to data**	During operation phase	Demonstrator was seen as a tool to confirm the solution of GD for components like devices used to dispose some waste. Then some waste is disposed and discover that there is a need for some extra activity to prove this further. Need of stopping the demonstration if performance not reach, or no need? Link with Reversibility

Figure 8. Issues discussed by PEP group 1

Case	Type of actors	Events card	Criteria cards	Time occurrence of the event	Description of the event
Case 01	CS	M11 **Loss of institutional interest for monitoring**	Q12 **Maintenance and risk of abandonment of the monitoring strategy**	Conception / operational phase	At a time, everything is well started, loss of interest and the situation comes to a high risk of abandonment of monitoring strategy
Case 02	CS	M3 **Data revealing a safety issue**	Q1 **Maintaining social trust in monitoring** Q5 **Robustness of monitoring to disruptive events**	Operational phase	A parameter is monitored. The evolution is modelled as inside of the safety envelope, but data collected show the parameter is going outside the safety envelope
Case 03	CS	M20 **Discrepancy between measurements and models**	Q5 **Robustness of monitoring to disruptive events** Q6 **Adaptability of monitoring strategy**	Beginning of the operational phase	How to consider models that do not fit with measurement? Monitoring could be considered as community. How can we improve models to limit discrepancies?
Case 04	TSO	M9 **Requirement of new data**	Q6 **Adaptability of monitoring strategy** Q9 **Uncertainty management**	Operational phase	Unique facility planned: geological disposal. But during the operational phase, there is a change in RWM strategy: how can we maintain safety with new types of waste for which facility was not originally designed?

Figure 9. Issues discussed by PEP group 2

Case	Type of actors	Events card	Criteria cards	Time occurrence of the event	Description of the event
Case 01	CS	M12 **Strong loss of societal confidence**	Q1 **Maintaining social trust in monitoring** Q5 **Robustness of monitoring to disruptive events**	License application submission	Demonstration due to a loss of societal confidence. The access of data for CS is not sufficient, according to the concerned protestors. Question of conditions of trust in the system Question of how the strategy could overcome such loss of societal confidence?
Case 02	TSO	M6 **Cyber-attack**	Q4 **Continuous security of data** Q5 **Robustness of monitoring to disruptive events**	Operational phase	Cyber-attack caused by a person who joined the core crew of GDF operator. It causes major damage and difficult to solve Question of how ensuring security of data all along the phases How can the strategy overcome such a disruptive event?
Case 03	RE	M3 **Data revealing a safety issue**	Q3 **Democratic monitoring** Q1 **Maintaining social trust in monitoring**	Operational phase	Temperature raised in an unexpected way. We don't know if it is a sensor's malfunction or a true measurement. What communication to have with CS? (How and when?) How to prepare a shared communication with scientific community? How to maintain trust of the system?
Case 04	TSO	M2 **Uncertainties about monitoring maintenance**	Q12 **Maintenance and risk of abandonment of the monitoring strategy** Q1 **Maintaining social trust in monitoring**	Operational phase	Potential defective fibre optics to be replaced in a monitoring cell that is already filled with waste packages. How will it damage the social trust and how to maintain it? Will this issue endanger the whole monitoring strategy? And the safety of GD?

Figure 10. Issues discussed by PEP group 3

3 events cards have been selected in two groups with a different perspective:

- M3: Data revealing a safety issue: Monitoring data reveals serious problems that can threaten safety (discussion around the safety envelope and discussion around a sensor malfunction)

- M9: Requirement of new data: Political or societal concerns lead to the requirement for monitoring additional data (discussions around data issues related to the necessity of include new waste in GD)
- M20: Discrepancy between measurements and models: Physics-based models and data-based models do not present same results on some key safety elements (discussions on how to consider models that do not fit with measurement)

4 criteria cards have been selected several times in the three groups to orient the discussion:

- Q1: Maintaining social trust in monitoring: Does the monitoring strategy generate/maintain trust of the different types of concerned stakeholders over time?
- Q5: Robustness of monitoring to disruptive events: Can the monitoring strategy manage difficulties encountered in the data collection, treatment, interpretation, and preservation over time? Can the monitoring strategy undergo disruptive and unexpected events (major discovery, financial crisis, armed conflict, etc.) without being blocked?
- Q6: Adaptability of monitoring strategy: Can the monitoring strategy be flexible and adaptative to the evolution of scientific context (new knowledge, technological breakthrough? Is the monitoring strategy sensitive to external social, financial economic, political constraints (loss of skills, financial crisis, evolution of political and societal requests, etc.)? Are there actual alternatives (B plan) at each stage?
- Q9: Uncertainty management: How does the monitoring strategy take into account uncertainties about the monitoring (insignificant uncertainty, D&R or feedback on the concept)?

The collective discussion with the participants after the PEP session validates the fact that PEP methodology can be used to ensure fair dialogue on monitoring in the future.

Finally, the multi-party dialogue implemented in sub-task 2.5 showed that it is helpful to go beyond unilateral interactions: having a technical presentation given by an expert to an audience sitting and listening and asking questions at the end. The PEP follows a more dynamic approach having exchanges on the same footing, each participant being inviting to bring an input to the discussion. For this purpose, the facilitator's role is crucial, to ensure equal participation and to help by reformulating and ensuring a common understanding. Civil society cannot have a similar contribution to the technical topics as the technical experts have. However, civil society always have elements to give regarding conditions for trust and to bring complementary views to technical expertise that could improve the quality of results. Members of the public can bring a different way of thinking that would be useful to consider in a comprehensive approach, by including members of the public in face-to-face discussions trust can be built, and it may lead to technical experts improving the way that they explain their concepts This demands a certain reflexivity on governance, in the spirit of a shared safety culture and mutual understanding. The main conditions for trust on digitalisation of monitoring systems and results are pluralism of expertise, transparency, regular points of dialogue and participation. Monitoring is a useful means to frame interactions between institutional experts and civil society as it allows members of the public to develop some understanding of issues related to geological disposal and to link these issues to safety.

3. Outcomes of the multi-party dialogue

This section presents the results related to participants views on monitoring, collected along the work carried in MODATS sub-task 2.5. Following the two workshops, the various meetings and the discussions linked to sub-task 2.5, many views emerged on the various monitoring topics that were discussed. sub-task 2.5 brought them together into thematic families of subjects; each one of which forms a separate sub-section below.

3.1 Diverse perspective on the meaning of core concepts

This first theme here brings together the discussions that occurred in the two workshops of MODATS sub-task 2.5 about the importance of having a common definition and a shared understanding for several core concepts, such as monitoring, pluralism, sociotechnical objects, etc.

One of the primary conclusions drawn from the workshops is the necessity for a comprehensive discussion on the meaning of monitoring and the repository itself, given the diverse perspectives on these concepts. The varying interpretations of the systems at play significantly influence how interconnected issues are addressed. For instance, monitoring can be viewed as a means to validate the knowledge underpinning long-term safety assessments, specify models for periodic reassessments, observe reversibility conditions, and enhance operational safety.

A notable point of discussion emerged around the uncertainty regarding the precise definition of "monitoring" and the potential interchangeability with the term "surveillance." As the institutional definition of monitoring and surveillance (from IAEA, SSG-23) were debated, tThe choice of terminology appeared to hinge on the scope of discussion. Indeed, “monitoring” seems to be related to sensors, sensor choice, positioning, data acquisition, when “surveillance system” could encompass data management, data analysis, decision-making, etc. The extent of this scope needs to be clarified on each occasion that discussion in held on monitoring to ensure better understanding between different types of actors.

However, consensus was reached on the overarching priority to safety – with safety being the primary and enduring concern for most stakeholders involved in the discussions. The links between monitoring and the assessment of the repository's performance with respect to safety was acknowledged and emphasized by most participants. It serves as a mean to both support and challenge the safety case, which relies on various elements such as models, mock-ups, experiments, and demonstrators. Consequently, any considerations related to the design, operation, or evolution of monitoring strategies should be evaluated in terms of their positive or negative impact on safety, necessitating a benefit-risk balance assessment.

Anticipating questions regarding redundancy, intervention protocols, sensor updates or replacements, etc., should be guided by an overarching safety strategy. The importance of safety in monitoring issues extends beyond post-closure safety to include operational safety. The division of responsibilities among operators, regulators, and experts concerning monitoring strategy, data management, and decision-making must be clarified, particularly in the event of incidents, accidents, or crisis situations.

All these discussions led to the conclusion that a glossary develop by a multi-party process was needed to enhance shared understanding and clarify the concepts at stake.

3.2 Data and models

This section sums up the questions raised about the use of models and especially digital twins. However, there is a large variety in the definition of digital twins, and the status of models regarding the data and the facility.

The issues surrounding data and models are central to monitoring and were thoroughly examined from various angles during the two MODATS workshops. The second workshop, in particular, delved into the realm of data digitalization, including tools like digital twins, and explored participants' views on the potential role of digital twins in a repository program.

While digitalization and the adoption of digital twins are viewed by some as emerging topics for the future, there exists a wide range of definitions and potential applications for these tools. Monitoring results and models are closely intertwined, with each informing, complementing, or challenging the other. Models were seen as crucial in establishing monitoring strategies and instilling confidence in data.

In cases of issues, doubts, or uncertainties, comparing monitored data with estimates of expected system behavior is vital. The alignment or discrepancy between the two can either bolster or weaken confidence in the system, addressing concerns such as sensor representativeness or the need for replacements.

Models contribute to a deeper understanding of thermal, hydraulic, mechanical, chemical, biological, and radiological processes within a repository. Some participants suggested that hybrid twin models, which blend data-driven and physics-based models, could enhance numerical simulations and, consequently, improve overall performance. These tools were seen by some as offering easier access, visualization, and manipulation of monitored and predicted data for both experts and citizens, thus enhancing comprehension and management of the repository, optimizing monitoring strategies, and improving safety. However, discussions were held on the potential drawbacks of digital twins designed as black boxes.

The need to explore the underlying uncertainties associated with these models is widely acknowledged and pursued. Digital tools, such as digital twins, should remain open to enable multi-stakeholder assessments of emerging uncertainties, ensuring adaptability and responsiveness to diverse perspectives.

3.3 Data and knowledge management

This section shows the concerns about the ability and the way to efficiently store and reuse very large quantity of data on the long term, and the more general issue of intergenerational transmission of the knowledge about the system.

Data management was considered as one of the key issues that should be addressed in a monitoring programme. Although, to some actors, collecting data might appear as the main concern, designing a monitoring system should also encompass more global issues linked to the safety case and plan how to interpret, analyse, sort, conserve and share data. Indeed, the inherent complexity of data is compounded by layers of complexity due to the diversity of sensors, the questions of who processes the data, the openness of the data, its maintenance in the long run. Most actors considered these issues as critical and that they should be tackled and discussed by all stakeholders. In this sense, the question of private property or openness of the data was considered crucial during the discussions: what will be the legal status of the data acquired through the monitoring systems?

The European Opendata directive[24] (Directive (EU) 2019/1024), which has been transposed into the law of the Member States, is not yet culturally always accepted by research community. Also providing to public monitoring data from industrial facilities is still for historical reasons, a tricky issue. But it is now a fact that all European projects are subject to data management plans, including data availability to public. In all European countries, monitoring data from industrial public facilities are subject to the same rules

These questions are linked to knowledge management issues and more specifically the questions of memory for society, maintain public interest in data, their long-term storage, and the risk of potential loss. It has been also suggested that the loss of methodology and knowledge necessary to data

[24] The Open Data Directive is a legislative framework introduced by the European Union to promote the availability and reuse of public sector information. Enacted in 2019, this directive aims to unlock the potential of government-held data by making it more accessible and reusable for citizens, businesses, and organizations across the EU. Under the Open Data Directive, public sector bodies are required to make certain categories of data available for free or at minimal cost in machine-readable formats, unless it is subject to legitimate restrictions such as privacy, national security, or intellectual property rights. By fostering transparency and innovation, the directive seeks to stimulate economic growth, drive efficiency in public services, and encourage the development of new products and services based on public data. It also emphasizes the importance of interoperability and standardization to facilitate the exchange and reuse of data across different sectors and borders within the EU.

interpretation could be avoided by also storing methods to analyse data. This could require an institutional process involving all the concerned actors.

Participants to the two workshops agreed that knowledge management plays a pivotal role in designing a monitoring strategy for a repository, given the diverse timescales and the involvement of various stakeholders. The growing complexification of all dimensions of knowledge in every field, both technical (sensors, data, AI, etc.) and institutional, poses a significant challenge to ensuring effective knowledge continuity. Thus, the accumulation of layers of complexity may lead to difficulties in reversing interpreted knowledge and hinder understanding or intervention in certain problem scenarios.

Sustaining interest in data throughout the entire repository process was considered crucial for knowledge continuity, especially considering uncertainties about the future of nuclear energy. Institutionalizing processes becomes essential to prevent data loss or misinterpretation. These processes should incorporate technical and institutional solutions to preserve raw data, categorize it effectively, and guarantee its availability and accessibility. A conclusion stemming from the discussion is that all monitoring decisions should be integrated into such a knowledge management process, guided by the traceability of knowledge and the preservation of the repository's meaning.

Knowledge management becomes particularly critical during the post-closure phase. Indeed, all participants did not seem to agree on the conditions for closure and the way the repository should be monitored – or not. Thus, questions arise about who will oversee long-term knowledge management and institutional control after closure. The scope of such control, encompassing research, monitoring, and knowledge management, remains uncertain. Given the unpredictability of long-term governance, maintaining flexibility and exploring diverse scenarios is essential.

The second workshop led to the statement that establishing robust intergenerational knowledge management involves obtaining "information about information" to ensure the future correct use of results and to prevent obsolescence due to evolving tools or physical degradation of stored data. Anticipating the creation of new tools and recognizing their effectiveness in part relies on the quality of previously acquired data. The increasing digitalisation of the system and the possible growing need for extensive data, particularly for AI tools or other new technologies, introduces practical challenges related to the compatibility or conversion of large datasets. Addressing these issues is vital for ensuring the longevity and use of the accumulated knowledge.

3.4 A dynamic process: different phases and timescales

This section focuses on the fact that all decisions and considerations regarding a facility must be made considering the ever-changing context. This permanent change tackles some issues of stability, consistency, and continuity through time of decisions and actions.

Disposals are projects undertaken over decades and should thus be planned as a dynamic entity, combining the different phases of the project and the inevitable technological, institutional, and social change.

A key point of the discussions was that the objective of monitoring depends on the phase of the project. For instance, the “research” phase will focus on understanding phenomena, processes and test solutions, whereas the operational phase will rely on industrial sensors designed to monitor process, health or environment issues and the need for possible maintenance of the disposal. The answers to the different possible problems may vary depending on if it happens before or during the operational phase or after closure. The question of closure was very central in the workshops since the need for post-closure monitoring seems to be an ongoing discussion and the conditions for closure did not seem to be consensual. When to close, how to close, what to do after closing and how long: all these questions are sometimes difficult to answer from civil society point of view. These questions also concern the long-term maintenance of the knowledge about the repository and the institutional control after closure.

The objectives and meaning of the monitoring could also depend on the political and societal context, which will inevitably change over the duration of the project. It was stated that a socio-technical project on such long timescales should always be flexible to social and institutional change: it is a mistake to imagine that the political system, the institutions involved, and the civil society will be the same all along the process. One of the potential changes is the end of nuclear energy in the future and thus the possible end of expertise regarding radioactive waste and matter. Specific skills and interest regarding the repository could fade away if nothing is done to tackle this issue. The discussions often led to the point that all monitoring choices, even for post-closure phase for which safety should be ensured by passive safety, should envisage that future generations could take different decisions regarding land use or retrievability for example.

The means of monitoring will also face changes, as technological evolution is anticipated and could impact the methods and tools available for monitoring the repository. One of the main examples of change that was discussed during the workshops is the potential for evolution of approaches to management and modelling of data. These changes question the possibility to adapt the monitoring system and to use the former results in new ways. It appeared necessary to have processes to integrate or not a new device/technology in the GDF embracing the dilemma between robustness and flexibility of the system. For such an update of the monitoring system, a cost-benefit analysis should be the basis of decision/discussion with stakeholders. All decisions concerning the use or not of a new technology should be addressed through the prism of safety, as integration of new technologies should not compromise safety.

3.5 Uncertainties, confidence and trust

This section shows the omnipresence of uncertainties and their various natures in a repository, making them a key feature of a GDF. It also deals with the core role of trust and confidence in the management of these uncertainties.

The uncertainties addressed in the safety case are varied, and include the natural variability of the rock, incomplete knowledge of processes, and the potential for unpredicted phenomenon, Since it is not possible to control everything in the industrial and natural system, and that total certainty on the safety of the system is unreachable, it was considered important to find ways to have confidence in the knowledge and understanding of the system. The use of models, the sampling strategy, and strengthening the understanding of the processes operating in a repository were quoted as strategies to try to reduce uncertainties. It also appeared important to include in the monitoring system design the possibility for an unexpected phenomenon to happen in the repository, to tackle future uncertainties that could rise. This prevision of the unexpected could take various form, such as adaptable sensors, room for other sensors to be set up after the beginning of the operation phase, etc. Uncertainties can thus come from various sources (structural uncertainty, data, models, etc.). However, uncertainties being unavoidable, one key aspect of implementing geological disposal discussed during the two events was the importance to have strategies for managing uncertainties (which is done in the safety case). Some questions regarding our link to uncertainty and knowledge, such as the level of certainty needed to close the facility, or when the uncertainties regarding a phenomenon are considered manageable or not, and who defines that “enough is enough”, were considered important to be debated widely across society.

Monitoring could help to reduce uncertainty in the system, for example by strengthening the understanding of some processes occurring in the short period after waste emplacement and prior to closure. However, it does not only create confidence in the system and its safety demonstration: for some participants to the workshops, it should be considered as a prerequisite for the construction of interactions with civil society and trust about the process. A real agreement on what to measure is a condition for a fruitful trust-building process.

The question of confidence and trust is deeply linked with the ones on uncertainty. Indeed, following Luhmann's theory on trust and complexity[25], in such complex and uncertain socio-technical systems, trust and confidence can be considered as mechanisms that help reduce complexity. There are many other ways to link trust and confidence to uncertainty and complexity, and this link was crucial for most participants. That is why developing a framework in which trust among all stakeholders can be built all along the way is crucial for such projects and was considered as a priority. However, it is important to keep in mind that, as said earlier, the purpose is not to build stakeholder's confidence, because confidence is a result, not a goal itself.

3.6 Transparency, pluralism, public participation, and the link with civil society

This theme presents the concerns raised by some actors about the question of transparency and pluralism in the process of the decision-making in the GDF and the ability for civil society to participate in these decisions (and the way to participate), highlighting that such mechanisms can strengthen safety and help build confidence through common understanding and views.

The necessity for a more pluralistic process emerged as a central theme in the discussions. Indeed, the presence of diverse interpretations of the same phenomenon or dataset can enhance the robustness of the monitoring system, depending on how these multiple interpretations are aggregated. Incorporating a broader range of stakeholders (such as through the actor plurality model in EURAD) or including critical voices in discussions, particularly for updating the monitoring system, was seen as conducive to gaining a better perspective.

While opening the monitoring process and methodologies to various actors or scientific fields may lead to conflicting results, it was believed that such conflicts could ultimately be beneficial. The term "pluralism," frequently invoked in discussions, encompasses a range of concepts and definitions: the need for diverse types of actors (TSOs, WMOs, REs, and CS) to interact, civil society's presence at every decision-making stage, access to different sources of institutional or non-institutional expertise regarding the GDF, and the openness of the scientific approach to developing different tools (such as models and sensors).

The issue of pluralism was closely intertwined with transparency and public participation concerns. It was unanimously agreed in both workshops that civil society should play a significant role in crafting the monitoring strategy—not necessarily from a technical standpoint, but rather to maintain a holistic perspective, for instance. Indeed, several examples demonstrate civil society's ability to challenge methods and results. To facilitate this, transparency was deemed essential for these projects. Any inadvertent disclosure of crucial information kept under wraps could jeopardize trust between civil society and repository authorities. Conversely, co-constructing a monitoring design with the public—its specific form yet to be more precisely defined—was seen as potentially fostering trust in the entire system. Therefore, dedicated experts could engage with civil society on all subjects, even the most technical ones.

Incorporating civil society for effective public participation necessitates transparency, as well as guaranteed access to resources for long-term involvement at all project stages, within a robust democratic process that genuinely engages all stakeholders on equal footing. In this regard, the increasing digitalization of systems presents a technical opportunity to implement a more democratic way of tackling these issues ans thus to enhance transparency and communication.

3.7 CS members views and expectations

Different from the precedent ones that were presenting a variety of views coming from the diversity of actors involved in the task, this subsection 3.7 presents the specific concerns raised by the CS actors

[25] N. Luhmann (1979): *Trust and Power*. Wiley, Chichester.

involved in the MODATS multi-party dialogue. They have been synthetized here as it was one of the core objectives of sub-task *2.5.*

The framework of uncertainty management proves helpful in moving beyond one-sided interactions, such as pedagogical ones or the "deficit model"[26]. The PEP methodology aligns with this approach.

While civil society may not contribute to technical topics to the same extent as technical partners, they consistently provide insights into the conditions necessary for trust. This underscores the importance of governance reflexivity in nurturing a safety culture.

From the CS perspective, trust in the digitalization of monitoring systems and results hinges on several key factors: pluralism of expertise, transparency, regular dialogue and participation opportunities, and the integration of monitoring with safety-focused actions.

Monitoring serves as a valuable tool for fostering interactions between institutional experts and civil society, helping to grasp the complexities of GDF issues and tie them to safety concerns. However, the digitalization aspect primarily represents a promising advancement in monitoring, which may overlook internal tensions (such as between models and measurements) and external challenges (like obsolescence and maintenance). Further research is needed in these areas.

Additionally, the questions surrounding post-closure monitoring remain highly relevant to CS members, as they directly impact the trust placed in GDF core concepts. Therefore, there is a need for continued socio-technical research in this area.

[26] Miller, J.D. (1983). "Scientific Literacy: a Conceptual and Empirical Review". *Dedalus.* **11**: 29–48.
According to the deficit model, it is sufficient to inform people to get their agreement. In other words, if they disagree, this is only because they don't know.

4. Perspectives for future activities in EURAD-2

This section presents new perspectives stemming from the works carried-out in MODATS sub-task 2.5: a new framework for a socio-technical interpretation of monitoring, that could be used for other socio-technical issues related to GDF monitoring, and the horizons of future organisation of multi-party interactions about monitoring systems and axis of future activities.

4.1 Framework's proposal for a socio-technical interpretation of monitoring

An analysis of the outcomes of this work carried out in MODATS sub-task 2.5 is proposed to build the grounding steps for a socio-technical interpretation of monitoring. This interpretation offers a dynamic vision of monitoring related to governance issues, based on various pillars: safety, monitoring strategy, data management, transparency, confidence / trust, decision making and transparency.

These pillars are broad themes that cut across most of the issues raised by the socio-technical topic of monitoring and enable us to grasp the complexity of the problems, the temporal dynamics and the differences in viewpoints between the various stakeholders. At the intersection of these different themes, specific questions may arise, linked to the divergence of viewpoints between the different stakeholders or the intertwining of social and technical issues.

4.1.1 Safety as the main concern

The main objective of a monitoring system, including its monitoring strategy, data management and data publication is safety, through its governance, confidence in political decision, and public trust in the global system. Safety is the main priority, and all considerations about monitoring or surveillance of such a facility should be considered through this prism, at every stage of the project. Safety of the installation is not an objective or a means, but an essential prerequisite guaranteeing a framework within which the project can proceed. It is therefore important to always approach the analysis of this type of socio-technical project including safety concerns.

4.1.2 Monitoring strategy

Monitoring strategy is based on scientific knowledge about which parameter and how it should be monitored, to provide relevant information to bring expert confidence for decision making in the frame of geological disposal management. These knowledges are coming from experiments but also from modelling activities. All these knowledges are supposed to bring confidence and certainty to allow a good decision-making process. It should be considered how to share such information and knowledge with stakeholders and especially public, considering this highly complex question about sensors and positioning optimisation.

4.1.3 Data management

Following data and related issues enables us to grasp the socio-technical complexity and dynamic nature of monitoring issues in a facility. Data management is one of the main tasks of a monitoring system, and the way in which data is acquired, used, transmitted, represented, stored, and analysed, are all important points to be examined to develop a common understanding of disposal throughout its life. Major knowledge management issues are linked to data management, so that data produced at any phase of the system can be understood, used and consistent in any other phase. These knowledge management issues are rising due to the need to handle, store and interpret vast amount of data on very long timescales. These conceptual problems of transmission of knowledge on the long-run then turns into very material and socio-organisational issues of compatibility (and retro compatibility) and preservation through time of these objects whose nature and physical form endlessly change. The questions of the access and use of these data also brings the stakes of transparency, openness, and

availability of these data. These issues are crucial for ensuring the data's reliability and for maintaining public trust at all steps of the project.

The massive use of digital tools is creating new challenges in all socio-technical fields, because these tools bring with them new configurations of knowledge and therefore new technical constraints and the need for new ways to manage this knowledge. In the case of nuclear waste disposal monitoring, growing challenges arising from the digitalisation of activities are closely linked to the use of digital twins, which raise questions about the representativeness of the phenomena monitored, the use of these tools, transparency, obsolescence, technological evolution, maintenance, long term storage, etc.

4.1.4 Confidence and trust

Confidence and trust play pivotal roles within the socio-technical system, particularly in the surveillance system of a GDF. The cultivation of integral trust is a prerequisite to enable public support of important decisions related to such systems. Examining monitoring issues through the lens of trust and confidence conceptualizes monitoring as a construct designed to reach confidence by exerting control over the studied object, in this case, the repository. As a construct, it reflects the concerns and interests of various stakeholders, which may converge or diverge based on actor types, project phases, or socio-political contexts. The robustness of monitoring systems is crucial; inadequacies can be interpreted as reflecting value dissimilarity and distrust, potentially leading to a decline in overall trust levels and cooperation. Understanding the dynamics of how monitoring contributes to building, strengthening, or weakening trust and confidence unveils the intricate complexities of these issues.

4.1.5 Decision-making

Decision-making processes are intricately linked to surveillance and monitoring within a GDF. The data and parameters selected for monitoring are deemed important because they offer information critical to the effective implementation of the project. This importance can manifest in various ways, from enhancing knowledge of phenomena to managing problems or unforeseen events, necessitating specific actions or countermeasures. The efficiency of a facility's monitoring system hinges on its seamless integration into an action plan based on observed results. Conversely, if no action is foreseen, as in certain post-closure scenarios, monitoring becomes useless. The definition of vital data, the management of results, and the formulation of decision-making plans illustrate how the facility is integrated into society and democracy. Governance and decision-making concepts at each project stage provide insights into both the significance of monitoring for society.

4.1.6 Transparency

Transparency is a fundamental aspect that interconnects confidence, trust, and decision-making within the context of monitoring systems for GDFs. An open and transparent approach to sharing information, processes, and decision-making fosters public trust. Transparent communication about the selection of monitored parameters, the reasoning behind decision-making, and the overall functioning of the monitoring system is essential. It ensures that stakeholders understand the system's intricacies, aligning expectations and facilitating a more informed and engaged public. By emphasizing transparency, monitoring systems contribute to building and maintaining trust, fostering a sense of accountability, and promoting a shared understanding among all involved parties.

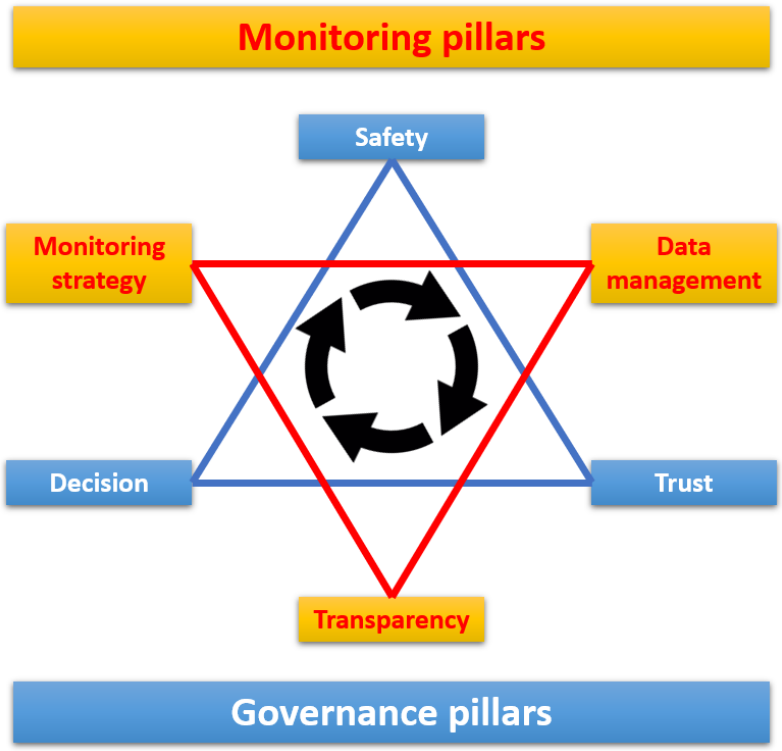


Figure 11. Proposed schematic interpretation of the pillars grounding a sociotechnical framework about surveillance system

This analysis could be represented in this figure, where themes are presented for monitoring related to governance issues. The lines between these points and the intersections between them illustrate the different issues that arise due to the convergence or divergence of viewpoints of the different actors on some topics or the intersections of technical and social issues about a certain topic. This star-shaped analysis grid tries to illustrate the fact that most sociotechnical issues concerning monitoring in a facility can be set at the crossroads of these general themes and helps build an analysis framework depicting the different views on the project along the different stages. This first step to establish a global vision of the issues at stake is shown here to push further discussions and does not claim exhaustivity. Indeed, this vision can heuristically contribute to highlight other structural perspectives, for example the details of accountability dimension in the governance pillars.

4.2 Key aspects for further activities

One of the important outcomes from the discussions during workshops in the frame of sub-task 2.5 was the agreement by the workshop participants that monitoring in the frame of EURAD is almost only research monitoring. This means that most of experimental systems are designed with a lot of sensors, to provide sometimes too much data, but the main goal is to understand phenomena or provide inputs for modelling activities. On the contrary, operational monitoring, is supposed to be designed in a different way, in order to follow phenomena with an optimisation of the number of sensors and positioning.

Going from research data acquisition to operational data acquisition requires several steps that are not really a common framework in EURAD community. It is even difficult to imagine which approach researcher, expert or civil society can have about data visualisation, analysis and interpretation.

As mentioned in introductory section, a lot of discrepancies in the way experts and non-experts can have discussion about monitoring, due to words interpretation, to safety case understanding, to disposal concepts depending of each country and also about what is monitoring exactly designed for.

In the realm of future activities, there is a distinct emphasis on fostering collaborative engagement, allowing researchers, experts (sometimes researchers and experts both involved in research programs

or safety assessment) and members from civil society to collectively examine a unified tool representing data from monitoring systems. This collaborative approach aims to promote transparency, inclusivity, and a shared understanding of complex monitoring issues.

These future activities, that could be implemented in knowledge sharing framework, could include:

- **Interactive Workshops** that bring together researchers, experts, and representatives from civil society to collaboratively explore and understand the tools used for representing data from monitoring systems. These workshops can facilitate hands-on experiences, discussions, and knowledge-sharing sessions.
- **Training Programs** to enhance the technical literacy of researchers, experts, and civil society members in navigating and interpreting data visualization tools. This initiative can empower participants to actively contribute to discussions on monitoring systems.
- **Open Access Platforms** or portals where diverse stakeholders can access and analyse data representation tools. This promotes democratized access to information, enabling broader participation in the discourse surrounding monitoring strategies.
- **Multi-Stakeholder Dialogues** that involve researchers, experts, and civil society in joint discussions about the design, functionality, and application of tools representing monitoring data. This ensures diverse perspectives are considered in refining and optimizing these tools.
- **Collaborative Research Initiatives** where researchers and experts work hand-in-hand with civil society representatives to evaluate and improve the effectiveness of data representation tools. This can lead to the development of more user-friendly and comprehensible tools.
- **Public Awareness Campaigns** to inform civil society about the significance of monitoring systems and the tools used for data representation (user interfaces, colours, units, etc.). This can foster a more informed and engaged public that actively participates in discussions related to repository safety.

By promoting collaboration and providing accessible avenues for engagement, these future activities aim to create a more inclusive and informed landscape where researchers, experts, and civil society collectively contribute to the effective representation and understanding of data from monitoring systems.

Furthermore, involving civil society in the data management process is a crucial aspect of promoting transparency and accountability. The inclusion of community stakeholders and concerned citizens ensures that diverse perspectives are considered in the decision-making process. Public participation not only brings valuable insights but also builds trust and credibility in the research and management processes. In the context of radioactive waste, where public concerns are often heightened, involving the society at large fosters a sense of ownership and shared responsibility.

As the European commission has established the Opendata directive, to ensure the transparency of public data (data produced in the frame of public fundings) to public, data management plans are crucial for all European projects in all scientific domains. These plans play a pivotal role in ensuring that data generated throughout research process are organized, accessible, and effectively used. In the context of radioactive waste management, where the stakes are high due to potential environmental and health implications, having a well-structured data management plan is essential.

The implementation of a comprehensive data management plan at the scale of a project such as EURAD is not only indispensable but also necessitates a meticulous approach at the level of each individual work package. A project of such magnitude involves diverse work packages, each contributing to the overall objectives. A global data management plan ensures cohesion and coherence across these work packages, establishing standardized practices for data generation, storage, and accessibility. This targeted approach ensures that data generated within a work package are not only preserved but are also easily accessible and interpretable by both current and future researchers. Such focused plans contribute to the longevity of knowledge produced within each work package, preventing data loss and enabling the seamless continuation of research efforts.

Furthermore, individual work package-level data management plans foster a culture of responsibility and accountability among team members. By clearly defining roles, responsibilities, and protocols for data handling within each work package, the risk of errors, misinterpretations, or loss of valuable

information is significantly reduced. This meticulous approach to data management within work packages contributes not only to the success of the individual components of the project but also ensures the integrity of the collective knowledge generated by EURAD. In essence, the synergy between a global data management plan and specialized plans at the work package level is crucial for the preservation, accessibility, and institutional memory of the wealth of data and insights produced throughout the duration of the project.

One of the main advantages of implementing data management plans in the field of radioactive waste management is that it facilitates the sharing of data with society as a whole, which is a fundamental guarantee of transparency and therefore trust. It emerged from the various discussions that trust cannot be decreed but comes from the facts that contribute to it. Transparency is certainly one of them.

By way of example, discussions took place on post-closure monitoring, generating opinions from some members of civil society that the idea of a monitoring system is a good way of transferring knowledge over time and to future generations. Some experts provided a rather different viewpoint regarding passive safety, a concept that does not require operational monitoring to ensure the safety of a RDG over time. Interesting discussions led to a consensus on one of the fundamental principles of monitoring: decision-making. Indeed, it was agreed by all participants that if the need for decision-making is justified, then post-closure monitoring can be envisaged. However, if no decision can be made, then the monitoring system is likely to be completely useless.

Last, it should be mentioned that future interactions with civil society should be more included at the level of whole work package or even at the interface of different work packages. As part of the task 2, interactions only focused on sensor purpose, and the results of this present work could have been more fruitful if they had been associated more to task 3 activities.

5. Conclusion

The work undertaken in MODATS sub-task 2.5 tackled several challenges, by 1°) implementing an experimental model of multi-party dialogue aiming at facilitating a mutual understanding on key topics related to monitoring systems, data management and digitalisation; 2°) by gathering some civil society's members' questions and expectations regarding these topics; 3°) and by proposing a first step towards a socio-technical interpretation of monitoring in the specific frame of geological disposal of radioactive waste.

Reflecting on past involvement of actors in EURAD, it has been recognized that fostering transparency usually helps to build trust in society. Monitoring is particularly well-suited to this transparency approach, as data produced are relevant for main society concerns like memory, knowledge transfer, confidence and trust. A monitoring system should therefore be designed in such a way as to enable the knowledge acquired to be made available. It was also discussed that datasets may be difficult to handle because of the material resources required or because of their technical complexity, but with all ongoing developments in the frame of IT or artificial intelligence, in addition to possibilities to create discussions between experts and civil society, some doors should open to better share knowledge.

The link between experts and society should be then strengthened to allow a confident and permanent link about such a legacy for future generations. While civil society actors may not contribute to technical discussions in the same manner as technical partners, they still provide valuable insights notably regarding trust-building conditions. This necessitates reflexivity on governance from all stakeholders, in line with the spirit of safety culture. This could be achieved through new approaches leading to research co-construction. In this perspective, the dedicated PEP tool and methodology about monitoring and digitalisation was a promising way to conduct these exchanges and proved that research associating civil society views could be further investigated.

The workshops organized within MODATS subtask 2.5, enabled experts and members of civil society to converge towards a shared understanding of specific issues, facilitating exchanges where each participant could contribute their perspective, influenced by their personal, environmental, scientific, societal sensitivities. The main topics which were addressed concerned questions about data, models and digital twins, knowledge management challenges, long-term issues, core concepts of confidence and trust between experts and with civil society. These topics, presented as outcomes which emerged in multi-party dialogues, helped to lay the foundations for a socio-technical interpretation of monitoring, that could be used for the organisation of other socio-technical exchanges related to GDF monitoring, and opened axis of future activities.

Multi-party dialogue, concerning monitoring topics, requires a suitable framework to effectively address their complexity. The framework proposed in sub-task 2.5 enabled to identify and discuss the diversity of perceptions and understandings by the members representing civil society and technical members.

Sub-task 2.5 aimed to foster trust-building multi-party processes addressing complex issues related to GDF monitoring by strengthening shared interests in the discussed objects and concepts, facilitating suitable methodologies for partners to contribute from different perspectives, and providing structural axes for further research, thus contributing to an ongoing enhancement of safety culture.

Appendix A. Agenda of Workshop n°1 and list of participants

FIRST MODATS "3+1 DIALOGUE WORKSHOP"

Date: April 18-20 2023

Place: Nancy, France

Objectives:

- Contribute to the development of mutual understanding and common views on the key challenges and topics on monitoring system and data management.
- Collect civil society's expectations on monitoring
- Introduce a socio-technical interpretation of monitoring systems
- contribute to the research (identify points of vigilance to have in mind)

Main Question: What are the views of the different actors on what the monitoring strategy should be? What is the contribution of a pluralistic surveillance strategy to safety over time? What are the satisficing conditions for monitoring?

Program of the workshop

Day 1 – April 18

Items	Time	Presentation - Topic	Speaker (his/her organization)
1	2:00 – 2:10p.m.	Welcome and general introduction	Christophe Debayle (IRSN)/ Julien Dewoghelaere (NTW)
2	2:10 – 3:05p.m.	Technical introduction on monitoring *40 minutes presentation + 15 minutes discussion*	Christophe Debayle & Camille Espivent (IRSN)
3	3:05 – 3:15p.m.	"Extended PEP serious game"	Louise Le Grand & Guillaume Lemaire (EM Nancy)
15 minutes break			
4	3:30 – 6.30p.m.	Group work on concrete cases	All the participants

Social dinner

Day 2 – April 19

Items	Time	Presentation - Topic	Speaker (his/her organization)
5	9:30 – 11:30a.m.	Restitution of the work on concrete cases	All participants
15 minutes break			
6	11:45 - 12:45p.m	Presentation of the link between monitoring system and the safety case	Camille Espivent (IRSN)
Lunch break			
7	2:00 - 3:00p.m.	Discussion about the link between monitoring and the safety case	All participants
8	3:00 – 3:30p.m.	Next steps	IRSN / NTW
15 minutes break			
9	3:45 – 4:45p.m	• Data management in the Bure Underground Research Laboratory. • Presentation of CIGEO for the next-day visit.	Johan Bertrand (ANDRA)

Day 3 – April 20 morning

Visit of the Bure Laboratory

List of on-site participants			
Participants	Organisations	Type of actors	Country
Christophe Debayle	IRSN	TSO	France
Wilfried Pfingsten	PSI	RE	Switzerland
Nathan Ben Kemoun	IRSN	TSO	France
Guang Hu	PSI	RE	Switzerland
Jan Verstricht	EURIDICE	RE	Belgium
Malcolm de Butler	NTW	CS	France
Marianne Suignard	IRSN	TSO	France
Nadja Zeleznik	EIMV	TSO	Slovenia
Philip Matthews	NULEAF	CS	United Kingdom
Gauthier Fontaine	NTW	CS	France
Julien Dewoghélaëre	NTW	CS	France
Mansueto Morosini	SKB	WMO	Sweden
Gabriele Mraz	The Austrian Institute of Ecology	CS	Austria
Martin Schoenball	NAGRA	WMO	Switzerland
Alexis Geisler-Roblin	NTW	CS	France
Camille Espivent	IRSN	TSO	France

Johan Bertrand	ANDRA	WMO	France
Audrey Bonnelye	EM Nancy	CS	France
Louise Le Grand	EM Nancy	CS	France
Guillaume Lemaire	EM Nancy	CS	France
Céline Parotte	University of Liège	CS	Belgium
Colin Wales	Cumbria Trust	CS	United Kingdom

List of online participants			
Participants	Organisations	Type of actors	Country
Mario Crnković	Green team	CS	Bosnia and Herzegovina
Arto Laikari	VTT	TSO	Finland
Nico Graebling	UFZ	RE	Switzerland
Kateryna Fuzik	SSTC NRS	TSO	Ukraine
Oleksandr Solovyov	SSTC NRS	TSO	Ukraine
Mykola Sapon	SSTC NRS	TSO	Ukraine

Appendix B. Agenda of Workshop n°2 and list of participants

MODATS subtask 2.5

Agenda

24 - 25 October 2023
1st day: IRSN Centre du Vésinet, France
2nd day: Société géologique de France, Paris, France

How digitalisation and monitoring systems in the different contexts of DGR projects can contribute to a larger strategy of uncertainty management enabling trust-building processes in all phases?

24 October 2023 – Meet at 08:30 at RER A station Le Vésinet – Centre

15 minutes walks to reach the destination: "Le Vésinet IRSN centre"

Technical visit – 8:45-12:00

The morning will be dedicated to a visit of Le Vésinet IRSN centre that will bring us an interesting example of monitoring system: "the Téléray monitoring network".

12:00-14:00 *Lunch*

First session – PEP game session – 14:00-17:30

The first session will consist in a PEP game session. The participants will elaborate and discuss concrete cases on monitoring and digitalisation in small groups.

14:00-14:30 **PEP game introduction –** Julien Dewoghélaëre & Alexis Geisler-Roblin, NTW

14:30-17:30 **PEP game on digitalisation and monitoring**

17:30 **End of the first day**

19:30 **Social dinner**

25 October 2023

Second session – Panorama of monitoring & digitalisation key aspects – 09:30-12:45

The session will consist in presenting different types of actors' views on the key challenges of digitalization in relation to monitoring and uncertainty management.

09:30-09:50 **Example of a WMO's digital twin through the perspective of uncertainty management –** Johan Bertrand, Andra

09:50-10:10 **Discussion**

10:10-10:30 **TSO views on digitalisation through the perspective of uncertainty management –** IRSN

10:30-10:50 **Discussion**

10:50-11:10 *Break*

11:10-11:30 **Example of a RE's digital twin through the perspective of uncertainty management –** Wilfried Pfingsten, PSI

11:30-11:50 **Discussion**

11:50-12:10 **CS views on digitalisation through the perspective of uncertainty management –** Alexis Geisler-Roblin, NTW

12:10-12:30 **Discussion**

12:30-12:50 **Discovering an interactive monitoring tool –** Nico Graebling, UFZ

12:50-14:00 *Lunch Break*

Third Session – Monitoring, digitalisation and trust building conditions – 14:00-17:30

The session will be dedicated to PEP feedback session with a focus on building trust, including a TECDOC presentation on the subject.

14:00-14:30 **PEP restitution by the different groups**

14:30-14:50 **Discussion**

14:50-15:10 **IAEA TECDOC 1208 and trust building** – Gauthier Fontaine, NTW

15:10-15:50 **Discussion**

15:50-16:20 *Break*

16:20-17:20 **Synthetic discussion**

17:20-17:30 **General conclusion**

List of participants (in red = online participants, in black = onsite participants)				
Name	Forname	Organisation	Type of actors	Country
Benkemoun	Nathan	IRSN	TSO	France
Bertrand	Johan	Andra	WMO	France
Camille	Espivent	IRSN	TSO	France
DEBAYLE	Christophe	IRSN	TSO	France
Dewoghelaere	Julien	NTW	CS	France
Fontaine	Gauthier	NTW	CS	France
Fuzik	Kateryna	SSTC NRS	TSO	Ukraine
Geisler-Roblin	Alexis	NTW	CS	France
Graebling	Nico	UFZ	RE	Switzerland
Hansen	Johanna	Posiva Oy	WMO	Finland
Hooge	Niels Henrik	NTW/ Noah	CS	Danemark
Laikari	Arto	VTT	TSO	Finland
Malcolm	de Butler	NTW	CS	France
Marianne	Suignard	IRSN	TSO	France
Mihók	Peter	NTW/CEPTA / CSLG	CS	Slovakia
Montoya	Vanessa	SCK CEN	RE	Belgium
Morosini	Mansueto	SKB	WMO	Sweden
Mraz	Gabriele	NTW/Österreichisches Ökologie-Institut	CS	Austria
Munoz Pellicer	David	AMVALOR	WMO	France
Njaa	Oskar	The Bellona Foundation	CS	Norway
Pfingsten	Wilfried	PSI	RE	Switzerland
Sapon	Mykola	SSTC NRS	TSO	Ukraine
Schoenball	Martin	Nagra	WMO	Switzerland
Wales	Colin	NTW/Cumbria Trust	CS	United Kingdom
Zeleznik	Nadja	EIMV	TSO	Slovenia

Composition of the PEP groups during the PEP session

Second sub-task 2.5 Workshop

Legend:

	civil society representative		RE reoresentative	in red - online participation
	TSO representative		WMO representative	**in bold - facilitator**

Group 1

Alexis	**Geisler-Roblin**
Johan	Bertrand
Camille	Espivent
de Butler	Malcolm
Peter	Mihók
Wilfried	Pfingsten
Mykola	Sapon

Group 2

Christophe	**Debayle**
Gauthier	Fontaine
Kateryna	Fuzik
Gabriele	Mraz
Colin	Wales
Nadja	Zeleznik

Group 3

Julien	**Dewoghelaere**
Nathan	Benkemoun
Nico	Graebling
Niels Henrik	Hooge
Arto	Laikari
Oskar	Njaa

Appendix C. Practical cases elaborated for Workshop n°1

Topic 1 - Practical cases related to data delivered by sensors

The two practical cases related to data delivered by sensors have been discussed by working group n°1.

- **Practical case 1 - spurious data**

The geological disposal is under operation and the waste packages are being transferred into cells. To avoid problems of failure, it has been chosen that the temperature would be monitored at different scales (in the cell and farther from the packages) with several sensors based on different technologies. However, people in charge of the data analysis face some challenges: the sensors in the cell indicate a temperature in the normal range of the model but the farther sensors indicate that the temperature in the cell should be higher. Uncertainties arise regarding the necessity to recalibrate or not the sensors and the consistency of the data provided by the two scales of monitoring.

Questions

•What is the ideal balance between having diverse methods of monitoring and the risk of having to manage an unpredictable inconsistency in data? How to design safe monitoring systems considering this?

•To what extent could one consider that the different sensors monitor the same phenomenon? On what method could rely on the matching of the data sets?

•What difference between data sets stemming from the different sensors can be considered normal or abnormal (or problematic)? Who can determine this difference? And what to do if the difference is too important? Should there be thresholds? And how to define these thresholds?

- **Practical case 2 - No data for unexpected phenomenon**

50 years after the beginning of the operative phase, new studies have discovered a physic-chemical coupling in radionuclide behaviour that has never been modelled before. It seems important to monitor this new phenomenon in order to understand to what extent the safety of the disposal can be impacted. Modelling this new phenomenon requires new data that cannot be directly provided by the existing system. Strategies to adapt the system are being discussed.

Questions

•To what extent can the sensors and the monitoring system be flexible enough to be adapted or updated when an unplanned/event arise? On what methods (indirect measurements, proxies, models, etc.) should rely the adaptation or the update of the monitoring system?

•Should interventions be planned during the operative phase to add news sensors? What is the balance between the risk of such an intervention and the risk of a new unknown phenomenon?

•What is the ideal balance between having a robust precise monitoring system and a flexible one?

•Should “useless” data be acquired and stored to try to prevent such cases?

Topic 2 – Practical cases related to systems that allow to collect, view, analyse and understand the transferred data

The two practical cases related to systems that allow to collect, view, analyse and understand the transferred data have been discussed by working group n°2.

- **Practical case 1 - Inconsistency between data and models**

The geological disposal has been licensed and is under operation. The waste packages are being transferred into cells that are monitored. The sensors provide for data in a way that seems reliable. However, people in charge of their analysis face some challenges: for example, in one cell, H2 concentration value is significantly higher from the other cells, without any obvious explanation, and is in conflict with the models. The H2 concentration values are still below the limit where explosion risks

arise but since the phenomenon is not understood, there is no reason to believe that it will remain this way.

Questions

•What is the ideal balance between the risks posed by intervention (radiological exposure, explosion caused by air perturbation…or potential unknown situation at the time of intervention) and the drawbacks of staying in ignorance of the phenomena into play?

•Is it desirable to plan for a priori intervention thresholds, before operational phase, for any type of monitoring results? What organisations shall be implied in the definition of these thresholds?

•To what extent monitoring systems should be designed to be adaptable, flexible and easy to maintain?

- **Practical case 2 - Representativeness of witness cells**

Among the thousands of cells that are planned to be built to host the HLW packages, a few of them are selected and called 'witness' proxy cells, which means that they are monitored and that they represent, for the parameters monitored, the evolution of the other cells that don't have sensors. The assumption that the data collected from the witness proxy cells represent the state of the other cells is demonstrated on paper but cannot be verified. There is therefore a risk that some cells evolve in a different way than the witness proxy ones. Yet, it is not self-evident that each and every cell should be monitored at the same level than the witness proxy cells: beside the question of cost, it could result in too much intrusion into the host rock and lead to jeopardizing the safety in the long term (pathways for the radionuclides).

Questions:

•On what methods (experience feedback, mock-ups, modelling…), could one consider that the proxy cells represent well the state of other cells? For how long this capability to represent shall be maintained? What would be the conditions to consider a proxy cell as representative enough of other cells?

•To what extent it would be accepted that some aspects of the state of the facility are unknown, uncertain or only known through results of numerical models?

•Would extensive monitoring be the priority over long-term safety?

Topic 3 - Traceability of knowledge

The two practical cases related to traceability of knowledge have been discussed by working group n°3.

- **Practical case 1 - Data maintenance in the long run**

20 years after the start of the operation of a GDR, the WMO agreed to open all the archived data to some university modelling laboratories. During the past 20 years, the operation went as planned and no serious incident was monitored by sensors. The reprocessing of the data by the university teams indicate that even if the conclusions of the operator were mostly right, the main modelling software used for gathering key data was obsolete and unclear (some important parameters were hidden and/or inaccessible). After further inspection by the operator, it appeared that the model used for the last 20 years was developed by a company which was now closed. This information went public, and a social controversy started, as the operator was vividly criticized for a leak of prudence and transparency for 20 years.

Questions

•What is the ideal balance between openness to alternative interpretations and institutional methods for monitored data? How could key skills in both fields be maintained over time?

•Which organisations should be involved to verify the complete understanding of data?

•To what extent monitoring data processing should be designed to stay permanently traceable?

- **Practical case 2 - Keeping data alive**

In the last quarter of operation life of the GDR, the regulatory authority asks for a transversal and detailed proof of long-term safety based on all monitored data, in preparation for the process for authorization of closure. Therefore, a complete historical inventory is done, taking into account the several generations of underground and surface technical devices, and the generations of models and of skilled persons. It appears that an important part of the oldest generations of collected data cannot be interpreted anymore, even if the results of the models are still available.

Questions

•To what extent it would be accepted that some parts of the interpretation of monitored data of the facility are unknown or uncertain?

•What should justify the decision to keep data in a perfect state for a long time? On what criteria? What should weigh the possibility to interpret data at any time?

•How could the economic aspects of this maintenance be considered? On what criteria?

Cross-cutting theme - Governance process

The practical case related to governance process has been discussed by the three working groups of Workshop n°1.

Practical case - Technical innovation for post-closure monitoring

A monitoring system has been set up and has been in operation for 50 years. A major innovation (e.g. wireless sensors with self-charging batteries that can be maintained almost indefinitely) is then introduced. No provision has been made for updating the technology in closed galleries (without affecting safety). There is a strong expectation in society that monitoring should continue beyond closure.

Questions

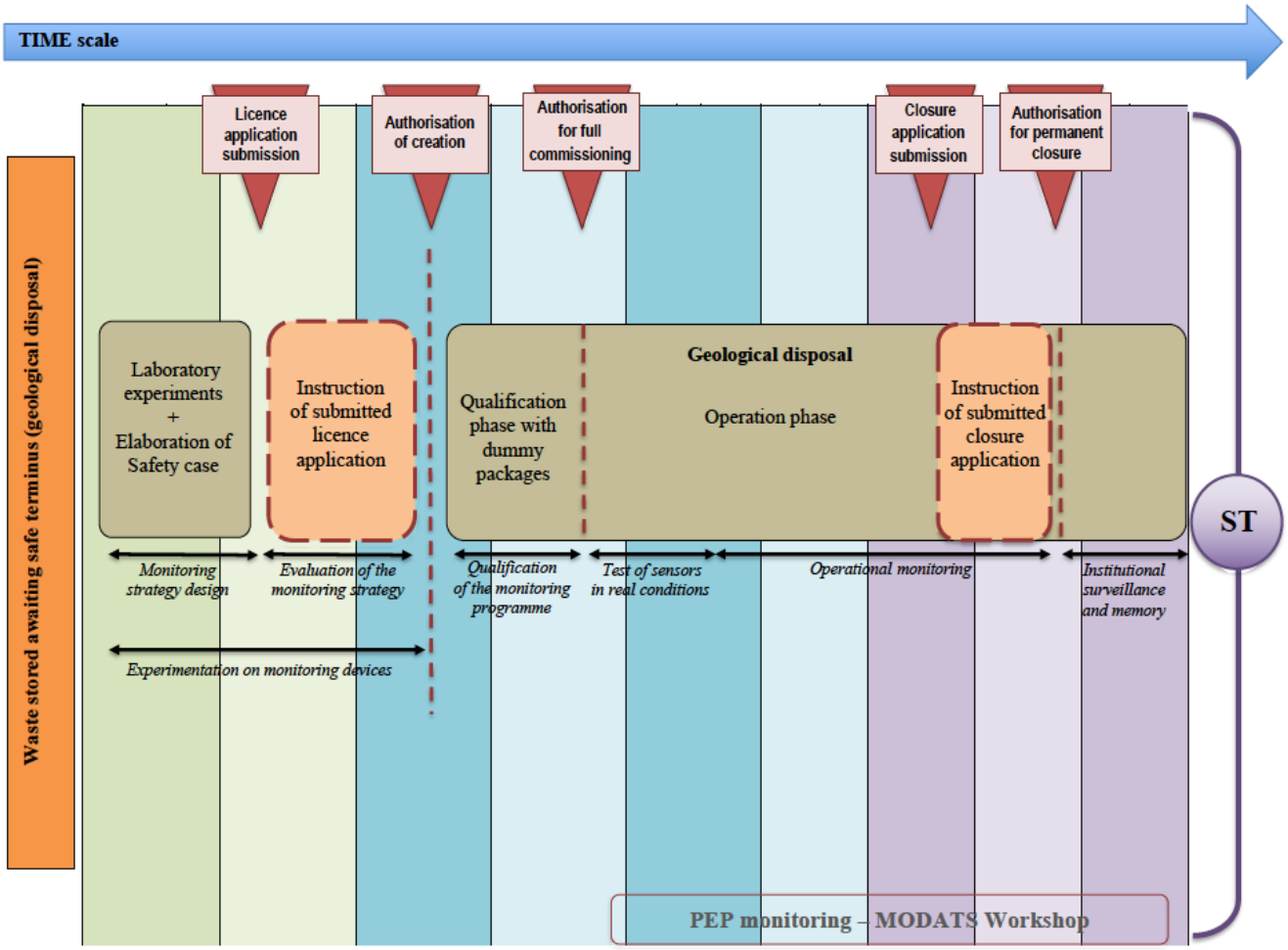
•To what extent should the implementation of geological disposal allow for the updating of the facility's monitoring system?

•By what means (technical or non-technical) can the updating of the monitoring system be anticipated?

•Should the potential update of the monitoring system only concern the galleries yet to be constructed or also those already storing waste?

•Is it desirable to adapt the monitoring objectives to technological innovations? How can this be done? What is the meaning of post-closure monitoring?

Appendix D. PEP material



List of PEP events cards on monitoring and digitalization

M1- Defective monitoring demonstrator: The demonstrator that was planned in the safety case for license application is not able to provide data to confirm initial expectations *E.g., • Failure of several sensors; data is not collected as expected*

M2- Uncertainties about monitoring maintenance: Uncertainties remain about the ability to maintain well-functioning the monitoring system over time *E.g., • Uncertainties remain about the ability of defective devices to be replaced (access and lifetime), • Questioning of the availability of spare parts in decades due to technological evolution, • Calibration issues due to replacement*

M3- Data revealing a safety issue: Monitoring data reveals serious problems that can threaten safety *E.g., • Abnormal range of humidity in a monitored cell • Measurement of temperature higher than expected • Detection of problematic concentration of gases • Detection of a malfunction of one monitored waste package*

M4- Defects in the monitoring system: Wrong adjustments in the monitoring system leads to potential problem for safety *E.g., • Use of non-conforming materials for the sensors and/or material for data collection and management*

M5- Incident related to the monitoring system: An incident disrupts the operation of the monitoring facilities *E.g., • A* power shortage interrupting the data collection, *• Damage of the monitoring devices due to construction works*

M6- Cyber-attack: A cyber-attack is conducted on the DGR data centre *E.g., • loss of waste packages' tracking data; falsification of the data by terrorists*

M7- Difficulty to intervene on monitoring devices: Some events necessitate to replace monitoring devices and difficulties are encountered *E.g., • Physical access problem to the sensor; intervention on the malfunctioning sensor that could alter safety conditions*

M8- Major technological breakthrough for monitoring: Research offers new opportunities for monitoring strategy *E.g., • technological breakthrough in battery for wireless sensors; Artificial Intelligence's fast development leads to new computational tool and improvement for implementing digital twin of DGR*

M9- Requirement of new data: Political or societal concerns lead to the requirement for monitoring additional data *E.g., • Modification of the DGR waste inventory (bitumen, graphite, military legacy, etc.) • Requirement of a new type of data like in situ corrosion rate*

M10- Links with reversibility requested: Expectations for strong and transparent links between DGR monitoring and reversibility strategy rise in public policies *E.g., • A report from national Parliament demands a reinforcement of the "oversight" strategy like prescribed by NEA • Recoverability requirements increase; existing monitoring provisions supporting reversibility are not sufficient*

M11- Loss of institutional interest for monitoring: Sudden or gradual changes lead to consider no more the continuation of the monitoring programme, nor its maintenance, as a priority *E.g., • Complete automation of data management leads to a loss of interest for monitoring • A change in political orientation causes a restriction of budget in monitoring programmes*

M12- Strong loss of societal confidence: Due to a technocratic and non-transparent process, local and/or national organisations publicly demonstrate a growing distrust towards the strategy and results of monitoring *E.g., • The absence of communication related to a problematic monitored event leads to concerns about the DGR monitoring strategy and its data management, • Rising demands for pluralist access of data*

M13- Data preservation issue: Due to a problem encountered over time, the preservation of exploitable data is jeopardized. *E.g., • Data centres saturation due to an excessive amount of data accumulated over time • Excessive energy demands for data conservation • Loss of competencies for running and maintaining monitoring systems*

M14- Debate on the representativeness of data: During the elaboration of the monitoring strategy or after an incident during the operational phase, the question is raised about favour a light monitoring programme or opt for an extensive monitoring *E.g., • Discussion about implementing monitoring only on test cells or having all the cells monitored but only some packages in it*

M15- Data treatment issue: An incident occurs that could have been prevented but the data was hidden by data treatment processes (pre-treatment, cleaning, flagging or treatment processes of data) *E.g., • Monitoring detects dissemination (Bq/m3) but the corresponding data is judged as "extreme non-significant"/artifact value*

M16- Obsolescence of the data format: Data format has evolved over time, generating a problem with the interpretation of data *E.g., • Software/hardware compatibility •Old stored data is no longer readable*

M17- Request for post-closure monitoring: Due to evolution of societal and/or political context, there is a request for post-closure monitoring *E.g., • Modification of legal requirement on monitoring during the DGR closure phase • Societal request for a planification of a post-closure monitoring strategy*

M18- Data interpretation issue: After treatment, cross-checking of several sets of data indicates potentially abnormal behaviour for a package/cell. The need to intervene is discussed *E.g., • Contradictory data concerning packages of the same cell • One parameter indicates a problematic situation, while the other parameters show normal results*

M19- Problem with the automated monitoring system: While the fully automated monitoring system is running, a safety issue is encountered raising the question of the level of human intervention for a reliable system *E.g., • Need of human backup for the maintenance of the system • Request for human control of measurement*

M20- Discrepancy between measurements and models: Physics-based models and data-based models do not present same results on some key safety elements. *E.g., • the resaturation is not supposed to happen within hundreds of years but sensors detect high humidity in the host rock*

M21 – Controversy on GDF digitalisation: The massive use of digital tools to monitor geological disposal facility (GDF) generates scientific or/and societal discussion. *E.g., • Scientific discussion on the real meaning of a GDF digital twin • Societal controversy on the risks and benefits associated with the monitoring digitalization*

List of PEP evaluation criteria cards on monitoring and digitalization

Q1- Maintaining social trust in monitoring Does the monitoring strategy generate/maintain trust of the different types of concerned stakeholders over time?

Q2- Pluralistic monitoring How does the monitoring strategy allow a continuous involvement of a diversity of expertise, actors, knowledge, and sensitivities?

Q3- Democratic monitoring Does the monitoring strategy allow encountered difficulties to be addressed democratically? Does it allow a pluralistic set of actors (including society) to participate in important choices related to monitoring all along the DGR implementation?

Q4- Continuous security of data Does the monitoring strategy ensure the security of data over time?

Q5- Robustness of monitoring to disruptive events Can the monitoring strategy manage difficulties encountered in the data collection, treatment, interpretation, and preservation over time? Can the monitoring strategy undergo disruptive and unexpected events (major discovery, financial crisis, armed conflict, etc.) without being blocked?

Q6- Adaptability of monitoring strategy: Can the monitoring strategy be flexible and adaptative to the evolution of scientific context (new knowledge, technological breakthrough? Is the monitoring strategy sensitive to external social, financial economic, political constraints (loss of skills, financial crisis, evolution of political and societal requests, etc.)? Are there actual alternatives (B plan) at each stage?

Q7- Maintaining reversibility Does the monitoring system ensure that reversibility is maintained over time?

Q8- Intergenerational monitoring governance: What room for manoeuvre does the planned monitoring strategy give to future generations?

Q9- Uncertainty management: How does the monitoring strategy take into account uncertainties about the monitoring (insignificant uncertainty, D&R or feedback on the concept)?

Q10- Maintaining preservation of data over time: Is the monitoring strategy able to maintain knowledge, data and keeping (active or passive) memory all along the stages of the DGR, including post-closure?

Q11- Resilience & Robustness of monitoring: What is the type of robustness of the monitoring system? Just Enough Essential Pieces (JEEP) or High - but vulnerable - Technology?

Q12- Maintenance and risk of abandonment of the monitoring strategy: To what extent is the monitoring strategy capable to ensure maintenance of the system over time? Is the monitoring system vulnerable to possible abandonment in uncontrolled conditions, before reaching a Safe Terminus?

Q13- Transparency and access to data: Does the governance of the monitoring system ensure transparency regarding monitored events all along the DGR phases? What level of access to data is planned by the monitoring strategy?

Q14- Data traceability: What resources are put in place by the monitoring strategy to track the origin of the data?

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