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Methodology for qualifying monitoring components

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Summary

This paper summarizes the work performed in Task 3.6, *Reliability and Qualification of components*, of the EU H2020 project Modern2020. It synthesizes progress made by eight expert organisations on a common multi-stage methodology for qualifying monitoring components (MC) of the measurement chain (sensor, connecting cable and/or wireless system/controller) at a Deep Geological Repository (DGR). This study was reported as document D3.6 [1] in the Modern2020 project and results from a multi-stage analysis including: i) the study of transferable experience gained from the energy and space fields, ii) the feed back of long-term and demonstration experiments operating in conditions close to those expected in repositories at Underground Research Laboratories (URLs) or at large mock-up, iii) the initiatives for the development of a qualification process for selecting and testing the monitoring components and at last, iv) the proposal for a global protocol appropriate to all monitoring contexts.

Introduction

This analysis converges towards a global protocol that may be subdivided in four steps. The first step concerns the selection of components (sensors, cables, housing, DAS etc.) based on detailed specifications of the application. It can be described as a theoretical exercise with lots of input from the manufacturers and from earlier tests for identifying possible influence parameters. The second step is that of laboratory tests for testing components under controlled conditions to quantify metrological performances. The third step concerns the on-site testing. It means testing of the whole system under realistic conditions, where variability (dust, variability of concrete, patience of worker...). It can also be part of the safety demonstration. At last, previous to on-site tests, an optional step based on mock-up tests may be considered if there is a need for a more realistic use of components. The best way to articulate this methodology could be that the organization in charge of

the surveillance shall document an Approval DOCument such as the one proposed in this paper with the goal of approving each component intended for use in the repository.

1. State of the art and gathering of transferable experiences from other fields

The ability to ensure reliable and durable monitoring system with repeatable quality through the time life is critical for DGR implementation. However, as there is still no implemented DGR existing analogies can also be a way for qualifying the monitoring components (MCs) and obtain reliable equipment over the long term. The analysis of transferable experience from other fields aims at summarizing the different protocols used by other industries with respect to the monitoring components to deliberately accelerate their ageing and qualify their use. This was done by taking into account the feedback from industries working in harsh environments through a bibliographic research made around two major companies EDF and ESA, involved in the energy and the space field, respectively and by comparing it to the approach proposed by Andra, the French agency for radioactive waste management, for the Cigeo project.

1.1. Experience from the energy industry field

Innovations (eg. new design of the hydraulics at Marèges, France), accidentology (eg. Malpasset, Rance) and pathologies of works at dams (alkali-reaction concrete at Chambon, France) fueled a need for remote long-term quality monitoring. This especially concerned reliability of data transmission as dams are not easily accessible in winter. Nuclear power plant monitoring was inspired by these practices by using similar sensors as dam monitoring, for instance telemetry systems. However, in order to take into account different characteristics between these structures, as well as the large number of sensors involved in hydraulic and nuclear power plants (around 20,000 sensors in 600 civil engineering works), EDF has defined and implemented an industrial policy for the choice, the qualification and the maintenance in operational conditions of auscultation equipment. It is based on the following three main principles: i)

- Use of a limited number of types of equipment,
- Development of a selection and qualification process for materials,
- Sustainability of qualified materials.

This has conducted EDF to develop an original approach for selecting and qualifying the components for the monitoring of Dams and of Nuclear power plants implemented through five main tasks summarized in Figure 1 after [2] and including:



Figure 0: Selection and qualification process implemented at EDF for monitoring components

The selection of material and suppliers further to a permanent watch on technologies is based on the following features: accuracy (absence of drift over time), insensitivity to environmental conditions (temperature, humidity, surges), reliability (inaccessible device, continuity of measurements), robustness (hostile environment: humidity, cold, lightning...), and maintainability.

The materials are selected according to their manufacturer characteristics. EDF is preferably looking for "close" (European) suppliers who are well represented in the area to benefit from a better after sales service and easier dialogue as part of a partnership. The cost aspect of the material is obviously considered. However, this criterion is weighted against the others (in particular the reliability and the robustness) because the recurrent failures of a hardware installed on an isolated site become very quickly expensive.

The laboratory qualification includes the verification of metrological characteristics, tests for sensitivity to influence quantities, verification of functional and ergonomic features, and verification of compliance with the standards in force, robustness and ageing tests.

At last, on-site qualification is performed either on large scale mock-up or on real structures. The former is generally operated in parallel with devices already in place and qualification pronounced after a satisfactory exploitation time lasting at least one year. The use of large-scale mock-up aims at verifying the behaviour of components at a larger time scale and at conditions similar to real ones or even better controlled. One example is that of the Vercors (Monitoring System for Reduced Scale Containment Model.) experiment developed for verifying the behaviour of components associated to a reactor structure [3].

1.2. Experience from the space field

Concerning the space field, Europe via The European Space Agency (ESA) has created its own European "organism" for space qualification, namely the European Space Components Coordination (ESCC). It is shown that despite different influencing parameters, due to the rocket take-off (vibrations) or the space conditions (vacuum, temperature, radiations), the qualification process is rather similar to that developed in the energy field. The selection of components is a complex process that alone accredited companies (SAFT, TRAD, IAS) are able to perform. It includes the analysis of performances, design, operational, environment, manufacturing and testing. The testing of components requires qualification campaigns in space simulators, controlled clean environments, thermal vacuum space cycling, vibration pot and irradiation facilities and is considered as achieved when the Part Approval Document (PAD) is fully filled up and signed [4].

1.3. Andra's approach for the repository field

An overview of typical environmental conditions, expected operating performances such as durability and precision, and other specific constraints imposed by the repository safety requirements were presented in the MoDeRn Technical Requirements Report [5]. It is recommended that available state-of-the-art monitoring technology is adapted and qualified to meet these requirements, and where necessary innovative technology is developed and qualified as well. To illustrate this recommended approach, a succinct description of the qualification process that Andra has set up is provided. It entails testing and qualifying the complete measurement chain, by progressive steps, knowing, to be able to anticipate them, the failure rates and mastering the possible long term drifts. The overall

process is inspired from the qualification guide for non-destructive methods. Global test sequence includes four stages such as in Figure 2:

- Stage one consists in acquiring in-depth knowledge of the sensing technology, engineering solutions, practical implementation constraints. It aims at selecting the technologies best suited to the specific requirements of monitoring the geological repositories for long-lived nuclear wastes. When commercially-available sensing chain performances do not fulfil requirements, research programs will be initiated.
- Stage two consists in carrying out laboratory tests, under fully supervised and/or controlled environmental conditions, to qualify the sensitive component and assess the complete measurement chain performances. Sensors are tested in air, and embedded in host material of interest.
- Stage three consists in outdoor tests, to evaluated field implementation influence. At this stage, the sensing chain is preserved from hazardous conditions, extreme temperature or gamma rays. Unexpected influence parameters might thus be revealed.
- Fourth stage involves hardening in view of the application environmental conditions. In the envisioned French geological repository, temperature (25°C to 90°C), gamma radiation (dose rate of 10Gy/h at HLW contact), and hydrogen (up to 100%) are amongst the main stresses to be analyzed.

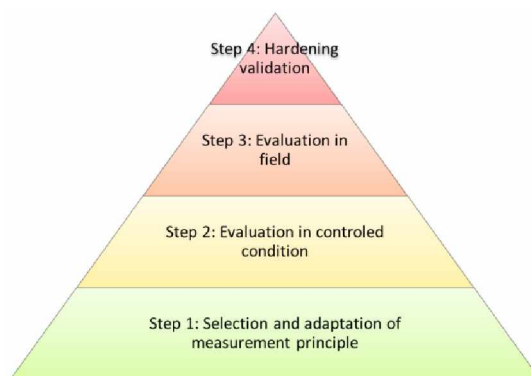


Figure 2: Qualification process for technology implementation in the Cigeo projet

1.4. Main feedback from other fields

Results indicate that there is a strong synergy between DGR and other fields (Energy, Space,) concerning the needs, such as robustness, long-life power supply, and optimization of communications. All fields consider at least three common stages: i) Selection of components, ii) Laboratory qualification and iii) On-site qualification.

2. Lessons learned from existing long-term experiments

The second part of this study concerned the analysis of case studies of monitoring components operating in conditions close to those expected in repositories. The main idea was to obtain information about ageing, accuracy, possible drift over time and robustness of sensors installed. This was done through a selection of large in situ experiments performed at URLs or in large mock-ups (GCR, FEBEX, SEALEX, POPLU, PROTOTYPE). The selected experiments can be shared into two categories: demonstrator and long-term. In demonstrators the general rule was to use high Technology Readiness Level (TRL) monitoring components essentially wired connected sensors such as in GCR and FEBEX. However, for the sake of redundancy and also for qualifying new or low TRL

instruments, more innovative components including wireless sensors were applied in long-term experiments such as in POPLU, MPT or in SEALEX. Each selected experiment was summarized through an experiment form detailing the type (long-term or demonstrator), present status (dismantled or on-going), goals, means and main results with respect to survival rate of sensors, the failure origin, if any, and the possible improvements [1]. Table 1 summarizes main conclusions with respect to the survival rate of wired/wireless sensors for the given experiment duration.

Table 2: Behaviour of sensors for a selection of long-term or demonstration experiments at URLs

Partner	ANDRA	NAGRA AMBERG	IRSN	SKB	VTT	SKB
URL/LAB (country)	LMHM (F)	GTS (CH)	Tournemire (F)	Äspö (S)	Onkalo (FIN)	Äspö (S)
Dismantled long-term and demonstrator experiments	GCR	FEBEX in situ				
Long-term experiments			SEALEX	MPT	POPLU	PROTOTYPE
Duration (y)	6	18	6	5	5	8
Total number of sensors						
Wired/Wireless	-	176/0	149/105	194/33	132/0	328/0
Total/Survival	134/9	176/108	149/113	227/99	132/20	328/125
% survival rate	93%	39%	24%	56%	85%	61%

The first lesson is that experiments only lasted a few years which is far below the 100 year operational phase expected for DGRs. The second finding is that despite a strict selection of the best technical solution of the moment, the analysis of the different long-term and demonstrator experiments suggest improvements on monitoring components: 1) For wired sensors, preference was given to passive measuring methods such as the vibrating wire technique and the optical fiber distributed sensing for which an extension of recording time is required to demonstrate the absence of water short circuits along the cables. In case of potential leakage, wireless technologies should be used and the size and number of cables should be limited; cables should also be more armored and resistant to corrosion to prolong their service life. 2) For wireless sensors many problems occurred during swelling of the bentonite-based seal under waterflow. Improvements mostly concern a better isolation between transmitters and sensors for avoiding electrical short circuit with free water and the extension of batteries' lifetime.

3. Development of a qualification process

The process must first consider the list of influence parameters requiring a monitoring component. But this part is not included in the qualification process.

3.1. Methodology for selecting monitoring compounds

As for monitoring contexts in other fields the selection requires upstream to verify:

- Metrological characteristics and performances (compliance with environment requirements including lifetime, radiations levels, mechanical stress, thermal stress, humidity exposure, and storage duration...).
- Sensitivity to influence parameters (Temperature, Humidity, Stress, Strain, Corrosion under in situ conditions, Hydrogen...).

- Functional and ergonomic characteristics and design.
- Compliance with current standards (safety, CE marking, PAD, approved at accredited labs...).
- Operation: input/output power, operating temperatures, wavelength, modulation, consumption, end of life, etc.
- Testing: list the physical quantities, functionalities and number of tests to be carried out, establish the measurement ranges and the number of measurements to be made, select the off-site laboratories, screening definition, prioritize the realization of tests (laboratory or on-site).
- Quality and Product Assurance: focus on reliability and traceability, define the customers' reviews as early as possible, the list of documents to be delivered, how the hardware is accepted for delivery, and criteria for batch rejection.
- TRL: Propose the minimum required Technology Readiness Level.

3.2. Methodology for testing and evaluating monitoring compound

The second step of the qualification process consists in testing components under laboratory or real conditions of use. It is recommended that laboratory tests be conducted prior to field testing. A test form was sent to partners with the goal of having their feedback from laboratory testing methodologies. Two categories of laboratory tests were identified: Tests of robustness and ageing tests [1]. In both cases tests seek to estimate the degree to which a system or component can function correctly in the presence or stressful environmental conditions but ageing tests alone look at the normal degradation with actual time of use by accelerating artificially the process through a time-dependent stress.

Irradiation test is a good example of ageing test such as those performed on new sensors developed in the framework of Modern2020. Tests were performed at the IRSN (IRMA) and CEN-SCK (RITA) facilities with Total Ionizing Dose (TID) of about 1MGy and of 0.1 MGy, respectively. Most of the tests concerned Optical fibers and provided very promising results in view of their integration in a DGR. However, a lot of work remains to do to quantify precisely the Radiation Induced Attenuation on the fiber itself with the necessity to use a dopant or to evaluate the coupled impact of influence parameters (temperature, radiation, hydrogen...) on the sensing cable.

An example of robustness test is proposed by VTT for the Nordic repository case with the aim of developing a procedure to simulate long-term conditions in EBS environment. Robustness tests are planned to be done in cycles so that it will give provisional results already during the test program. Test plan will consist of selected sensors and dummy sensors made to mimic the shape and having the same piping and tightness as the real ones and manufactured from different materials. Idea is to test sensor enclosure and sensor cable armouring/sheltering pipe with the dummy sensors. A test would consist of 20 iterative steps as illustrated in Figure 3.

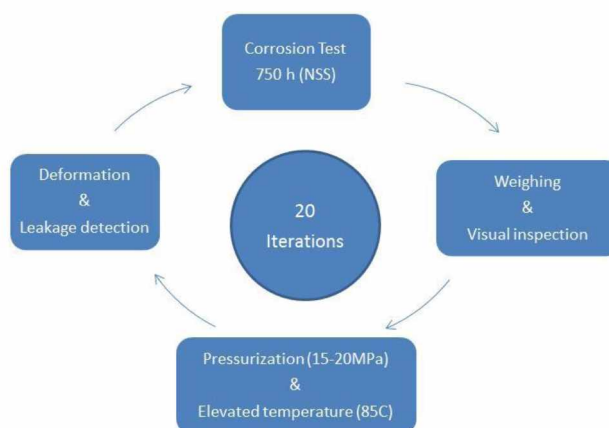


Figure 3: Example of cyclic robustness test applied to monitoring compounds to simulate their long-term conditions in the EBS environment

Contrary to laboratory tests, on-field tests may allow testing the complete measurement chain metrologically and functionally under real conditions of use. But for the moment, only demonstrators in underground, long-term experiments at on-site/off-site laboratories or at large mock-up can serve as dummy on-site tests. Monitoring strategies like that proposed by Andra also suggests using some “sacrificial”, “surveillance” or “witness” structure exhaustively equipped to fulfil the monitoring goals at the future repository.

4. Discussion and conclusion

The study resulted from a multi-stage analysis including: i) the study of transferable experience gained from other industry fields, ii) the analysis of case studies operating in conditions close to those expected in repositories, iii) the initiatives for the development of a qualification process for selecting and testing the monitoring components and at last iv) the proposal for a global protocol appropriate to all monitoring contexts. Main conclusions are that:

- A strong synergy with respect to the monitoring components exists between energy and space fields with needs for a DGR facility such as robustness, long-life power supply, and optimization of communications. The qualification process of those different fields always consider at least three stages including i) Selection of components, ii) The laboratory qualification and iii) On-site qualification.
- Despite a strict selection of the best technical solution of the moment, in situ and long-term experiments performed at URLs or at large mock-ups suggest improvements that can only be checked in situ where conditions will be as close as possible of the real one at DGRs.
- The Initiatives for the development of a generalized qualification procedure must combine robustness, ageing and on-field tests. This can be summarized by the global sketch given in the Figure 4.

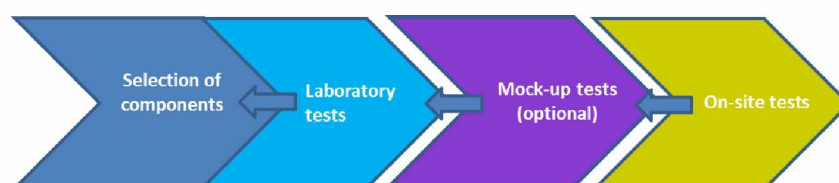


Figure 4: Global sketch for the qualification of monitoring components in DGRs

The proposed global qualification protocol combines the same three successive steps proposed by other fields with an optional large-scale mock-up stage and a retrofit process in case of dissatisfaction of one of the three/four major steps. The first step concerns the strict selection of component candidates with the aim of measuring influence parameters and to define the list of tests to be carried out. The goal of the second step is to proceed on the laboratory testing of components/combined components under adverse conditions. The last step is linked to testing under real conditions of use. To package this methodology, an Approval DOCCument (ADOC) is proposed as a mean to control the approval status of a monitoring component whatever the envisaged repository context (Table 2).

Table 2: Example for ADOC sheet for a monitoring component qualification

ADOC - Approval DOCCument for a monitoring component qualification

Revision: 1 / 1

Project:	Doc n°:
Prepared by:	Date:
Approval requested by:	
Family:	Component:
Technology Detail specification:	

Approval status:

Validation (signature required): ☐ Yes ☐ No

Component selection:

TRC:	Procurement by:
Influence parameters with measurement range and sensitivity:	<input type="checkbox"/> Ok <input type="checkbox"/> Not Ok
Sensitivity to influence parameters:	<input type="checkbox"/> Ok <input type="checkbox"/> Not Ok
Verification of functional and ergonomic characteristics:	<input checked="" type="checkbox"/> Ok <input type="checkbox"/> Not Ok
Verification of metrological characteristics:	<input type="checkbox"/> Ok <input type="checkbox"/> Not Ok
Verification of compliance with current standards:	<input type="checkbox"/> Ok <input type="checkbox"/> Not Ok
Requirement for additional tests (in case not ok):	<input type="checkbox"/> Yes <input type="checkbox"/> No
If yes, test required Lab - Robustness:	<input type="checkbox"/> Yes <input type="checkbox"/> No
Lab - Ageing tests:	<input type="checkbox"/> Yes <input type="checkbox"/> No
In situ - Long-term:	<input type="checkbox"/> Yes <input type="checkbox"/> No
In situ - demonstration:	<input type="checkbox"/> Yes <input type="checkbox"/> No

Laboratory test (testing of components/combined components under adverse conditions)

1. Test of robustness: ☐ Yes ☐ No

Laboratory name:	Certification/accreditation number:
Detailed Specifications (type of test, steps, iterations...):	
Reporting:	Number: Date:
Results:	<input type="checkbox"/> OK <input type="checkbox"/> Not OK

2. Ageing tests: ☐ Yes ☐ No

Laboratory name:	Certification/accreditation number:
Detailed Specifications (type of test, steps, iterations...):	
Reporting:	Number: Date:
Results:	<input type="checkbox"/> OK <input type="checkbox"/> Not OK

On-site test (testing of the whole components under realistic conditions)

1. Tests at LRLS: ☐ Yes ☐ No

URL:	Certification/accreditation number:
Detailed Specifications (type of test, steps, iterations...):	
Reporting:	Number: Date:
Results:	<input type="checkbox"/> OK <input type="checkbox"/> Not OK

2. Testing at witness structure/cells at DGR: ☐ Yes ☐ No

DGR:	Certification/accreditation number:
Detailed Specifications (type of test, steps, iterations...):	
Reporting:	Number: Date:
Results:	<input type="checkbox"/> OK <input type="checkbox"/> Not OK

Modern2020

The objective of the ADOC document is to provide information about a monitoring component and its acceptability with respect to its selection, laboratory test and on-site test. The entity in charge of the surveillance of the repository shall document the ADOC sheet for approval of each component type intended for use in the repository.

5. Acknowledgements

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