Milestone 55
Completion of full-scale trials in a realistic testing environment

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Abstract

Milestone MS55 consists of a status update report of subtask 7.6.2 'Demonstrating systems and methods' of WP7 'Innovations in cemented waste handling and pre-disposal storage'.

In this milestone report, the work relevant for the milestone MS55 **"Completion of full-scale trials in a realistic testing environment"** is described to summarise the achievement of the task 7.6 objectives. This document highlights the work done to validate the completion of Milestone M55.

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1 Milestone Description

Milestone MS55, associated with Work package 7 ‘Innovations in cemented waste handling and pre-disposal storage’, Task 7.6. ‘Demonstration and implementation of monitoring, maintenance and automation/digitalization techniques’ has been completed on 16/08/2024.

The readiness of the milestone was reviewed and agreed upon by Ernst Niederleithinger (BAM) as WP7 leader.

2 Introduction

Accurately predicting the behaviour of nuclear waste especially in a waste package, is a challenging task. Some deterioration is to be expected. However, techniques which offer some early indications of degradation or change would greatly increase the regulators' confidence in the safe storing of waste packages. Such techniques may, in the future, become routine depending on the ease of use, suitability of the information provided and package ageing.

The aim of task 7.6 “Demonstration and implementation of monitoring, maintenance and automation/digitalization techniques” was to demonstrate that the technologies, methods, and models developed in Tasks 2 to 5 can be used in a real storage with nuclear waste. This led us to evaluate (test and verify) the performance of the selected technologies by the deployment of an instrumented package at an end-user’s real storage facility or, if not possible, at a similar environment.

The second subtask of 7.6 was T*7.6.2: Demonstrating systems and methods*. Work on this subtask has begun at month 31 and lasted until the end of the project under the lead of Orano.

This subtask includes the following actions:

- Implementation of an experimental set-up
- Selection of all technologies by a validation based on their availability, TRL level, and the safety case requirements needed for their implementation. These technologies would include both external and embedded technologies developed in Sub-tasks 3.1 and 3.2.
- Performing a series of full-scale trials in a realistic testing environment.

For the selection of the waste package/mock-up and the location of the demonstration test, the technology as well as the parameters which were monitored needed first to be determined.

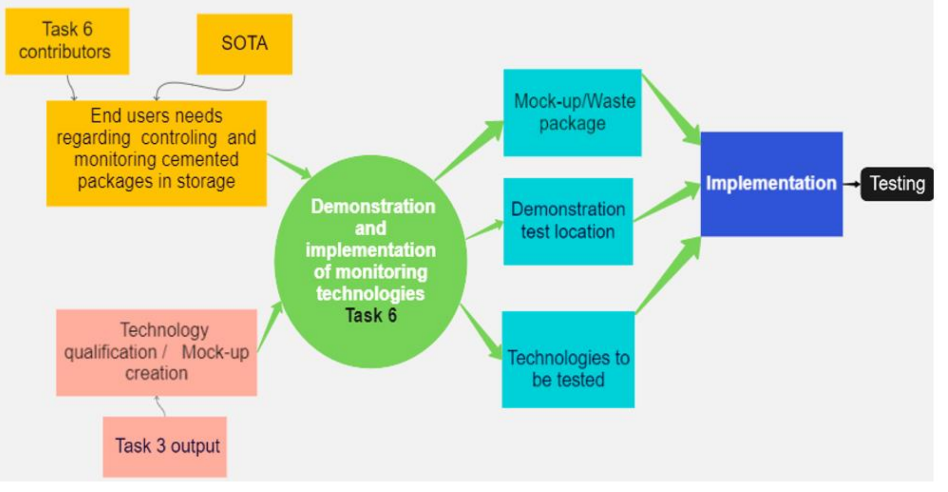

Figure 1: Method for selection of parameters to implement the demonstration test

As it is seen in the figure above, there were three inputs that were needed for the decision and the implementation of the demonstration trial. These were:

- The technologies that were tested,
- The mock-ups that were implemented,
- The storage configuration constraints that each technology (and its mock-up) has.

This milestone text is complemented by a full deliverable describing in detail the implementation and demonstration of monitoring, maintenance and automation/digitalization techniques for improving safety during the storage and handling of cemented waste packages (D7.8).

3 Task 7.6: Condition of the test

3.1 Technology selection

Four technologies were selected for the demonstration test, based on their availability and TRL:

- Embedded RFID,
- SciFi / SiLiF,
- Sensorized RF Identification box,
- Air coupled ultrasonic inspection.

The other technologies were not selected:

- The Muon tomography demonstrator developed by INFN couldn't be shipped to a demonstration site, thus the test needed to be performed directly at INFN´s location. Therefore, for Muon tomography a dedicated mock-up has been made, which has been shipped to INFN location.
- Acoustic Emission TRL was at the time too low to be tested in a realistic environment. That is why Magics decided to perform a 2-year trial at mock-up scale, following lab scale experiments, with several mock-up containing different kinds of cemented matrix placed in either accelerated or non-accelerated conditions.

3.2 Mock-up/Waste package

The creation of mock-ups to test the technologies selected needed to fit with an existing package. A reference package was defined at the beginning of PREDIS WP7 to give some features of a package that could be replicated as a mock-up. Therefore, the mock-ups used to demonstrate the technologies had to comply with the characteristics of the reference package.

The four technologies selected had several constraints that had to be taken into account for the demonstration test:

- RFID sensor contains sensors that are embedded inside the cemented matrix. For this technology a dedicated mock-up needed to be produced. The RFID mock-up, produced by BAM/VTT, was a 200L drum with embedded sensors to monitor humidity, temperature, and pressure. This setup allowed the assessment of the sensor's performance in measuring these critical parameters within a cement matrix.

- SciFi/SiLIF and Sensorized RFID required the measurement of radioactivity. Therefore, they needed a dedicated mock-up that includes a radioactive source. Since both technologies could be installed on the same mock-up and have the same mock-up specifications only one single active mock-up was produced. The technologies were installed at the same mock-up during the demonstration test.

- Finally, NNL's old mock-up available for use for PREDIS was a > 25-year-old inactive Magnox package from the Magnox Encapsulation Plant (MEP) at Sellafield, UK. It was designed to allow a storage of 50 years above ground followed by 50 years below ground prior to closure of a Geological Disposal Facility (GDF)

So three types of mock-ups were utilized to realistically test the four selected technologies, addressing various constraints and requirements.

3.3 Demonstration test location

The demonstration task had to be carried out in a realistic testing environment. Since there was no possibility to perform the test in a radioactive facility, the conditions of a representative storage area of an end-user site have first been defined and were compared with the conditions available at several partners' platforms (NNL, UJV and Orano).

Also, in order to integrate the technology in a realistic storage configuration, the following constraints have been fixed and discussed with technology developers:

- The technologies had to remain accessible during the whole demonstration test, but the mock-ups were placed behind other cemented packages, to have cemented packages around each mock-up. These cemented packages had to be moved to access the actual mock-ups.
- The data had to be remotely accessible through a "data collecting area" and also in a platform that can be readable from outside to have continuous access to the data.
- A data collecting area representing a command room needed to be separated from the storage unit (several meters of concrete shielding away).

Furthermore, the technology constraints for the demonstration test (in terms of stacking, power and Wi-Fi supply, etc.) have also been considered and were taken into account.

Finally, it was decided that NNL's Air coupled ultrasonic inspection demonstration test was performed directly at NNL's location and that the three other technologies could be tested in an UJV storehouse at Prague. The commissioning of the UJV mock-up facility was completed in October 2023. Preliminary data collection tests were conducted locally at UJV to ensure seamless integration and data transmission to the Azure Platform.

4 Results of the demonstration tests

4.1 RFID embedded technology

The instrumented RFID mockup drum was transported from BAM to UJV on October 11th, 2023, and installed at the demonstration site the next day. Data collection began a few days later and continued uninterrupted for three months, with data being uploaded in near real-time to the MS Azure database. Despite occasional upload disruptions due to internet connectivity challenges, particularly in a nuclear facility several stories underground, the sensors and wireless communication units on the lid functioned continuously. The voltage of the RFID unit remained stable, indicating consistent communication through the metal lid. Initial temperature spikes were observed due to cement hydration, and pressure remained at atmospheric levels without signs of deterioration. Key conclusions include the feasibility of long-term sensor installation within waste packages, current capabilities to measure temperature, humidity, and pressure, potential system extensions for other sensing technologies, the ability to transfer data without batteries or wires, and the need for more robust and certified components to advance the technology readiness level.

4.2 SciFi / SiLiF

For the demonstration test at UJV, INFN installed five detection systems, with four mounted at different angles on the mockup drum and one in an adjacent room for background measurements. Each system included SciFi and SiLiF sensors connected wirelessly after initial setup. The drums, filled with concrete, were used to test signal transmission through heavy shielding. Powered by rechargeable batteries and connected to a WiFi subnetwork, data were stored locally and transferred to the Azure cloud. After optimizing the electronics, the systems measured automatically, successfully detecting gamma rays from a 137Cs source, revealing anisotropy in gamma emission, and indicating potential concrete cracks.

4.3 Sensorized RF identification box

UniPi developed a device using passive gamma and neutron counting combined with LoRa technology to monitor radiological levels in radioactive waste drums (RWDs). During the demo, a LoRa node with four gamma and two thermal neutron detectors was attached to the mock-up drum, with a gateway located two floors above. The system measured the ambient dose rate on the drum's surface, successfully transmitting data wirelessly without repeaters due to LoRa's penetration capability. The test aimed at verifying radiation measurement accuracy, assess wireless transmission in internet-limited environments and evaluate battery life. After three months, the system showed a 15% battery reduction, with potential for prolongation by reducing measurement frequency. Communication remained strong with an RSSI over 190 dBm. The system accurately detected a structural defect through increased radiation fluency, with measurements closely matching expected values and confirmed by handheld detectors.

4.4 Air-coupled ultrasonic inspection

To evaluate the potential use of this technology for 500L drum inspections, NNL procured a set of ultrasonic transducers for testing within the NNL Workington Laboratory Rig Hall. A transducer was positioned towards a mock package, maintaining a distance of a few millimeters, and the transmitted wave was detected by a receiver. This detection proved that the transducers were successfully sending and receiving a wave across the skin of the container. The transducer transmitter was mounted on a KUKA KR120 robot arm and programmed to repeat positioning of a transducer at a single point on the drum. The receiver was fixed to the other side of the drum at the same height. Upon repetition of this measurement, the transducer receiver display indicated the same results, proving the repeatability of the inspection method. Finally, the inspection system was deployed on a dented 500L drum to prove that a signal could be deployed and received even when the drum skin was damaged. A signal was successfully received, and the results saved for future analysis.

5 Main outcomes

The demonstration tests, conducted at NNL and UJV facilities, used mock-ups to validate the technologies' real-world functionality and advance their Technology Readiness Levels. The tests confirmed that the four technologies developed and tested in the lab scale as part of Task 3 function well in a realistic environment.

The next step for all technologies would be to repeat them in a representative realistic environment, specifically within an industrial setting that includes multiple active cemented packages and package movement. This will allow for the assessment of their impact on calibration procedures (such as modifications in dose rates around the packages) and the integration of the new data monitoring into the dedicated dashboard.

6 Milestone finalisation

The organisation and implementation of the above-described demo test was the target of the milestone “Completion of full-scale trials in a realistic testing environment”. It has been shown that the selected technologies all worked well. The milestone has been reached in due time.

7 References

[1] D7.8 PREDIS “Report on demonstration and implementation of monitoring, maintenance, and automation/digitalization techniques for improving safety during the storage and handling of cemented waste packages”

[2] D7.10 PREDIS “Final project report on innovations in cemented waste handling and pre-disposal storage”