WP7 Innovations in cemented waste handling and pre-disposal storage

WP7 TEAM

JUNE 5TH 2024

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

WP7 Objectives

- Compile information about the **state of the art** of current methods and procedures for cemented waste management with specific focus on monitoring/long-term storage
- Identify opportunities for **improved store automation**, reducing human exposure to radiation
- Identify options for post treatment of packages and potential approaches to **improve package design, construction and maintenance**

WP7 Meeting at UJV

Demo Test Evaluation at UJV

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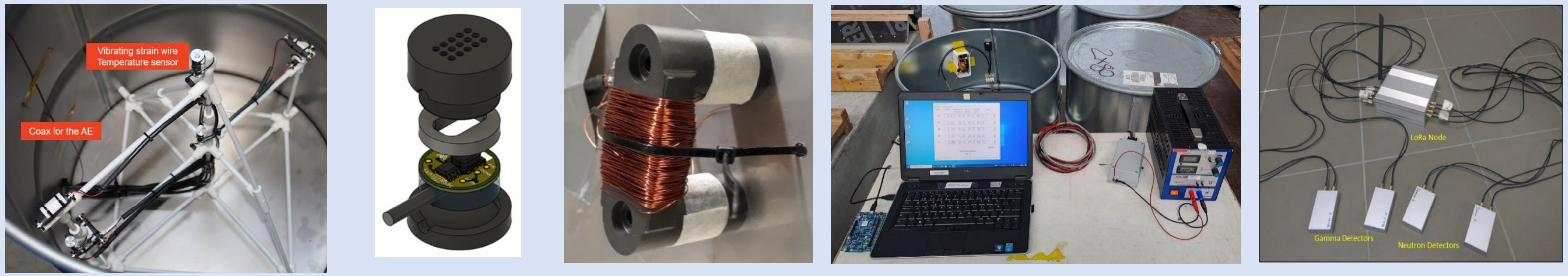
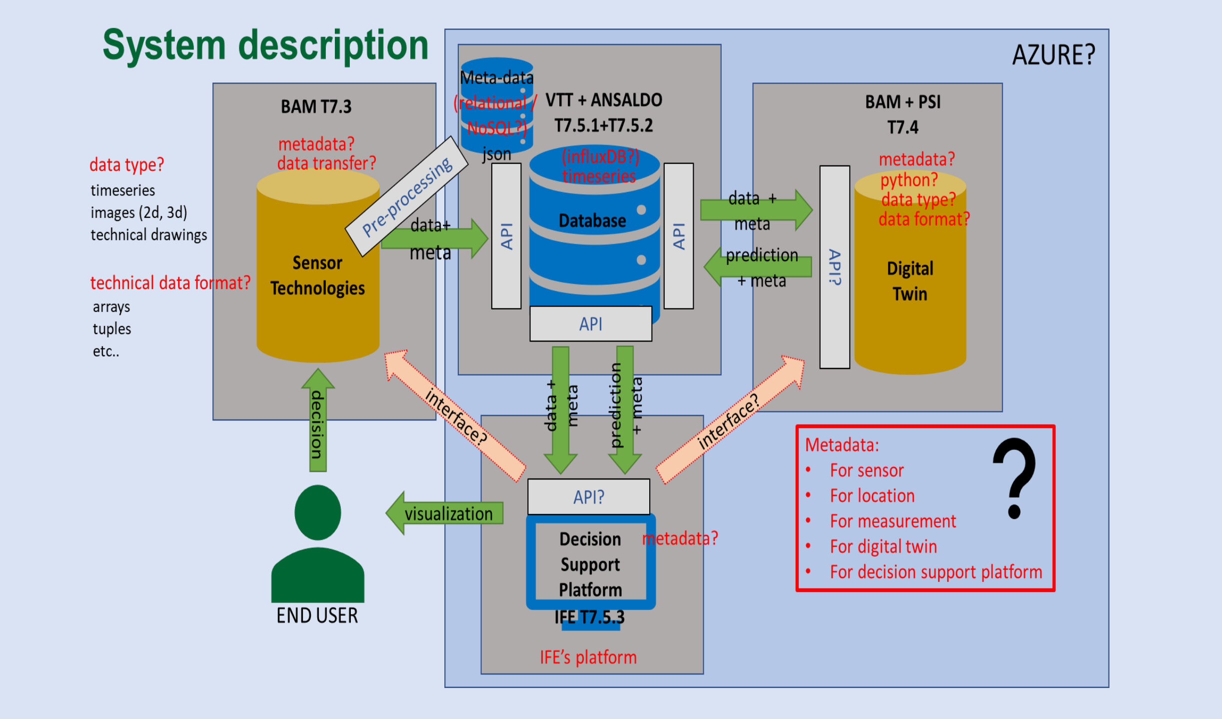
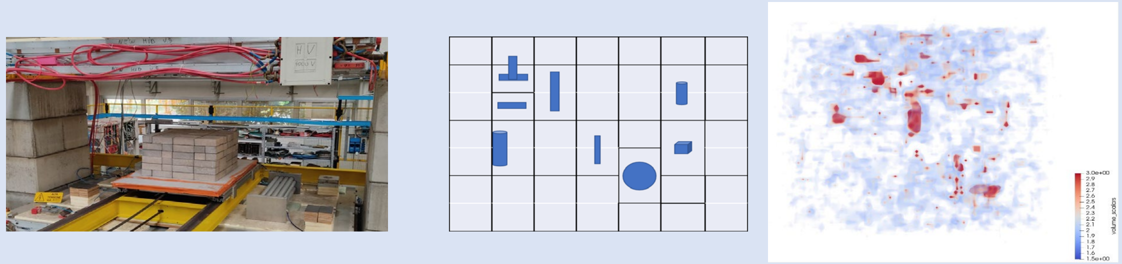
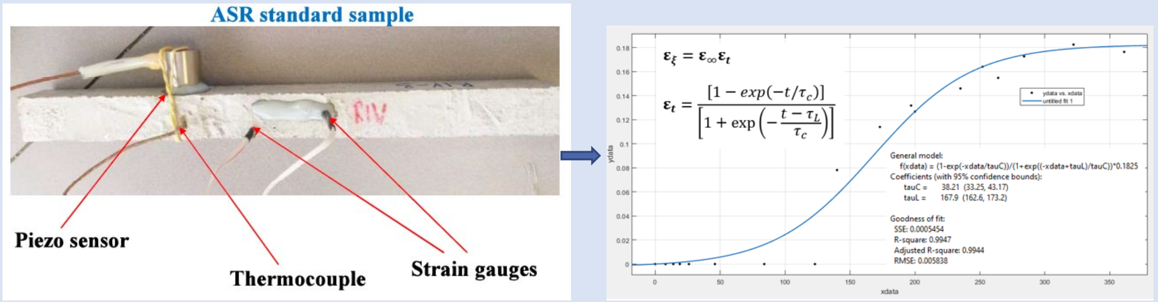
WP Objectives



- Identify, **evaluate and demonstrate** store and package **quality assurance** (mainly NDE) and monitoring technologies
- Adapt and demonstrate **digital twin technology**
- Develop and demonstrate **methods for data handling**
- Develop and demonstrate a **digital decision framework**







WP Expected Impacts

- More versatile and reliable condition monitoring technologies, which have been demonstrated on operating radioactive facilities and made available to end users
- Improved accuracy in predicting the behavior of waste/packages in stores through the integration of models with store and package monitoring information obtained using digital and machine learning technologies to enhance sampling, monitoring strategies and multi-method data fusion
- Increased safety (10% or greater reduction in direct human interaction with and exposure to waste packages), reduced cost (20% or greater reduction in costs related to late-stage detection of damage or deterioration

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WP7 Overview Technologies

- All technologies and tools being tested and developed in WP7

Technology
SciFi (gamma) radiation monitoring
SiLiF (neutron) radiation monitoring
Sensorised LoRa wireless sensor network for identification and integrity assessment of radioactive waste drums
Acoustic Emission for measuring ASR
Non-contact ultrasonic scanning
Embedded RFID Sensors
Muon tomography
Digital Twin, data platform and decision framework tools for predictive modelling, data handling, and data visualisation

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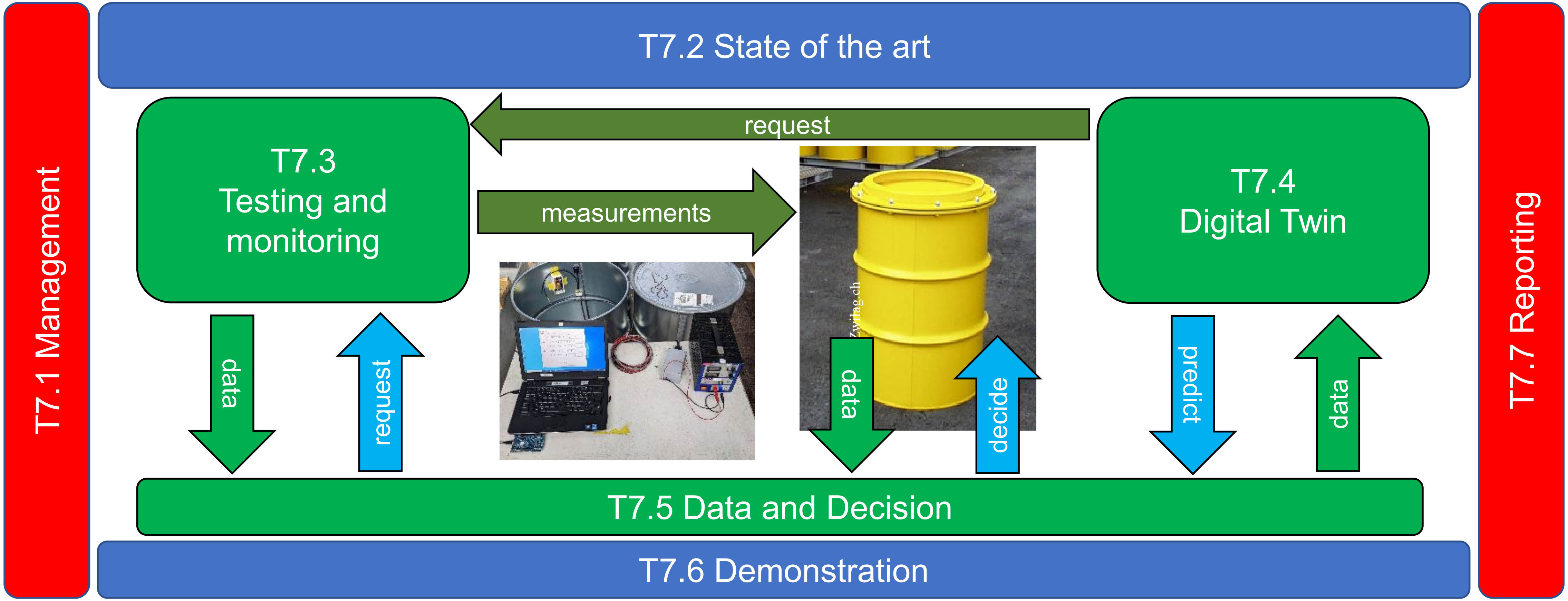
WP Structure



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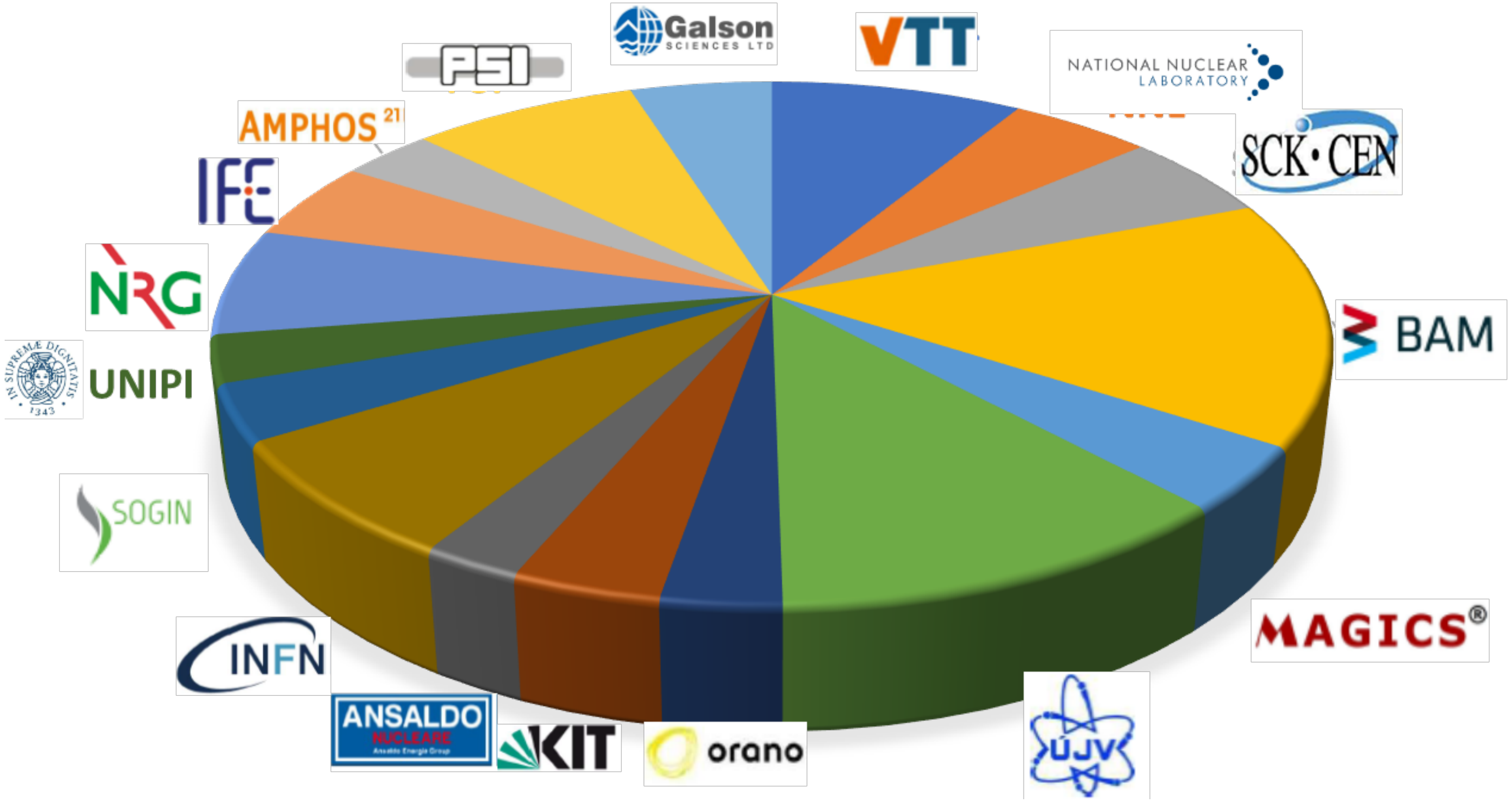
WP Partners



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Task 7.2 State of the Art

Task 7.3 Testing & Monitoring

Task 7.4 Digital Twin

Task 7.5 Data Management

Task 7.6 Demonstration and Implementation

Task 7.7 Dissemination

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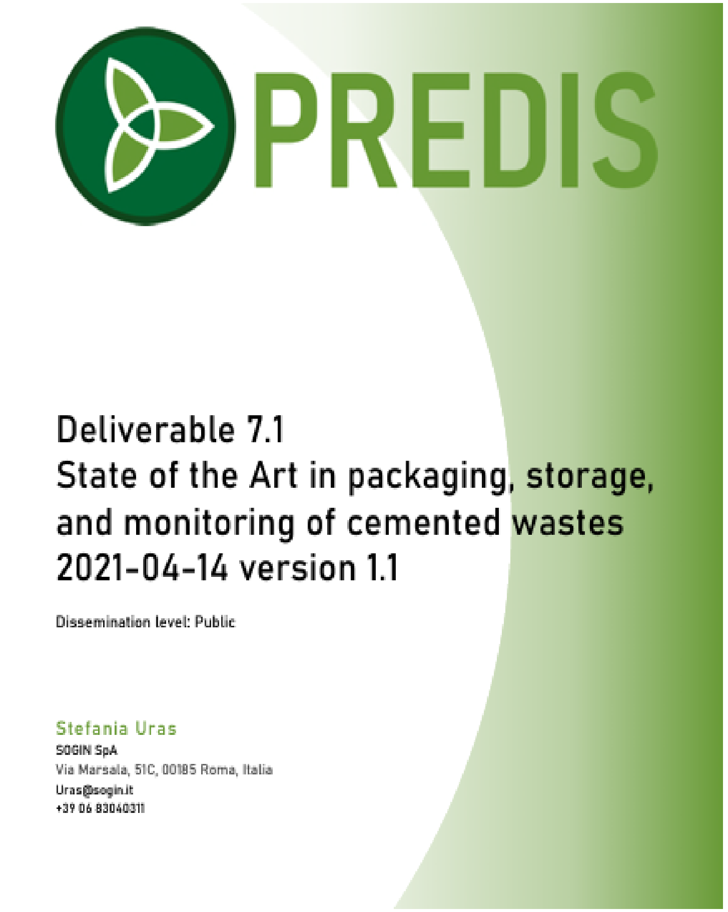
T7.2 State of the Art



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Deliverable 7.1
State of the Art in packaging, storage, and monitoring of cemented wastes
2021-04-14 version 1.1

Dissemination level: Public

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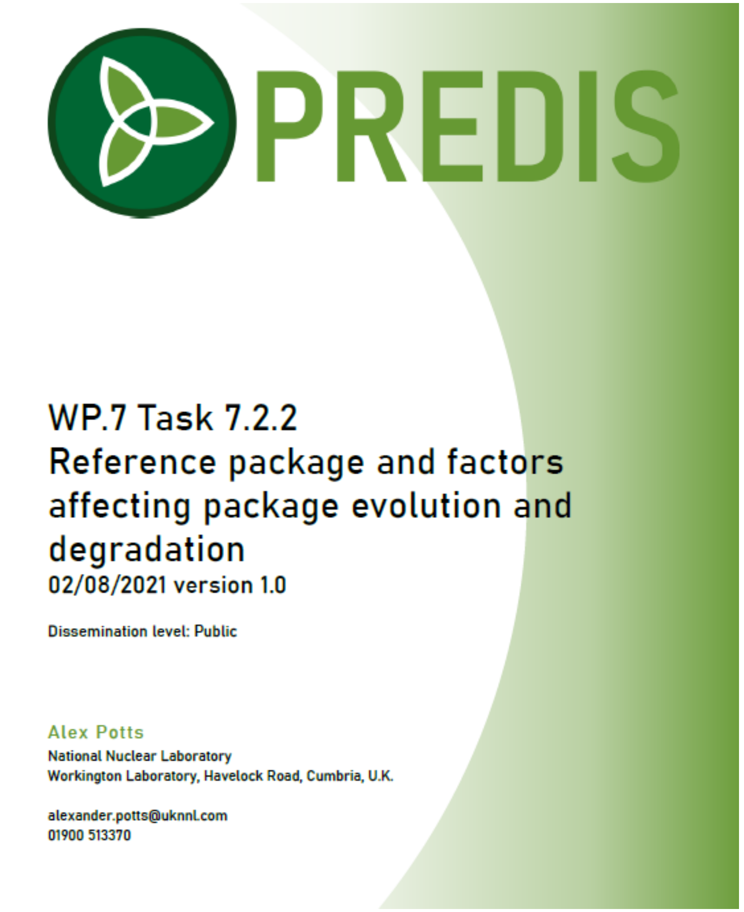

PREDIS

WP.7 Task 7.2.2
Reference package and factors affecting package evolution and degradation
02/08/2021 version 1.0

Dissemination level: Public

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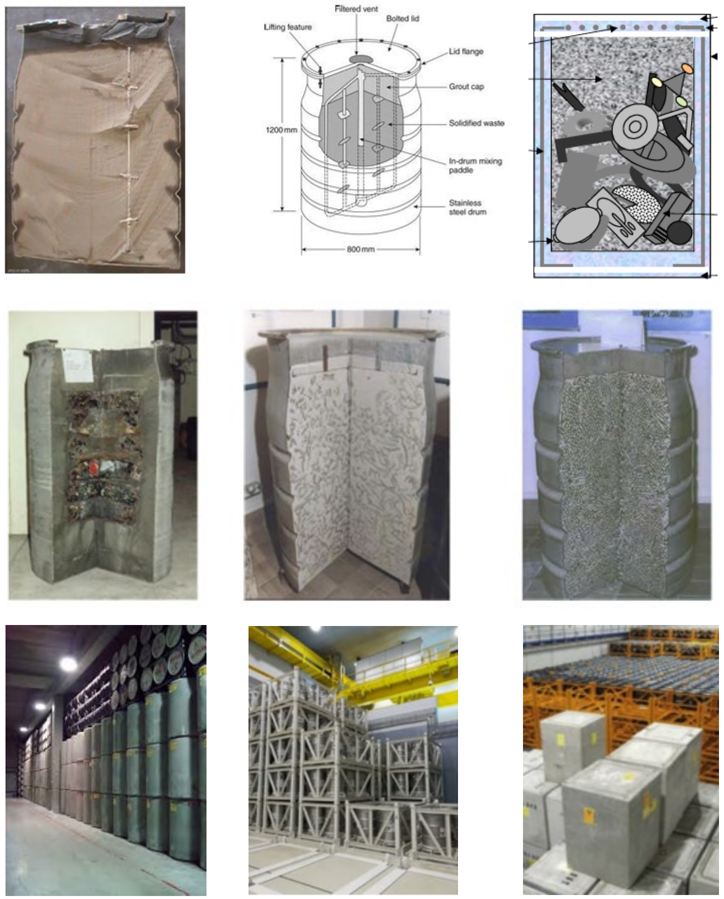

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Task 7.2 State of the Art

Task 7.3 Testing & Monitoring

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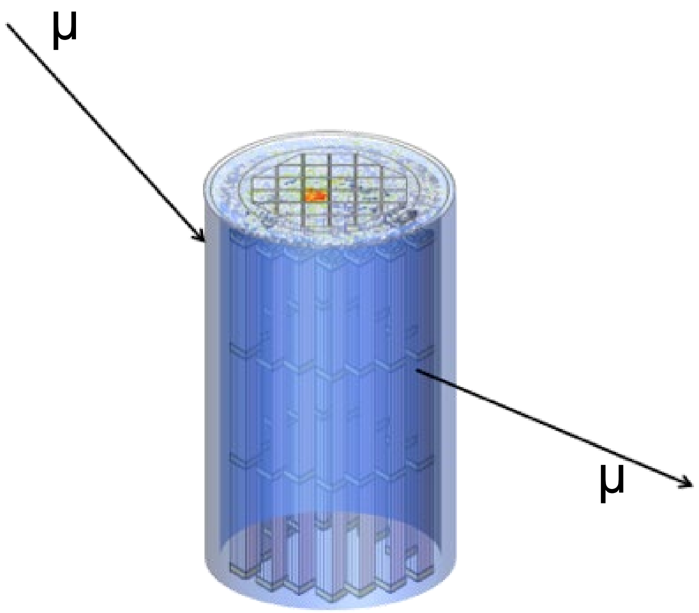
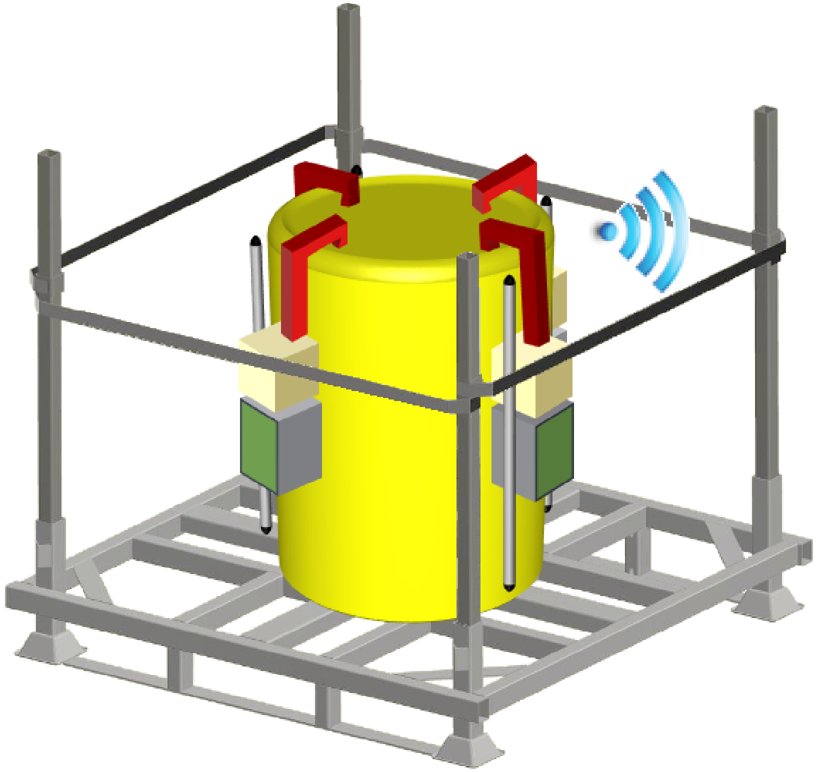
T.7.3 Innovative Instrumentation Summary

Paolo Finocchiaro (INFN)





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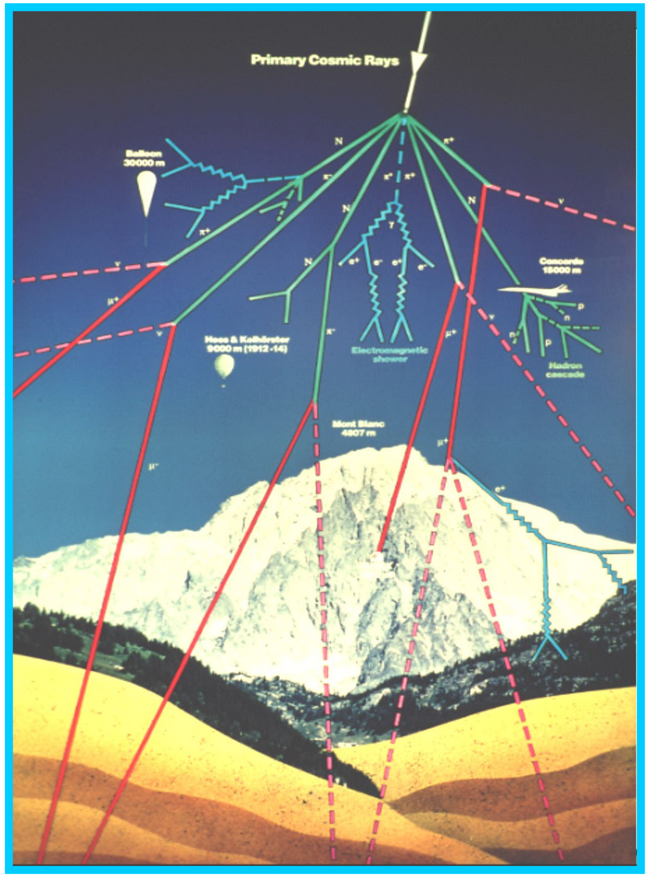
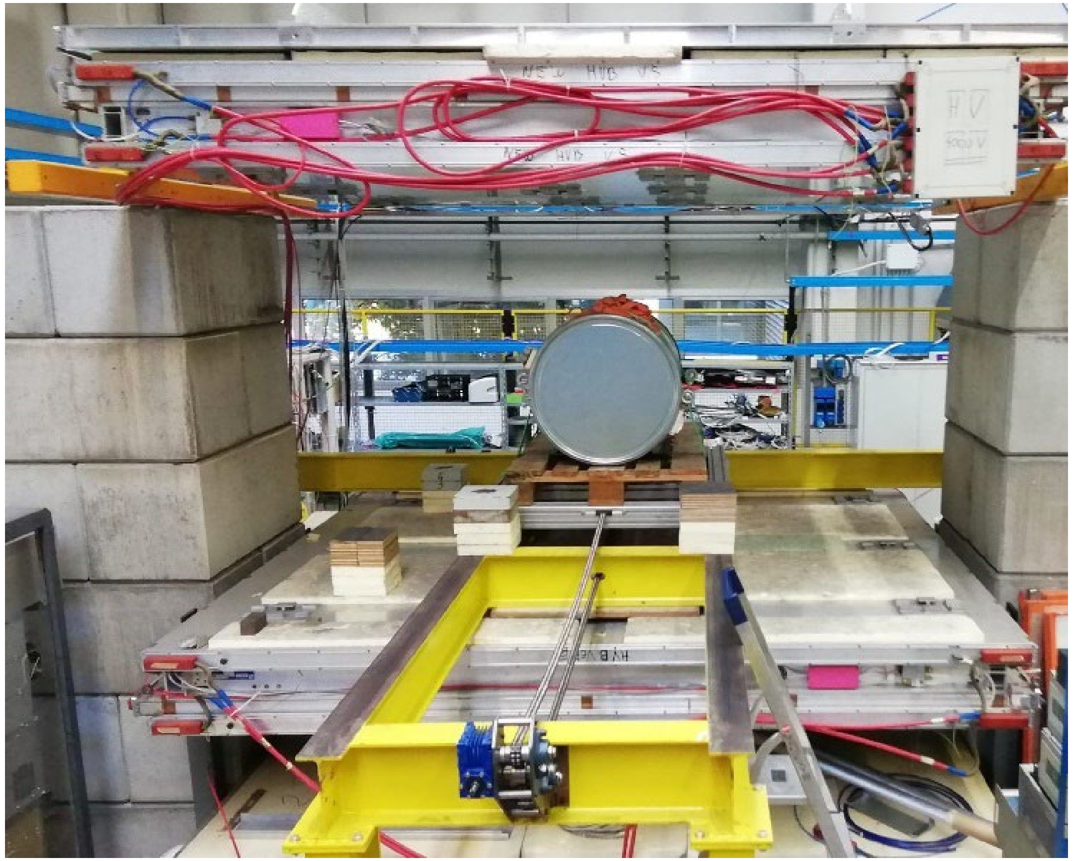
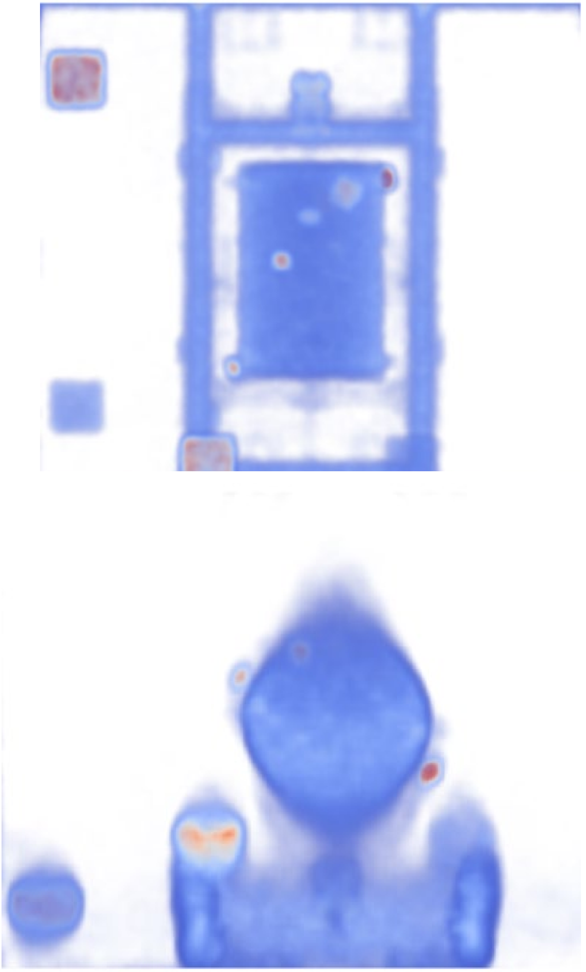
Muon tomography

Exploiting penetrating cosmic radiation to look inside thick objects







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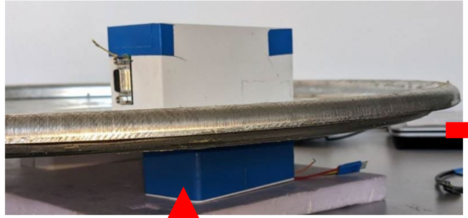
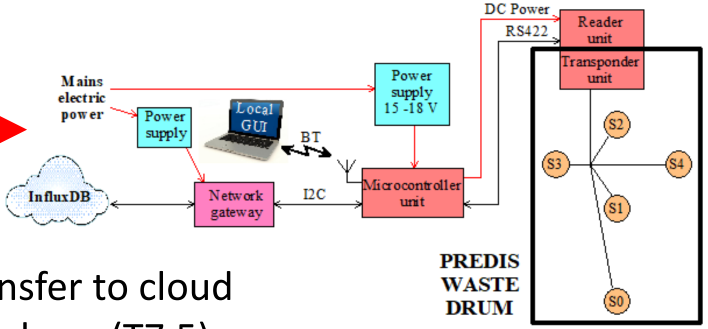
T.7.3 Innovative Integrity Testing and Monitoring Techniques: Wireless and batteryless package-embedded sensing

Specific technical challenges to be solved:
- Protecting the sensors against the harsh environment inside the package
- Wireless powering and communication of batteryless sensors through the steel lid

Units for wireless powering and data readout





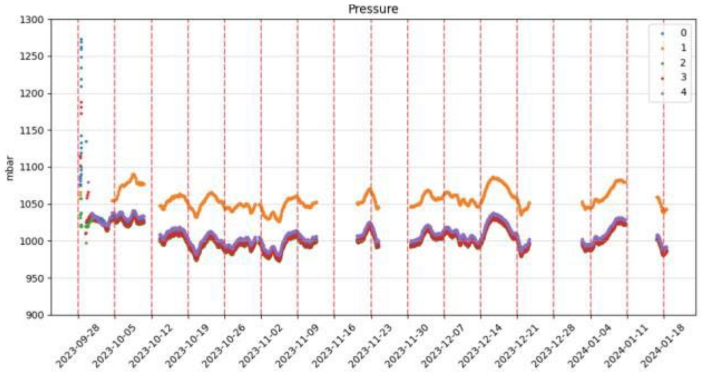
Transfer to cloud database (T7.5)

SensorNode (T, H, p, …)

SensorNode network mounted in package

Filled package in storage (T7.6)

Almost real time display on dashboard (T7.5)



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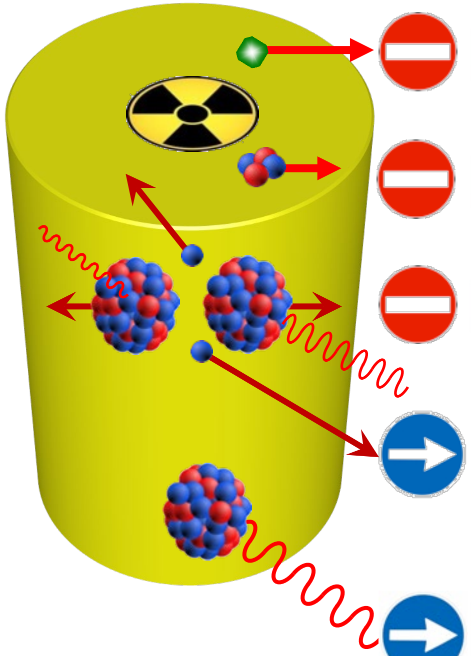
Cemented radwaste: radiological monitoring

what comes out?



beta particles are mostly stopped inside the material and in air

alpha particles are immediately stopped inside the material

fission fragments are immediately stopped inside the material

neutrons, from fission or (α,n) reactions, come out very easily typically at low dose-rates; in some cases there can be many

gamma rays are ubiquitous, penetrating, and come out easily and abundantly

basic radioactivity coming out is gamma rays and neutrons
they carry information from inside and are worth monitoring

→ **easier external monitoring**

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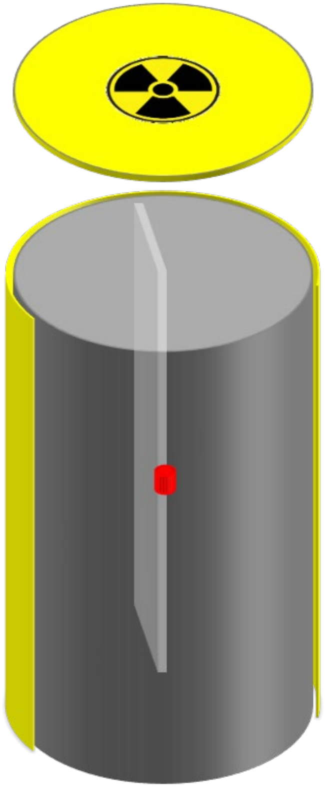
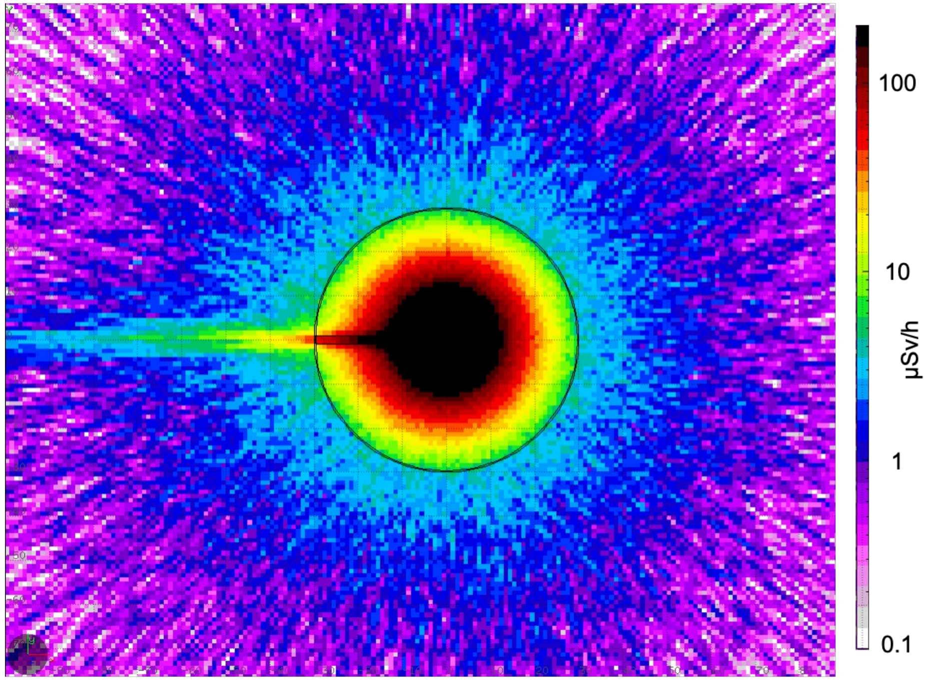
Cemented drum radiological monitoring
Goal: can we see asymmetries? anomalies?



simulation of a 1 cm wide vertical crack

and a ^{137}Cs (165 MBq) gamma source at the center



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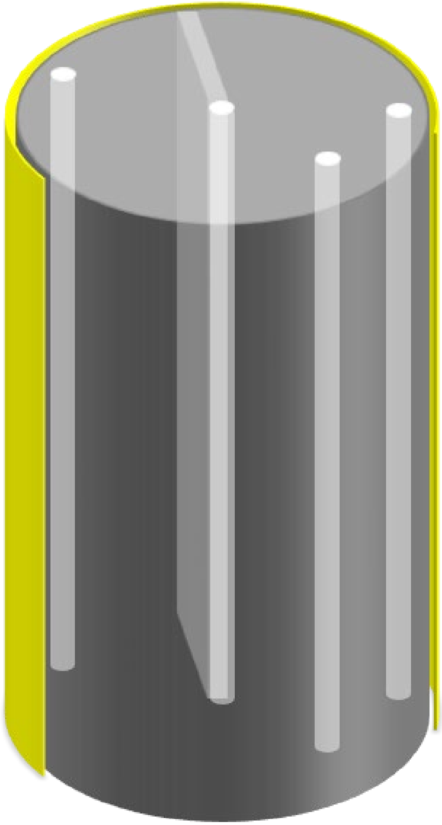
test at UJV-REZ Oct 2023 – Jan 2024

mockup



^{137}Cs gamma source (165 MBq)

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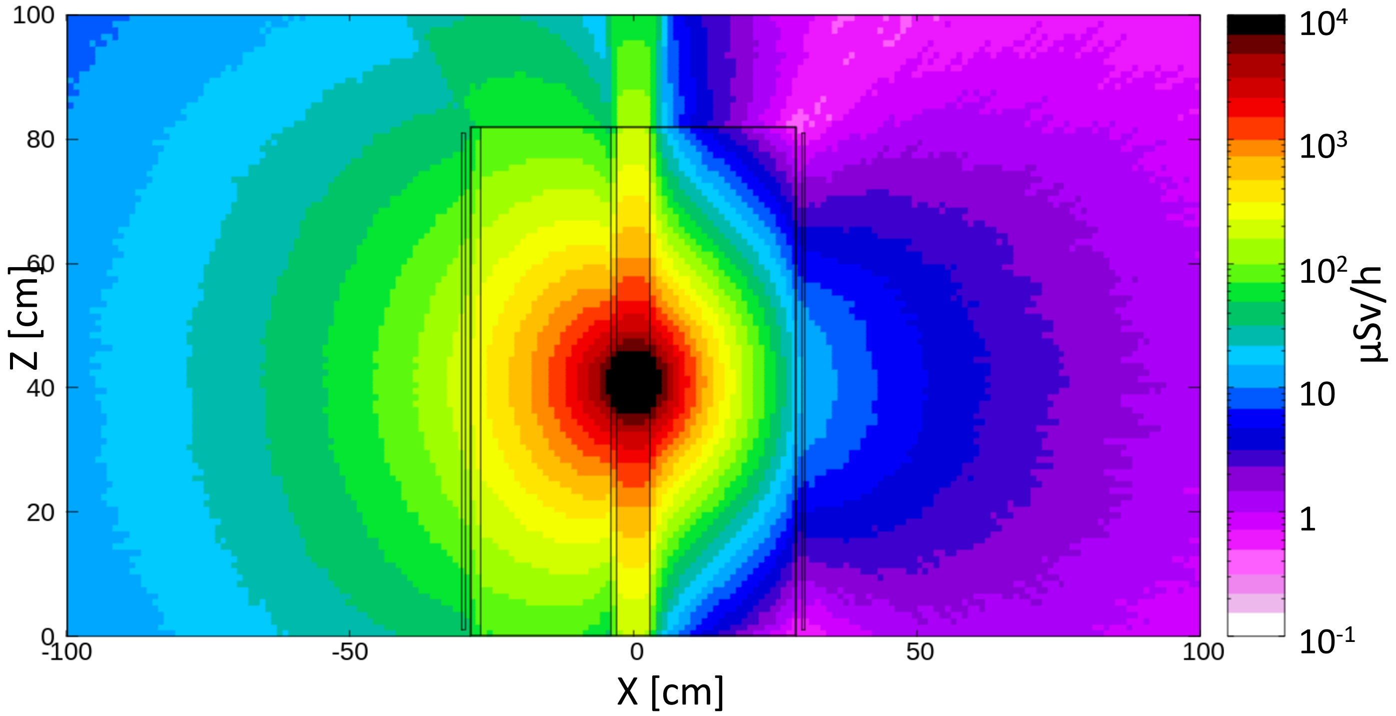
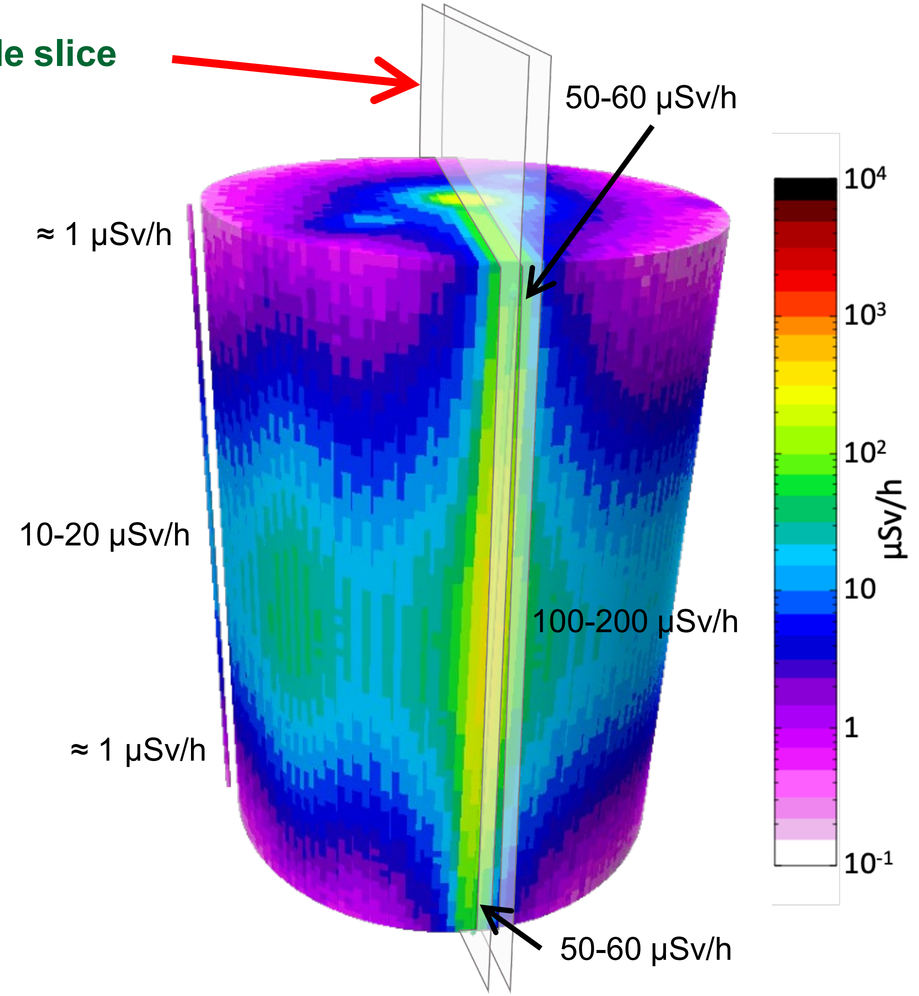
Dose rate simulation, measurement and verification

gamma dose rate in a 2 cm wide slice





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external package monitoring

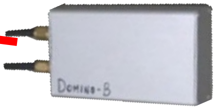
SciFi front-end electronics, DAQ
& wireless data transmission

SiLiF front-end electronics, DAQ
& wireless data transmission

SiLiF neutron counter

SciFi gamma counter

Teviso gamma counter



Domino neutron counter

detector and electronics
fully developed by INFN

detectors assembled and
electronics developed by Università di Pisa

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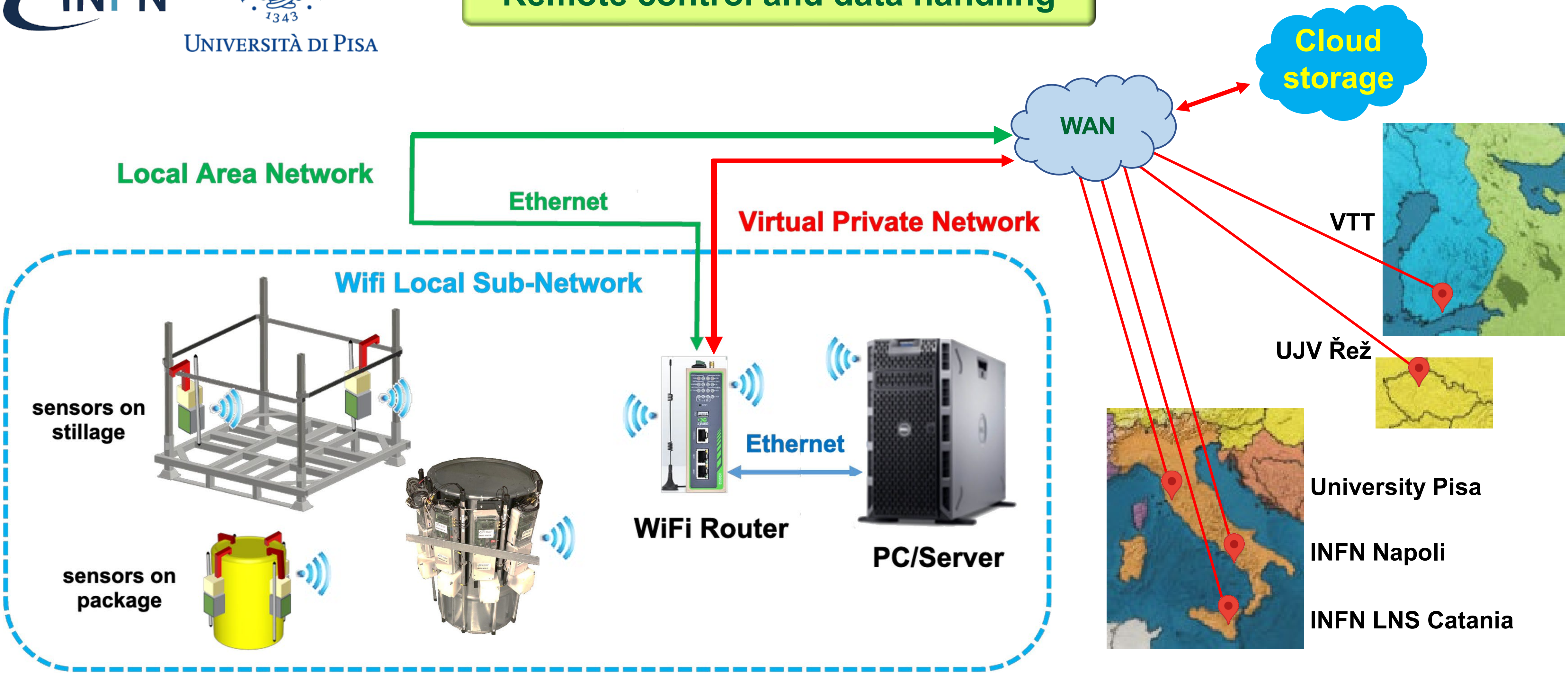
programme 2019-2024 under grant agreement No 945098.

Remote control and data handling



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PREDIS

Real-time monitoring of radioactive waste

- Michele Di Giovanni

- P.h.D. Student in Mathematics, Physics and Engineering
- Applications, Università della Campania - Luigi Vanvitelli

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

Context:

Context of Real-Time Waste Monitoring:

- Testing detectors at the UJV research center;
- Verifying technologies in safe environments with known results;
- Testing the control system and prolonged data collection.

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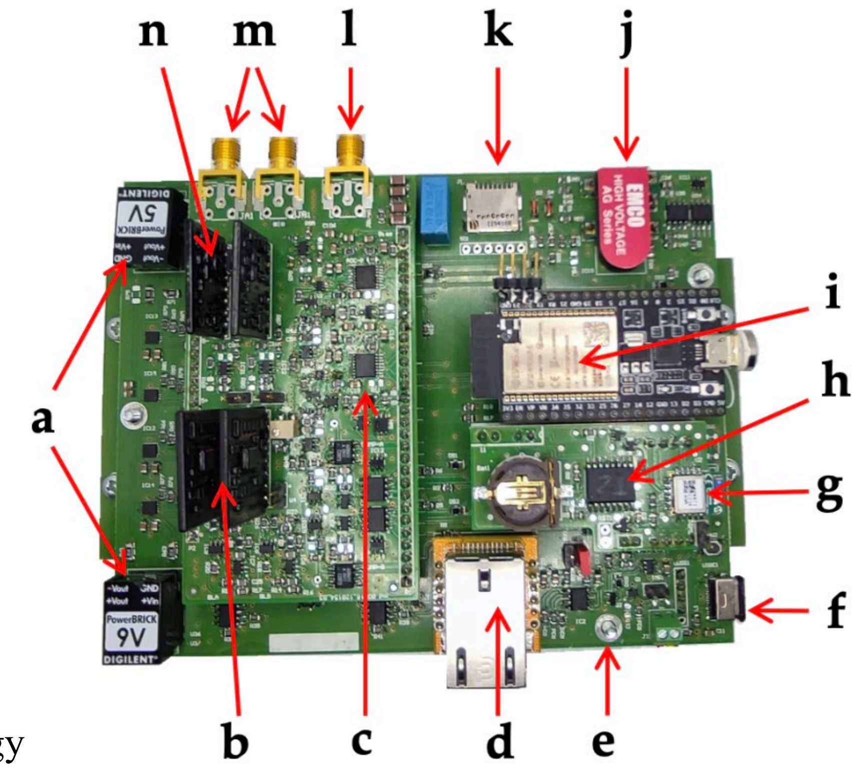
Read-out Electronic

The read-out electronic boards:

- Read Data From particle Detectors
- Start measurements;
- Activation via Bluetooth module or programmable RTC;
- Exposes an HTTP Server.



(**a**) Power supply (9V, 5V). (**b**) Shapers. (**c**) ADCs. (**d**) Ethernet Controller. (**e**) 3-position 152 switch: Power On with Battery, Power Off, Power On with USB. (**f**) USB bias. (**g**) Low-Energy Blue- 153 tooth. (**h**) RTC. (**i**) Microcontroller. (**j**) HV generator. (**k**) Micro-SD card. (**l**) Voltage bias to SciFi. 154 (**m**) SciFi signal inputs. (**n**) Charge Sensitive Pre-amplifiers.

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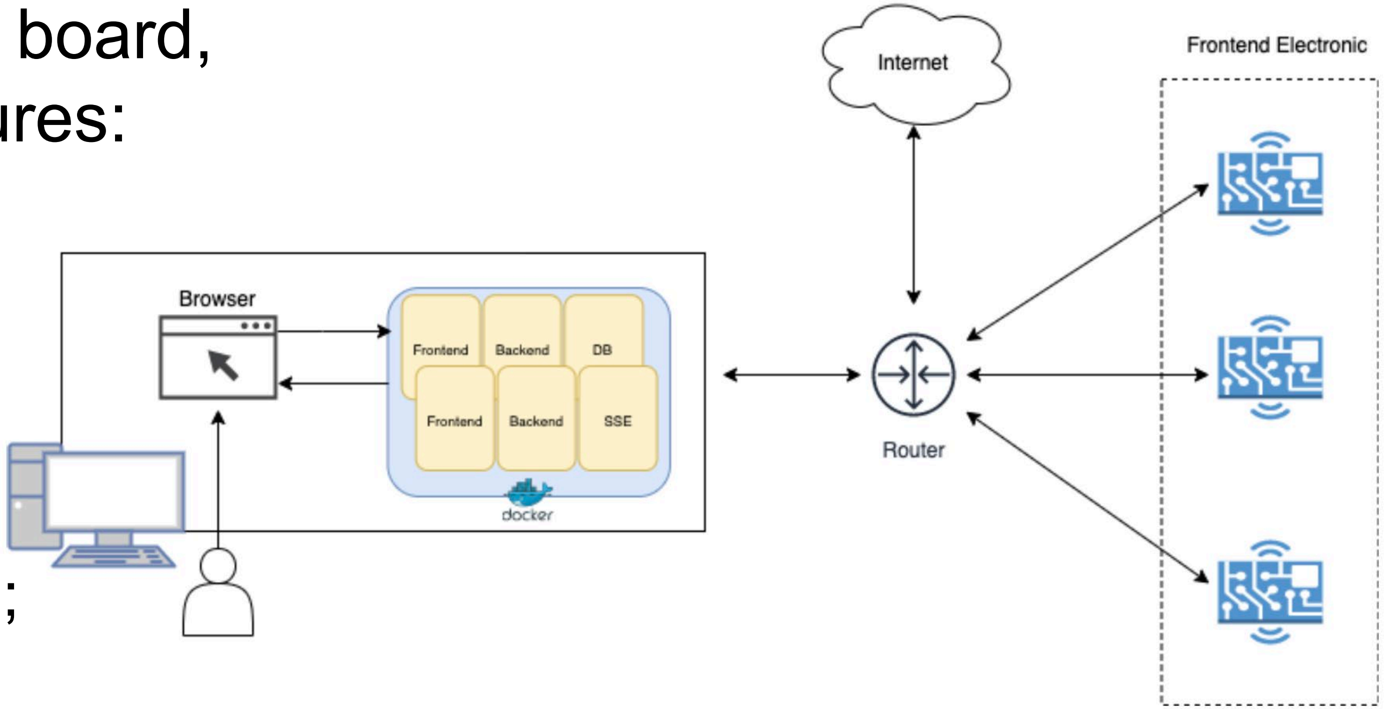
Software features

The software interacts with the board, providing some high level features:

- Dynamic Registry;
- Board Settings;
- Board Scheduling;

- Measures download and storage;
- Board Reliability;
- UI and Dashboard.



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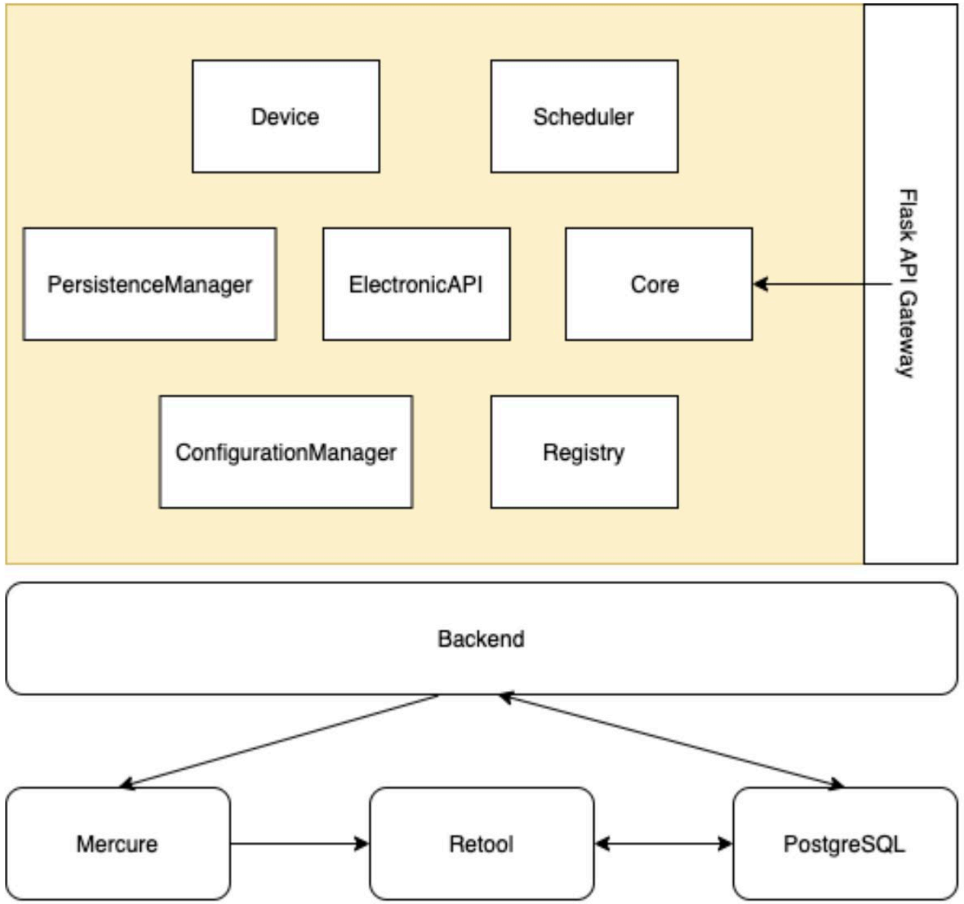
Software Architecture

Monolithic architecture based on Docker containers with four specialized containers

- Backend - Python/Flask:
- DB - PostgreSQL:
- Dashboard - Retool;
- Real-time SSE - Mercure.



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Ui and Dashboard

Devices

Turn on devices

devname	link	Thra	Thrb	Acquisition time	Alarm
PREDIS001	http://192.168.2.56:80/setup	32	32	60,000	18:23
PREDIS002	http://192.168.2.93:80/setup	23	23	60,000	18:23
PREDIS004	http://192.168.2.26:80/setup	18	18	60,000	18:22
PREDIS005	http://192.168.2.85:80/setup	25	25	60,000	18:22
PREDIS006	http://192.168.2.48:80/setup	1,600	1,600	60,000	18:22
PREDIS007	http://192.168.2.46:80/setup	1,600	1,600	60,000	18:23
PREDIS008	http://192.168.2.36:80/setup	1,600	1,600	60,000	18:22
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

9 results

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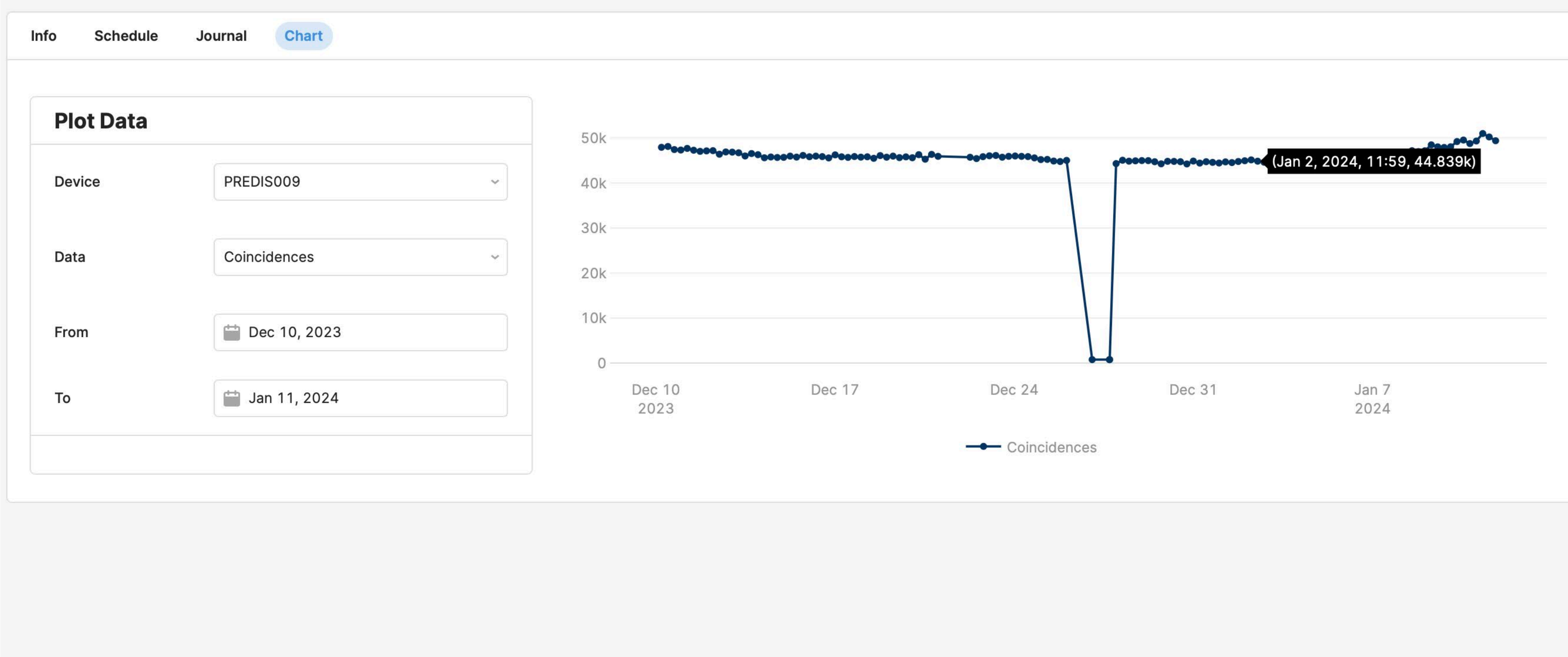
Ui and Dashboard



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Strengths and Future Developments

Real-time Monitoring Capabilities

Automated and Scalable System

Centralized Control and Data Management

User-Friendly Dashboard and UI

Extending control system's functionalities

Implementing a proper analysis tool for plant safety

Possiblity to apply **Vulnerability Assessment** and **Predictive Maintenance** techniques.

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Thank you for your attention.

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Task 7.2 State of the Art

Task 7.3 Testing & Monitoring

Task 7.4 Digital Twin

Task 7.5 Data Management

Task 7.6 Demonstration and Implementation

Task 7.7 Dissemination

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T.7.4 Summary I

- **Experiments under enhanced conditions** (e.g. in temperature) are **suitable to get an in-situ understanding of reactions ongoing** in the waste forms (like SCK-CEN is performing). The use of real scale waste forms avoid problems with upscaling of laboratory-based experiments.

- Even **simple mechanical models implemented in a digital twin (DT) are sufficient to predict the long-term behavior of waste forms**. If chemical reactions are expected to occur, additionally geochemical models can be implemented in the DT.

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T.7.4 Summary II

- **Advancement in predicting long-term stability:** Surrogate model based on 25 GEMS Python scripts simulates geochemical interactions, predicting waste containment over 100 years.
- **Efficiency through neural network-based model:** Neural network generates 1 million cases, reducing computation time from 78.4 days to ~1.9 seconds.
- **Insights into material deterioration mechanisms:** Evaluation of iron, aluminum, zinc, brass degradation provides detailed understanding crucial for waste containment integrity.

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T.7.4 Summary III

- **If the drums are stored under controlled humidity** (e.g. in predisposal), and the solidification of the waste was well thought through, **these drums are expected to be safe for the next 30-50 years.**

- **At the time the disposal** site goes operational it should be considered to **check if the radioactivity in the waste packages is below the exemption limit.**

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T.7.4 Summary IV

- Retrieve **data formats / interfaces** to connect and queries **to retrieve data is needed.**
- **Obtaining data** for the training **of the DT is complex**.
- **Difficult to get information of the waste compositions from the owners**.
- **Long term data storage.**
- **Cybersecurity.**
- **Technique is new in this field**, but **can be implemented fast**, when the issues mentioned above are solved.

→ See the next presentation of Guang Hu

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

T.7.4 Student - Outline

- Introduction
- Chemical Reactions
- Surrogate Model
- Sensitivity Analysis
- Results and Discussion
- Conclusions

Proceedings of the 2024
31st International Conference on Nuclear Engineering
ICONE31
August 4-8, 2024, Prague, Czech Republic

ICONE31-135796

DIGITAL TWIN AND SURROGATE MODEL FOR LONG-TERM GEOCHEMICAL PROCESSES IN NUCLEAR WASTE MANAGEMENT

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

T.7.4 Introduction

Essential Indicators for Material Stability: Detailed insights into chemical changes aid in predicting potential integrity threats affecting waste package stability.

Digital Twin Linking Reaction Rates: Establishes a digital twin connecting chemical reactions and material properties, vital for assessing long-term waste containment stability.

Interplay between Chemical Reactions and Materials: Understanding the relationship between chemical reactions and material properties enhances predictive modeling accuracy and reliability.

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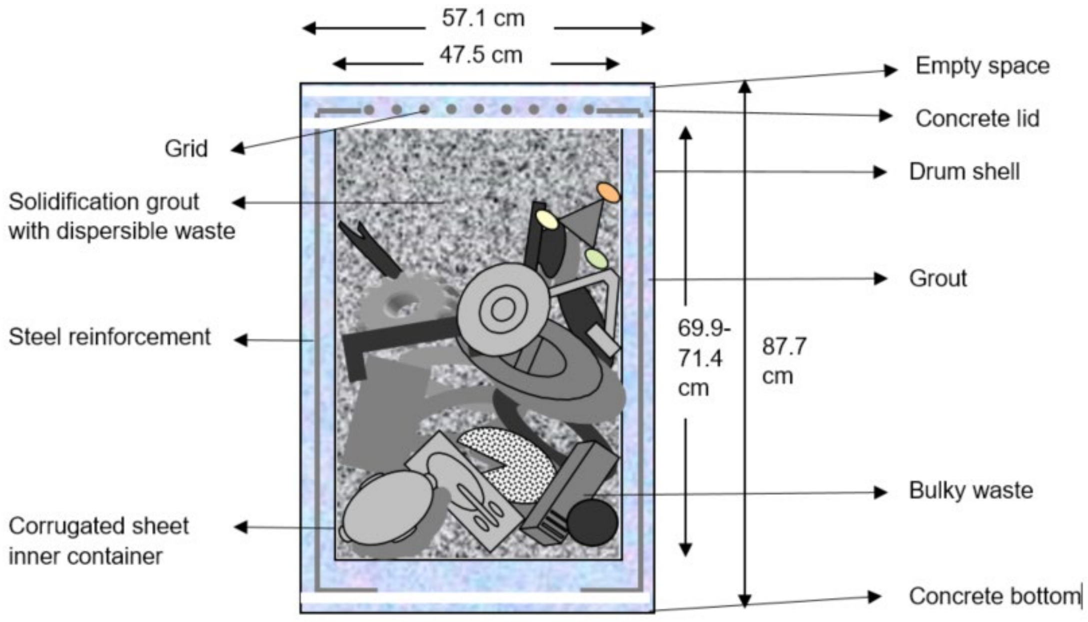
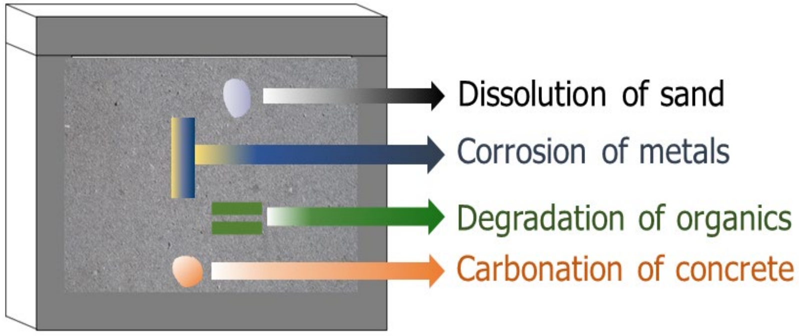
T.7.4 Chemical Reactions



Schematic diagram of a cemented waste package: Cement solidified dispersive and bulky waste in a 200 L steel drum. (Wällisch, A. 2020. Paul Scherrer Institut, Villigen, Switzerland. Pers. Comm.)



Simplified reaction stoichiometry

$SiO_2(s) + 2\ H_2O = H_4SiO_4(aq)$

$x\ Me + y\ H_2O = Me_xO_y + y\ H_2$

$2\ \{CH_2O\} = CH_4 + CO_2$

$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$

Schematic presentation of degradation processes in the waste package (Wieland 2019)

$$R_{dis}(t) = \frac{dm}{dt} = A\left(k_1(1-\Omega) + k_2 a_{H^+}^{-0.5}(1-\Omega)\right) \quad (\text{mol s}^{-1})$$

A: Reactive surface area (m^2)
k: Rate constants in neutral (k_1) and alkaline (k_2) conditions (mol s^{-1} m^{-2})log $k_1 = -13.99$; log $k_2 = -16.29$
a_H^+: Activity of protons
Ω: Saturation index

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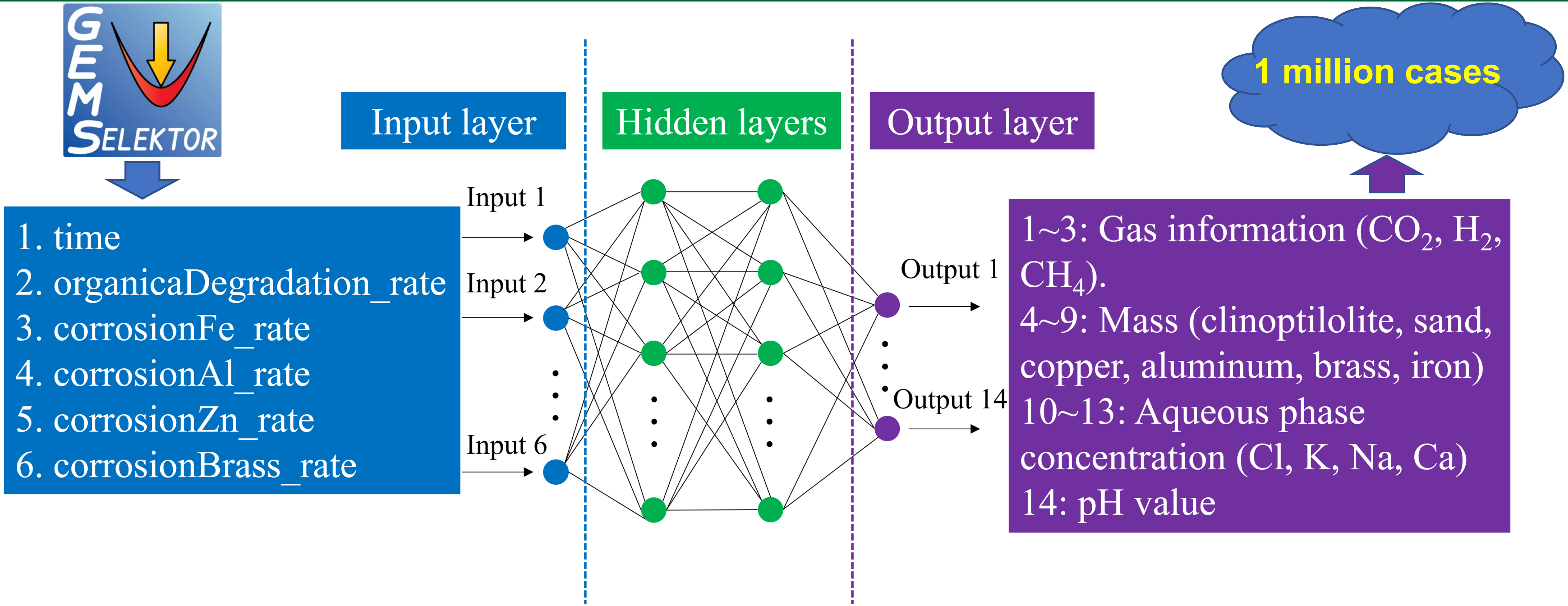
T.7.4 Surrogate Model



6 inputs and 14 outputs in neural network machine learning model

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T.7.4 Sobol Sensitivity Analysis

First-Order Index (**S1**):
Measures the direct contribution of an input to the output variance, ignoring interaction effects.

Total-Effect Index (**ST**):
Measures the total contribution of an input to the output variance, including both its main effects and interaction effects with other inputs.

$$S_{1i} = \frac{V_{X_i}\left(\mathbb{E}[Y \mid X_i]\right)}{V(Y)}$$

where:
$V(Y)$: Total variance of the model output Y
V_{Xi}: Variance due to input X_i

$$S_{T_i} = \frac{\mathbb{E}_{X_{\sim i}}\left(V_{X_i}[Y \mid X_{\sim i}]\right)}{V(Y)}$$

where:
$X_{\sim i}$: All variables except X_i

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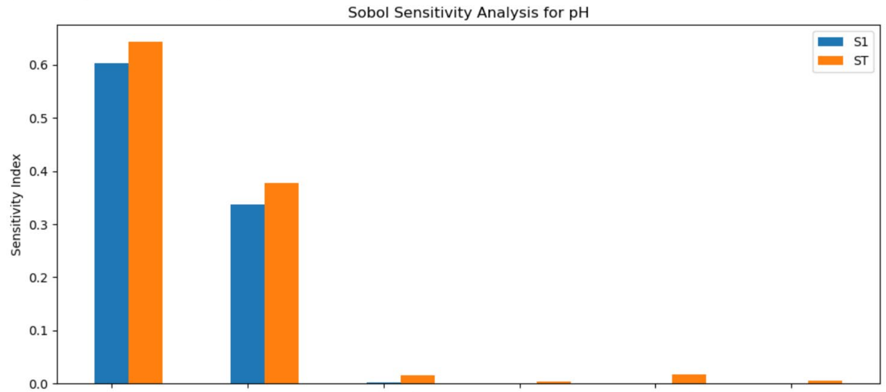
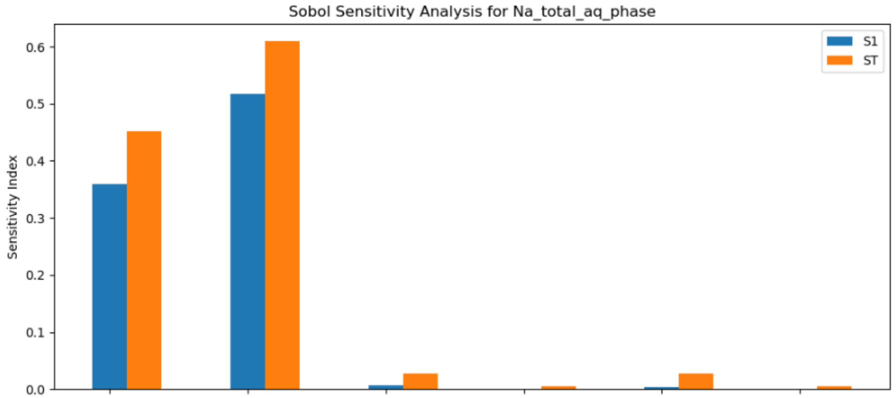
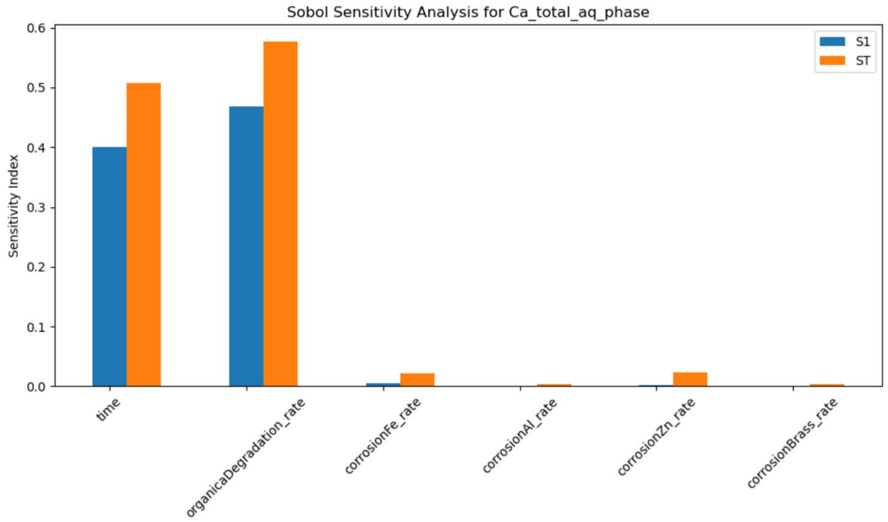
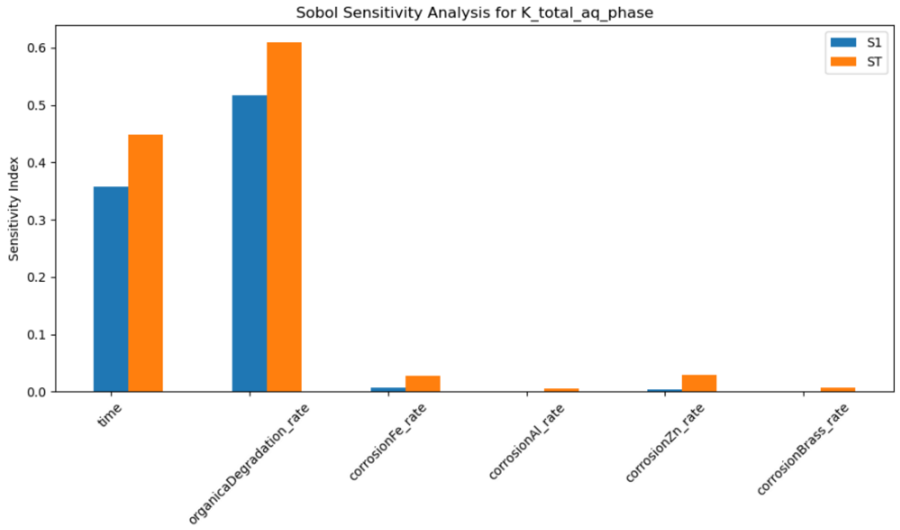
T.7.4 Results and Discussion



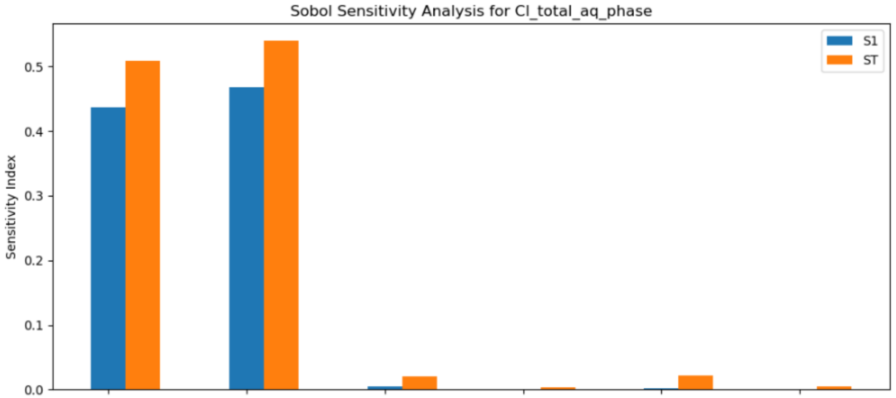


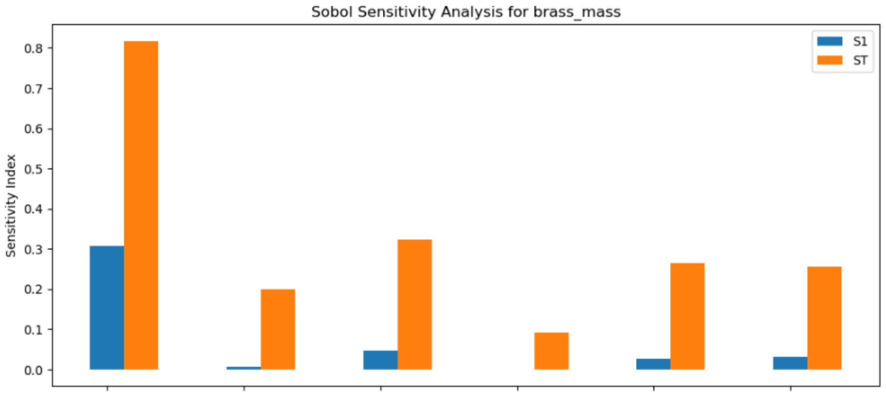


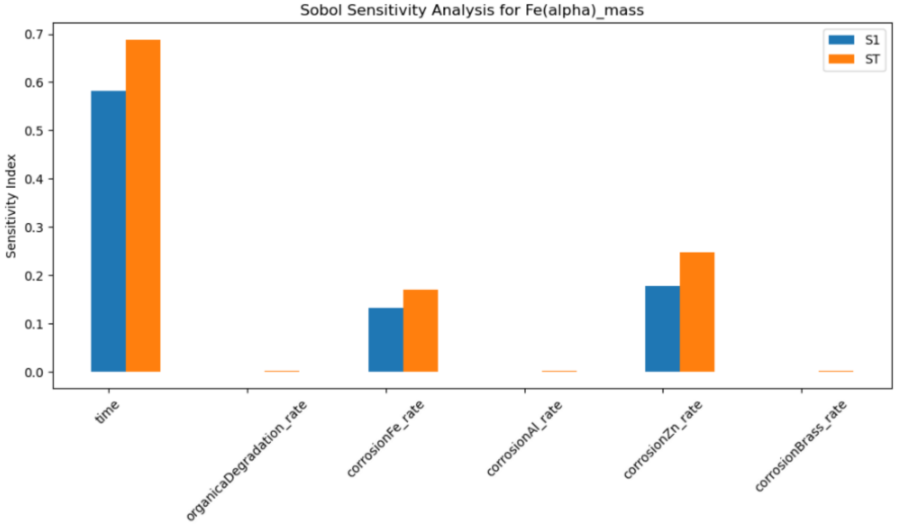


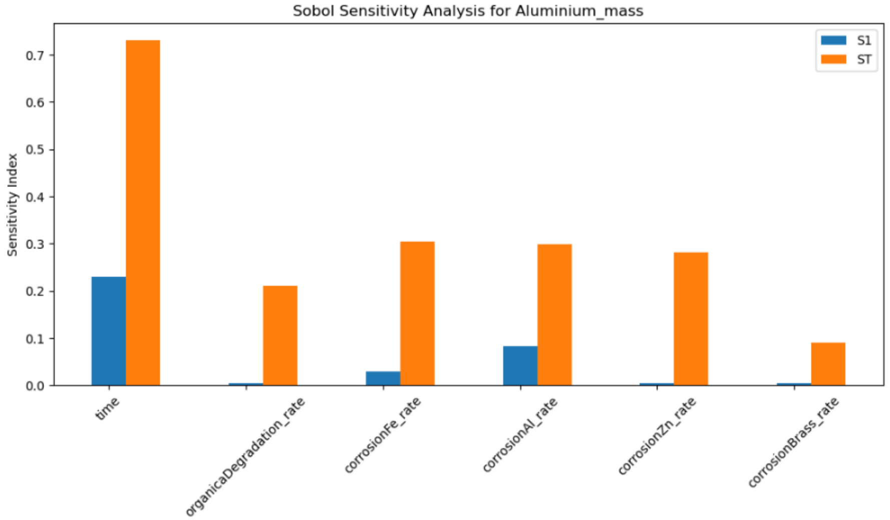
This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945098.

T.7.4 Results and Discussion









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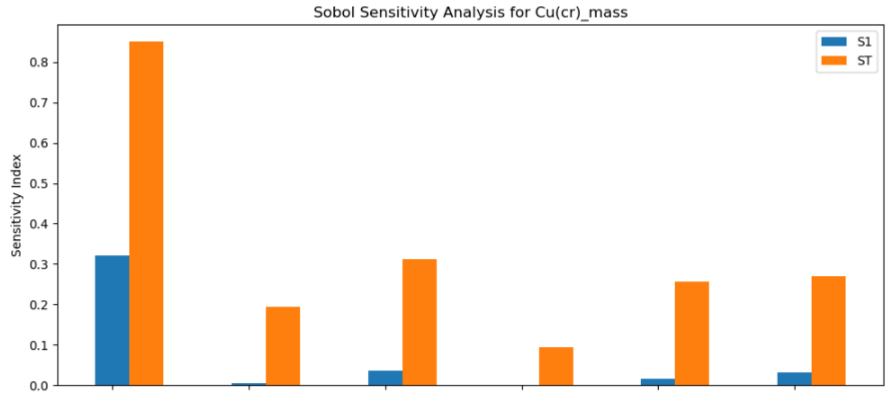
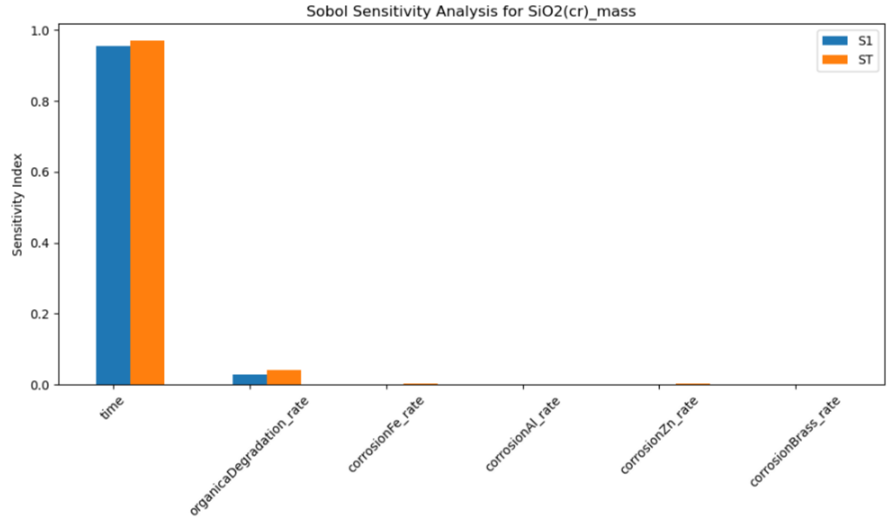
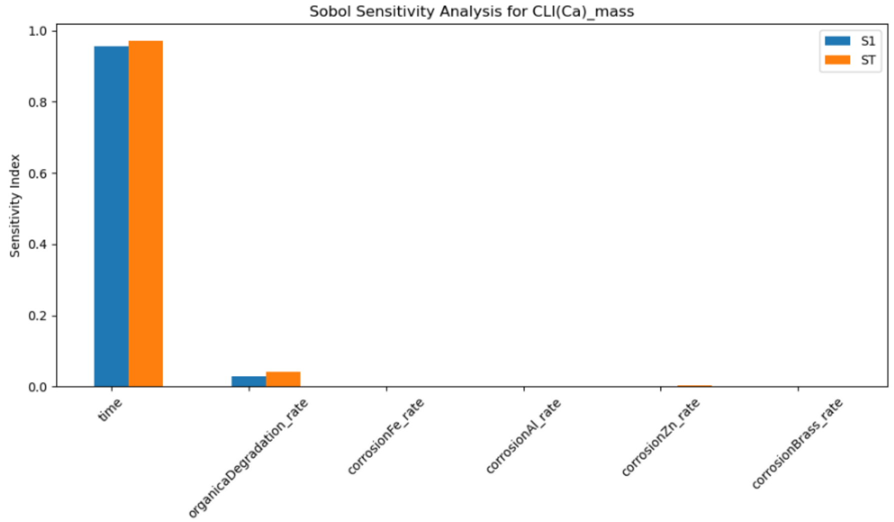
T.7.4 Results and Discussion







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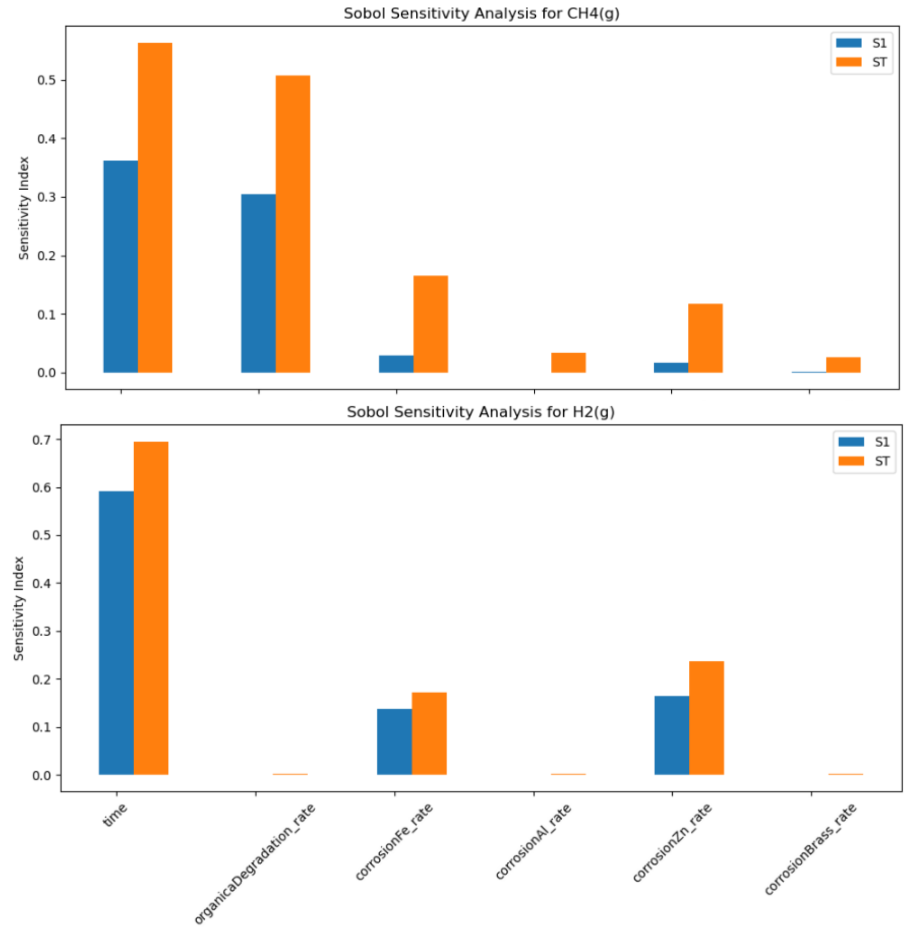
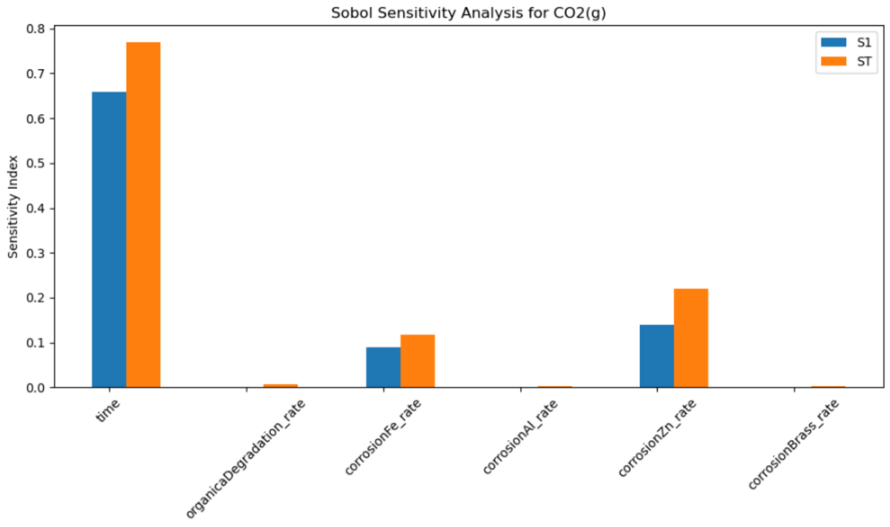
T.7.4 Results and Discussion





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

T.7.4 Conclusions

- It demonstrates the efficiency of neural network-based surrogate models in significantly enhancing computational efforts.
- It reduces the generation time of 1 million cases from nearly 79 days to under 2 seconds.
- Sobol sensitivity analysis across this extensive dataset reveals both the direct contribution and total contribution of an input to the output variance.
- Such digital twins might be used in future also for optimization of waste conditioning recipes for improved (interim) storage integrity.

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

Task 7.2 State of the Art

Task 7.3 Testing & Monitoring

Task 7.4 Digital Twin

Task 7.5 Data Management

Task 7.6 Demonstration and Implementation

Task 7.7 Dissemination

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

PREDIS

Database and decision framework summary

TUULA HAKKARAINEN

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

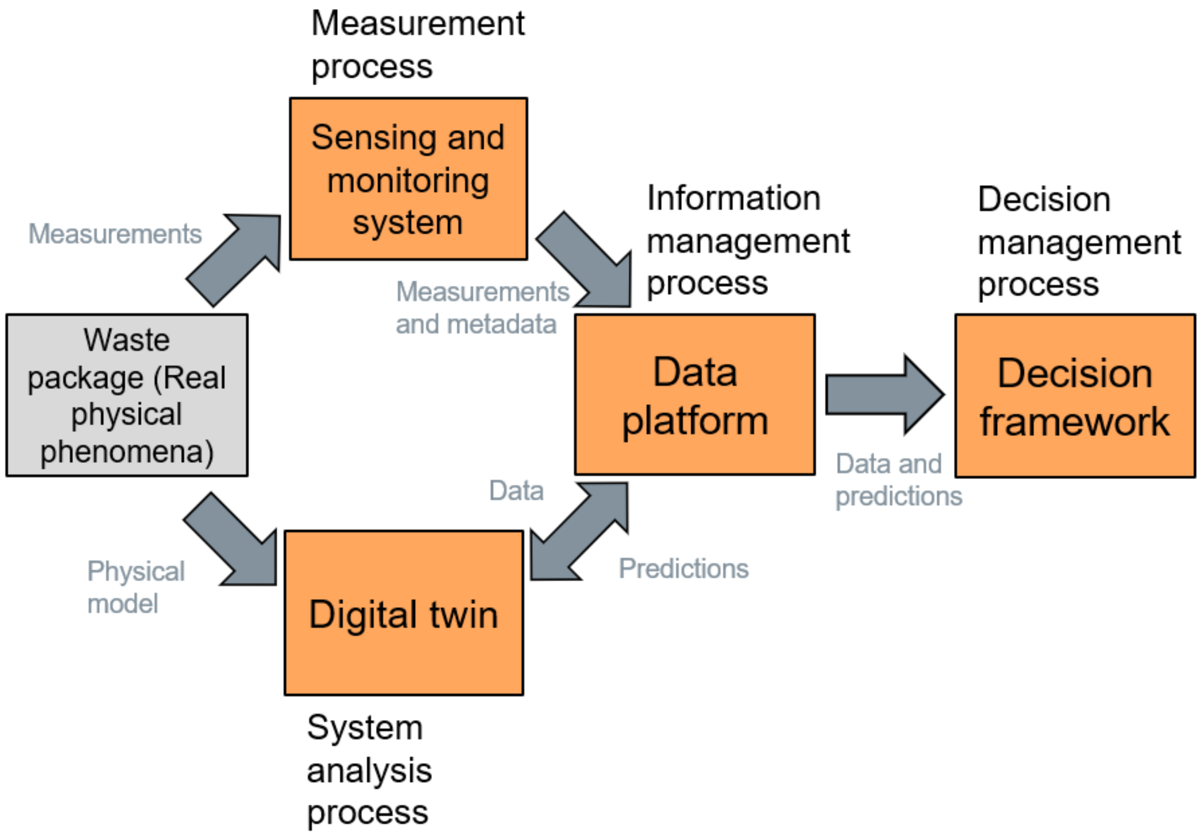
Objectives of T7.5 – Data processing, handling and fusion

- Goals of database and decision framework: to produce
  - A conceptual model for data handling and storage
  - Database and software prototype

- A joint showcase of T7.3 on innovative instrumentation, T7.4 on simulation and digital twins, and T7.5 on data processing, handling and fusion
  - Presentation at UJV
  - Exemplifying the collaborative, iterative, and integrative approach of the project, weaving together various strands of research and development

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

Data management framework high-level system architecture



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

Approach and results: Data platform

- A reference metadata model, accessible as a web service, was set up in a local server on a site.
- Four models (i.e., database tables) were associated (waste packages, sensors, nodes, images) with the possibility of managing data by the administrator and user groups with the necessary permissions.
- SQLite3 Database was preliminarily filled with the relevant data of the project. Once the waste packages are defined as a master table, any changes associated with them are automatically traced in a change history.
- Data was visualized in three different ways: admin mode, public, and by other external open-source tools to analyze the database structure and its consistency.

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

Approach and results: Decision framework

- Utilizing a decision platform that integrates ML and digital twin-powered predictions and Online Analytical Processing (OLAP) analysis holds the potential to significantly support informed decision-making.
- Through the integration of sensor data and other monitoring systems, the PREDIS platform provides immediate insights facilitating improved performance and safety in waste management processes.
- The real-time monitoring capabilities facilitate the instant detection of deviations from normal conditions and automated alerts upon the detection of irregularities for prompt corrective actions.
- The OLAP analysis empowers users to selectively extract and query data, allowing for analysis from various perspectives.
- This proactive approach ensures timely interventions, thereby minimizing the likelihood of incidents/accidents or environmental impact.

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

Conclusions

- **A conceptual model for data handling and storage was developed**, and a practical implementation was performed.
- The demonstration test at UJV confirmed that **monitoring data from sensors** can be automatically uploaded to the MS Azure cloud platform, and it can be **visualized on the decision platform**.
- A web-based decision platform with multiple dashboards was developed **to present information from different perspectives customized to different users**. Predictive numerical models of the digital twin can be integrated into the platform to further support decision making.

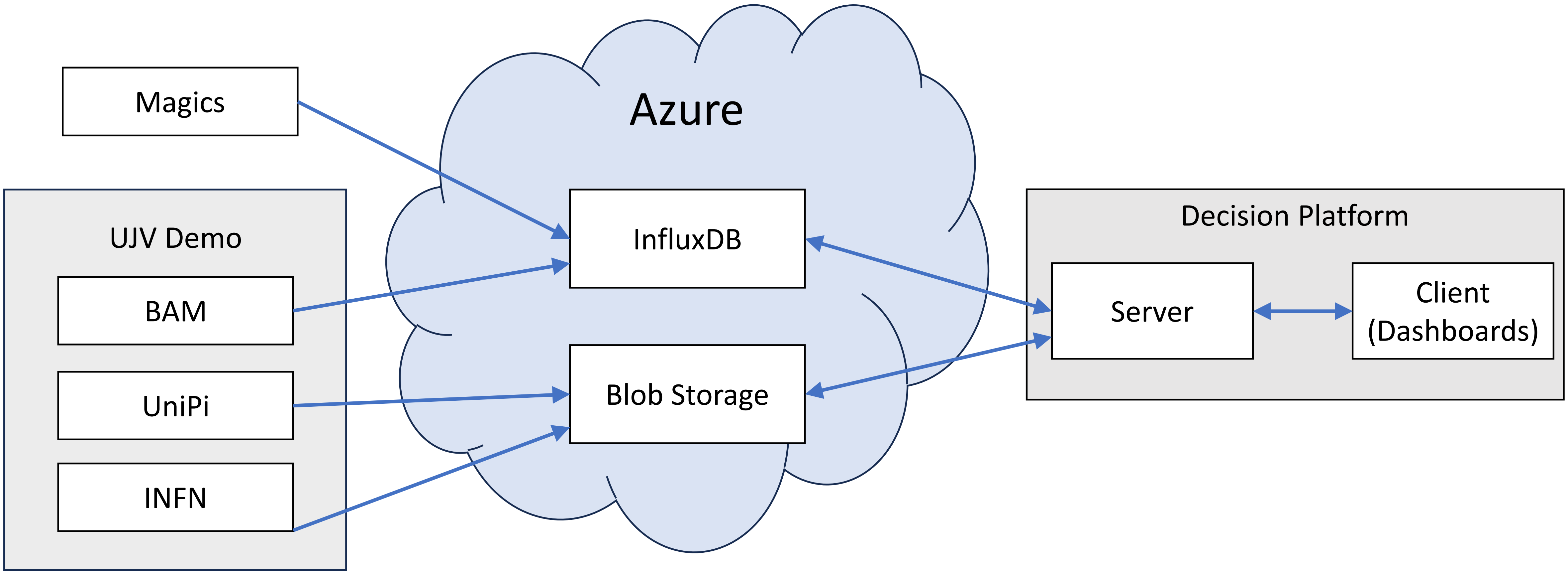
This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945098.

T.7.5

Informed decisions:
Nuclear waste monitoring with sensor-driven dashboards

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

Sensor Data Flow

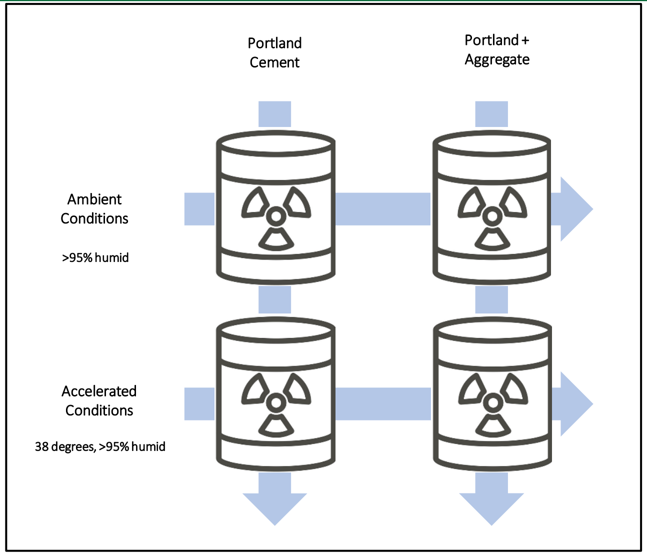


This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945098.

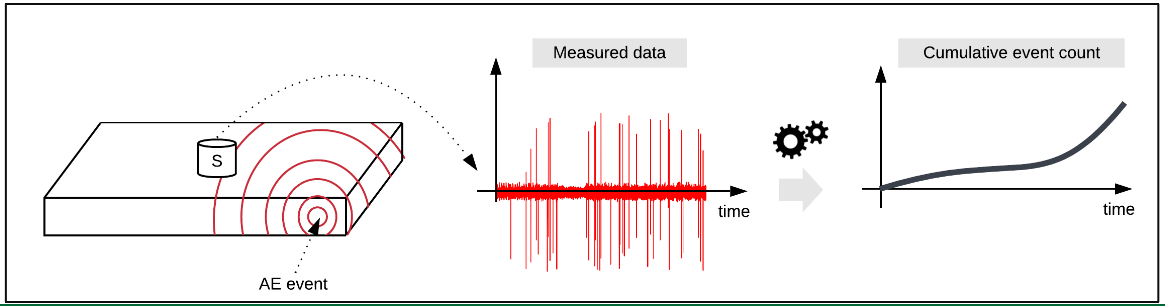
Sensor Technologies - Magics

- Measurement: Acoustic Emission events
- Phenomenon: Strain
- Drum-scale tests
  - Four drums filled with two different mixtures at two different environmental conditions.
  - Duration: 2 years (ongoing)
  - Sensors per barrel: 8 strain gauges, 8 temperature sensors, air pressure and 2 AE sensors

Physical Acoustics R15 AE sensor



Overview of drum-scale experiment



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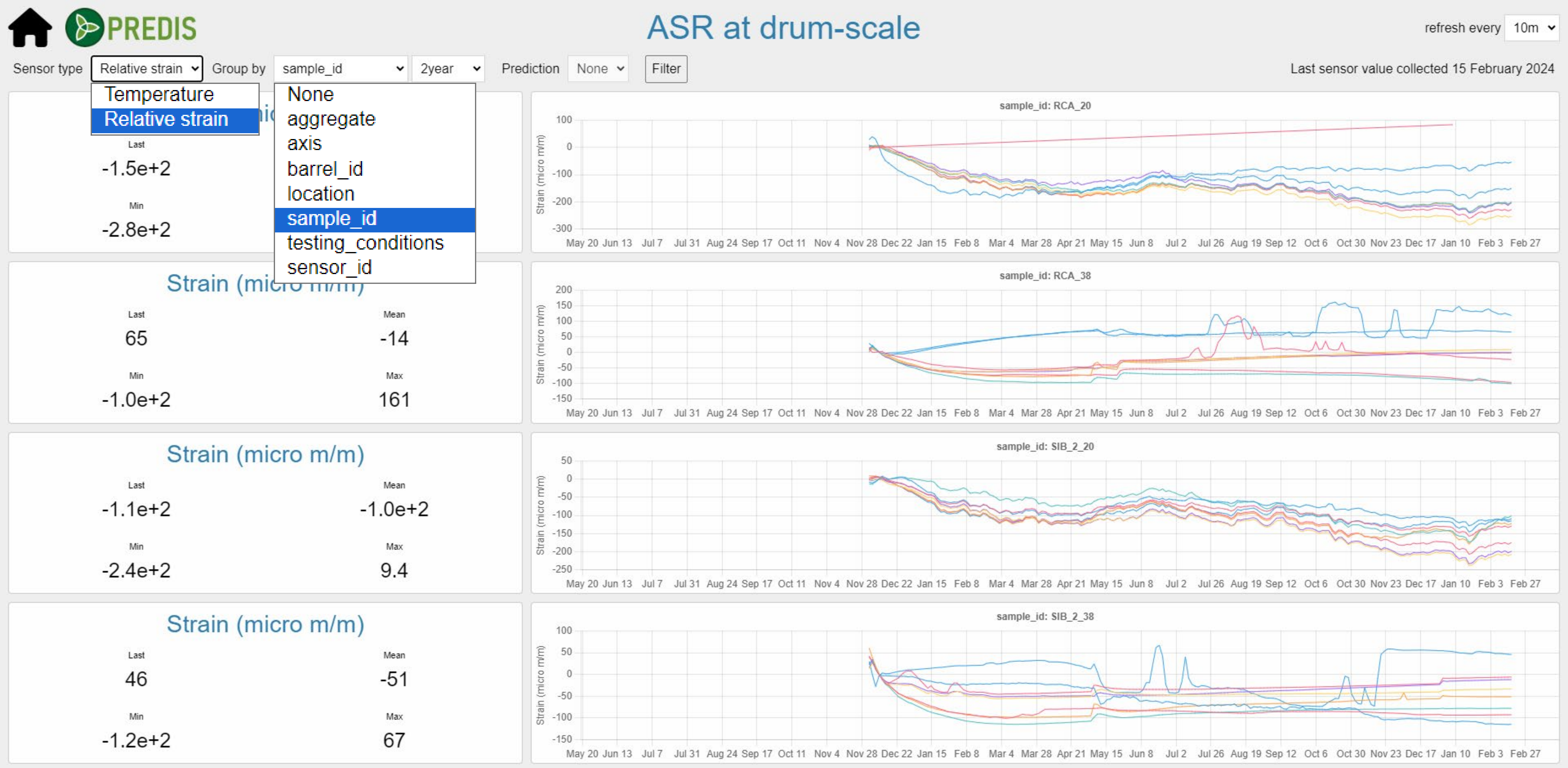

PREDIS
ASR at drum-scale
refresh every 10m
Sensor type Relative strain
Group by sample_id 2year
Prediction None
Filter
Last sensor value collected 15 February 2024
Temperature
Relative strain
None
aggregate
axis
barrel_id
location
sample_id
testing_conditions
sensor_id
Last -1.5e+2
Min -2.8e+2
Strain (micro m/m)
Last 65
Mean -14
Min -1.0e+2
Max 161
Strain (micro m/m)
Last -1.1e+2
Mean -1.0e+2
Min -2.4e+2
Max 9.4
Strain (micro m/m)
Last 46
Mean -51
Min -1.2e+2
Max 67
sample_id: RCA_20
sample_id: RCA_38
sample_id: SIB_2_20
sample_id: SIB_2_38
Strain (micro m/m)
May 20 Jun 13 Jul 7 Jul 31 Aug 24 Sep 17 Oct 11 Nov 4 Nov 28 Dec 22 Jan 15 Feb 8 Mar 4 Mar 28 Apr 21 May 15 Jun 8 Jul 2 Jul 26 Aug 19 Sep 12 Oct 6 Oct 30 Nov 23 Dec 17 Jan 10 Feb 3 Feb 27

Demonstration test at UJV storehouse 241

refresh every 10m

Room Temperature

Last – Mean –

Min – Max –

Room Pressure

Last – Mean –

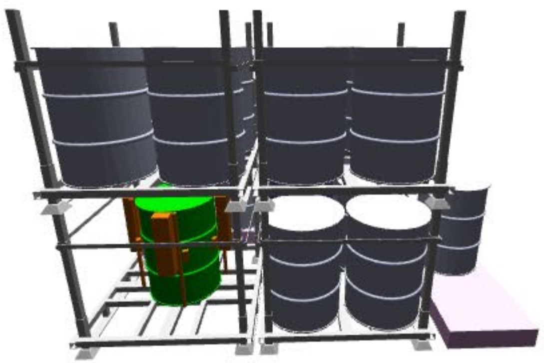
Min – Max –

Room Humidity

Last – Mean –

Min – Max –

3D demonstration storage configuration



Demonstration storage configuration

Dead sensors warning

Sensor Id	Sensor description	Duration since last value
Gamma_01_unipi	Gamma-ray detector 1 (channel 1)	2week5d1h25m23s
Gamma_02_unipi	Gamma-ray detector 2 (channel 2)	2week5d1h25m23s
Gamma_01_unipi	Gamma-ray detector 3 (channel 3)	2week5d1h25m23s
Gamma_02_unipi	Gamma-ray detector 4 (channel 4)	2week5d1h25m23s
Neutron_01_unipi	Thermal neutron detector 1 (channel 5)	2week5d1h25m23s
Neutron_02_unipi	Thermal neutron detector 2 (channel 6)	2week5d1h25m23s
Battery_01_unipi	Battery monitor (channel 9)	2week5d1h25m23s
Energy 10	RFID embedded sensor	1month1week3d22h17m36s
INFN-SCIFI-01	Gamma detector 0°	1month6d18h27m3s

Equipment area

PREDIS

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

Mock-up 1.2 (RFID embedded sensors)

refresh every 10m

RFID embedded sensors | All Sensors | 3month | Prediction None

Last sensor value collected 18 January 2024

All Sensors
RFID-SN-00
RFID-SN-01
RFID-SN-02
RFID-SN-03
RFID-SN-04

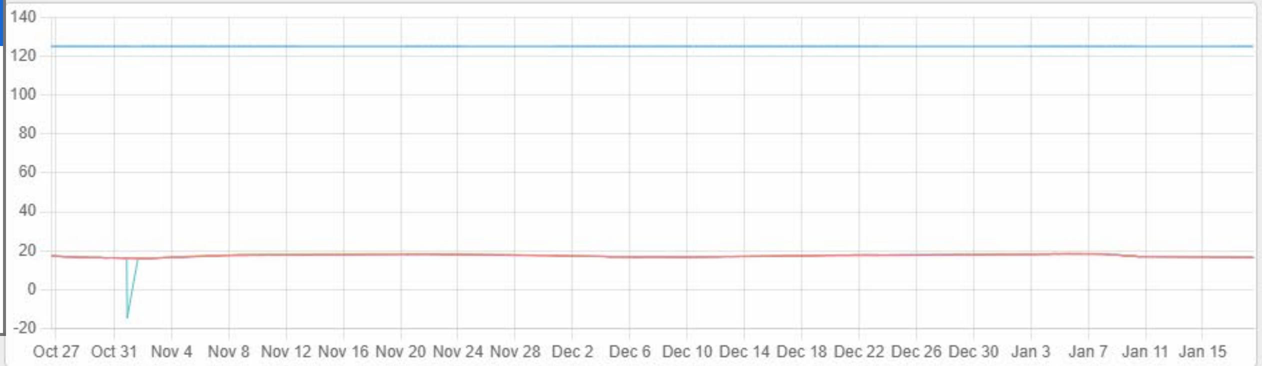
Temper

Last

17

Min

-14



Battery (V)

Last

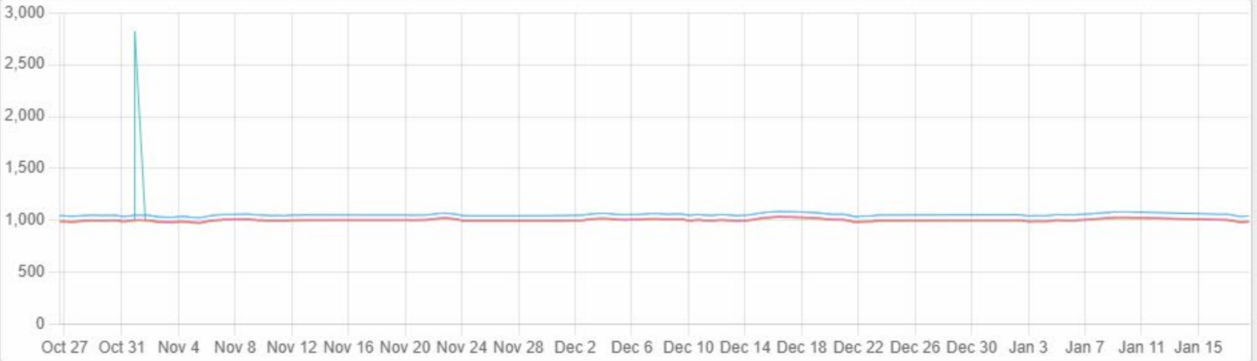
5.5

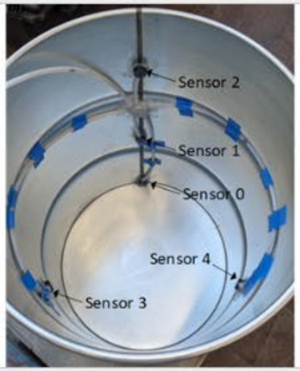
Reference

4.5

Pressure (mbar)

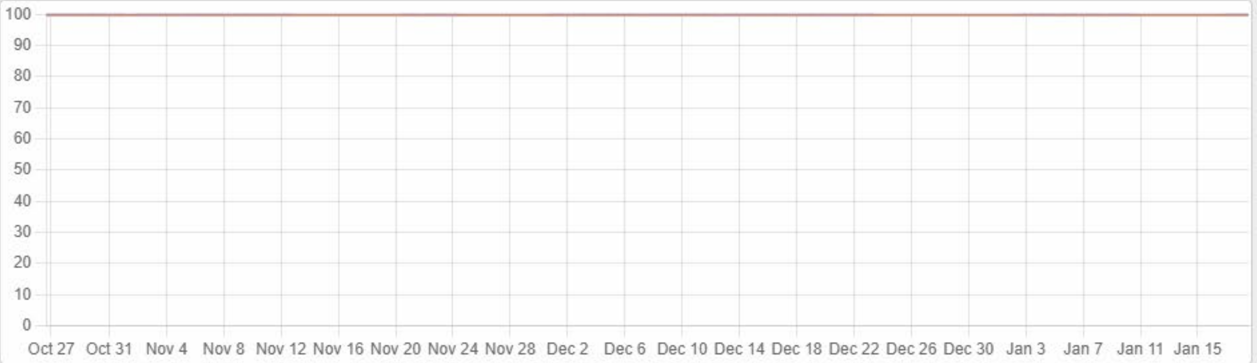
Last	Mean
992	1014
Min	**Max**
973	2822





Relative Humidity (%RH)

Last	Mean
100	100
Min	**Max**
99	100



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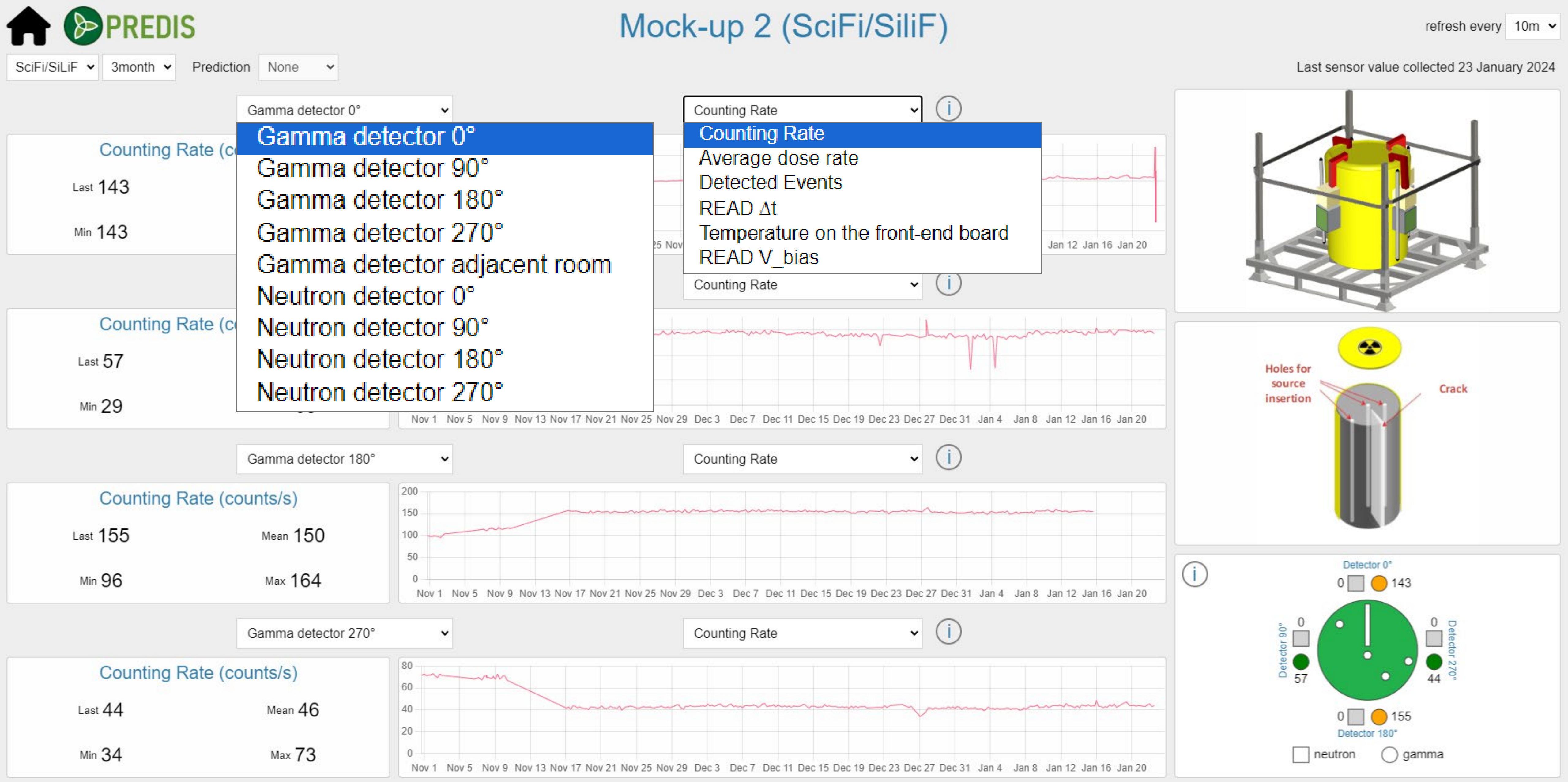

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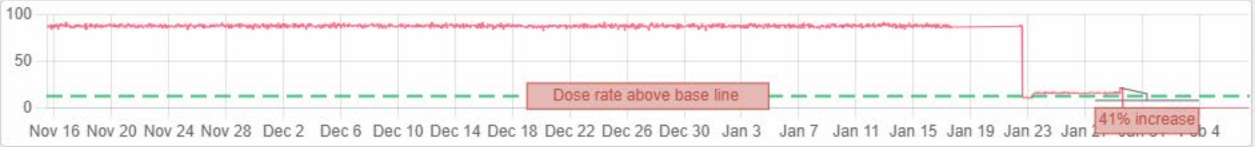
Mock-up 2 (Sensorized RF identification Box)

All Sensors | 3month | Prediction None | Alarms (2)

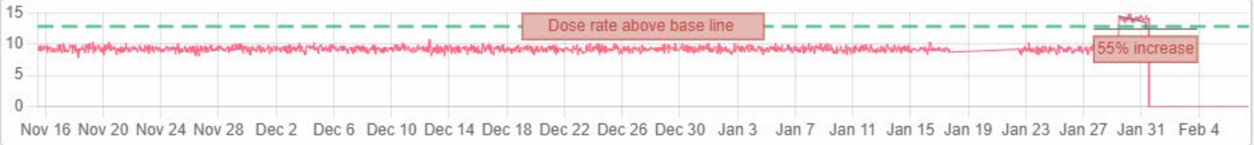
Last sensor value collected 7 February 2024 at 10:58

Battery (%)
Last 8 | Mean 80
Min 8 | Max 94

Gamma 1 (µSv/h)
Last 0 | Mean 71
Min 0 | Max 91

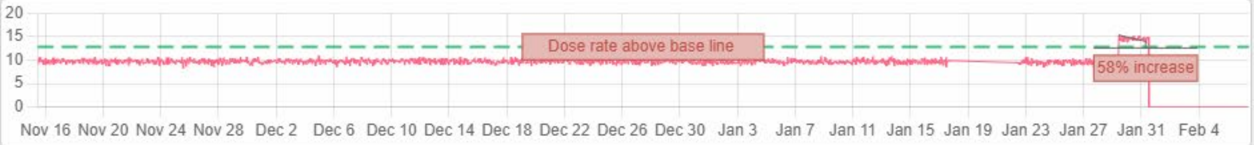


Gamma 2 (µSv/h)
Last 0 | Mean 8.5
Min 0 | Max 15



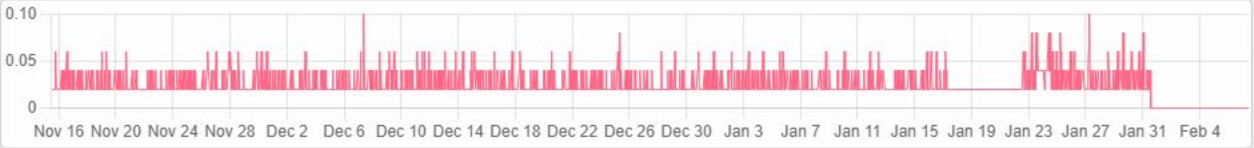
Gamma 3 (µSv/h)
Last 0 | Mean 19
Min 0 | Max 101

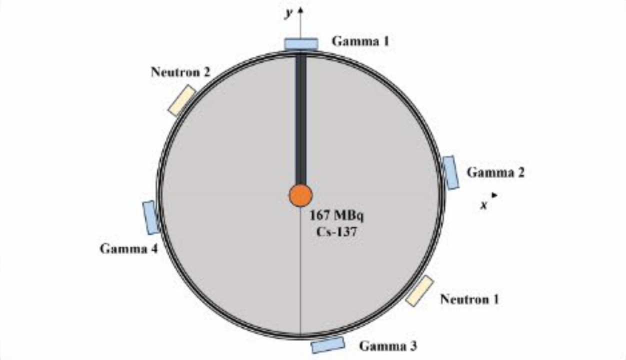
Gamma 4 (µSv/h)
Last 0 | Mean 8.9
Min 0 | Max 15



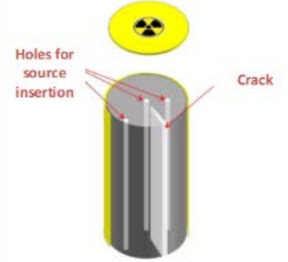
Neutron 1 (µSv/h)
Last 0 | Mean 0.024
Min 0 | Max 0.10

Neutron 2 (µSv/h)
Last 0 | Mean 0.025
Min 0 | Max 0.10





Mock-up 2 description



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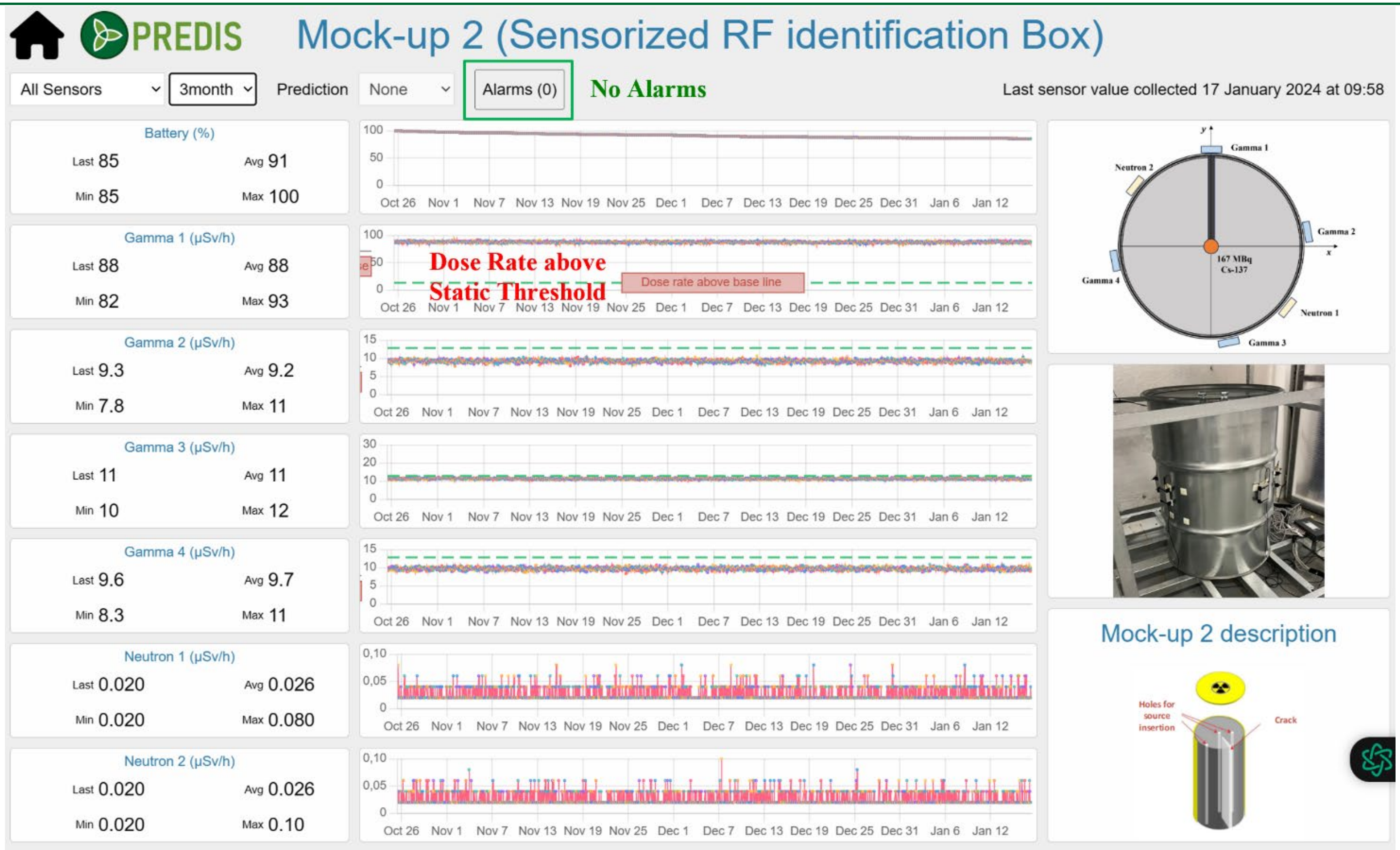
Alarms – Static Threshold



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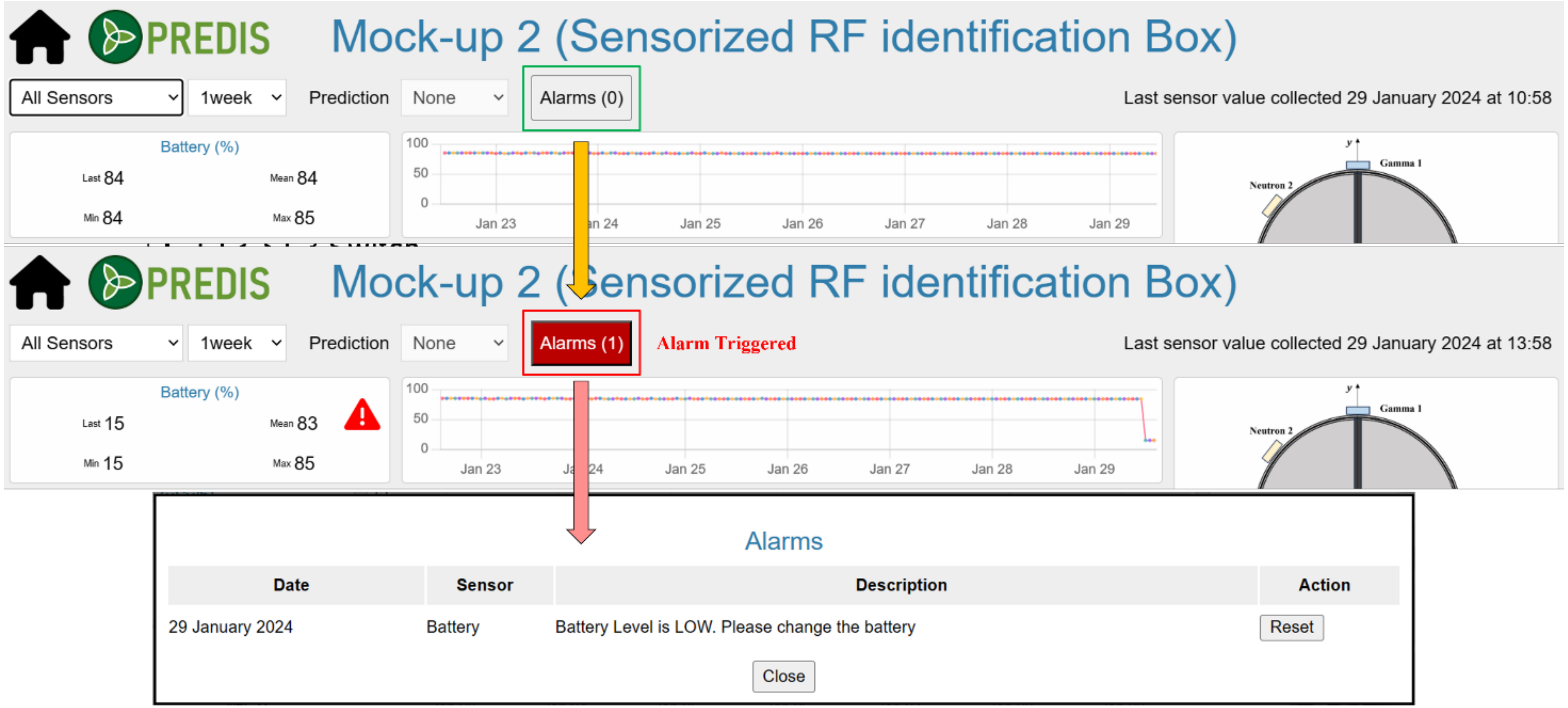
Alarms – Battery falls below 20%



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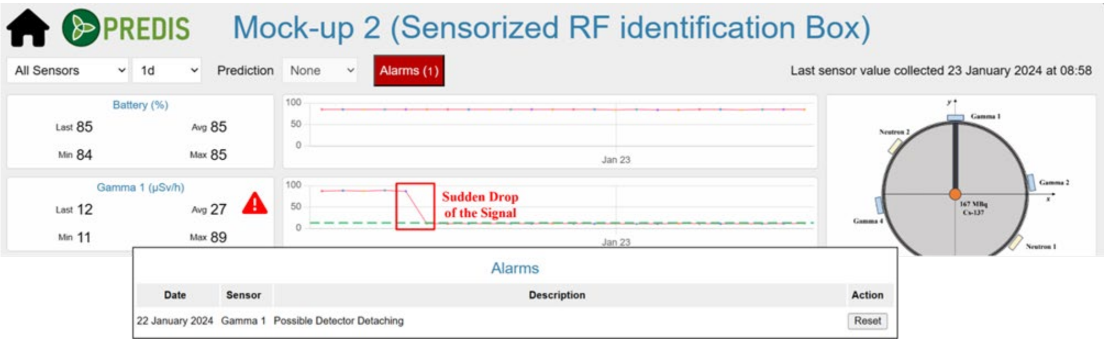
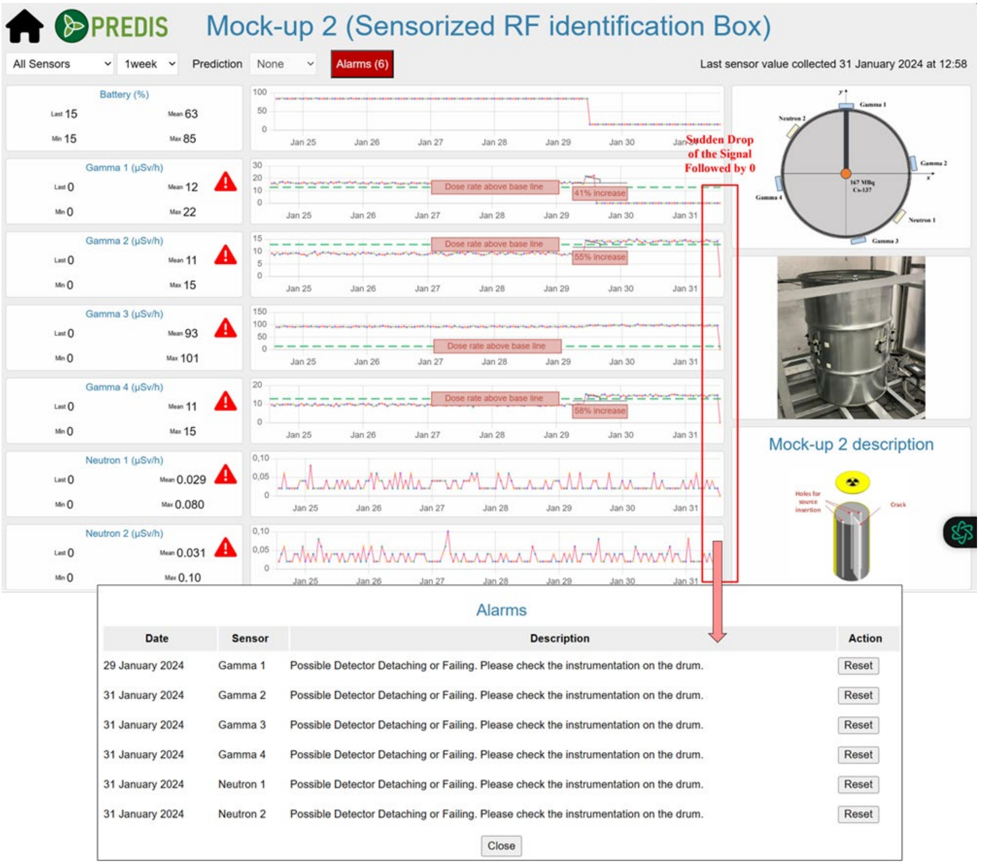
Alarms – Detectors Detaching or Failing

- Sudden drop – Possibly Detaching
- Followed by 0 – Potential Failure





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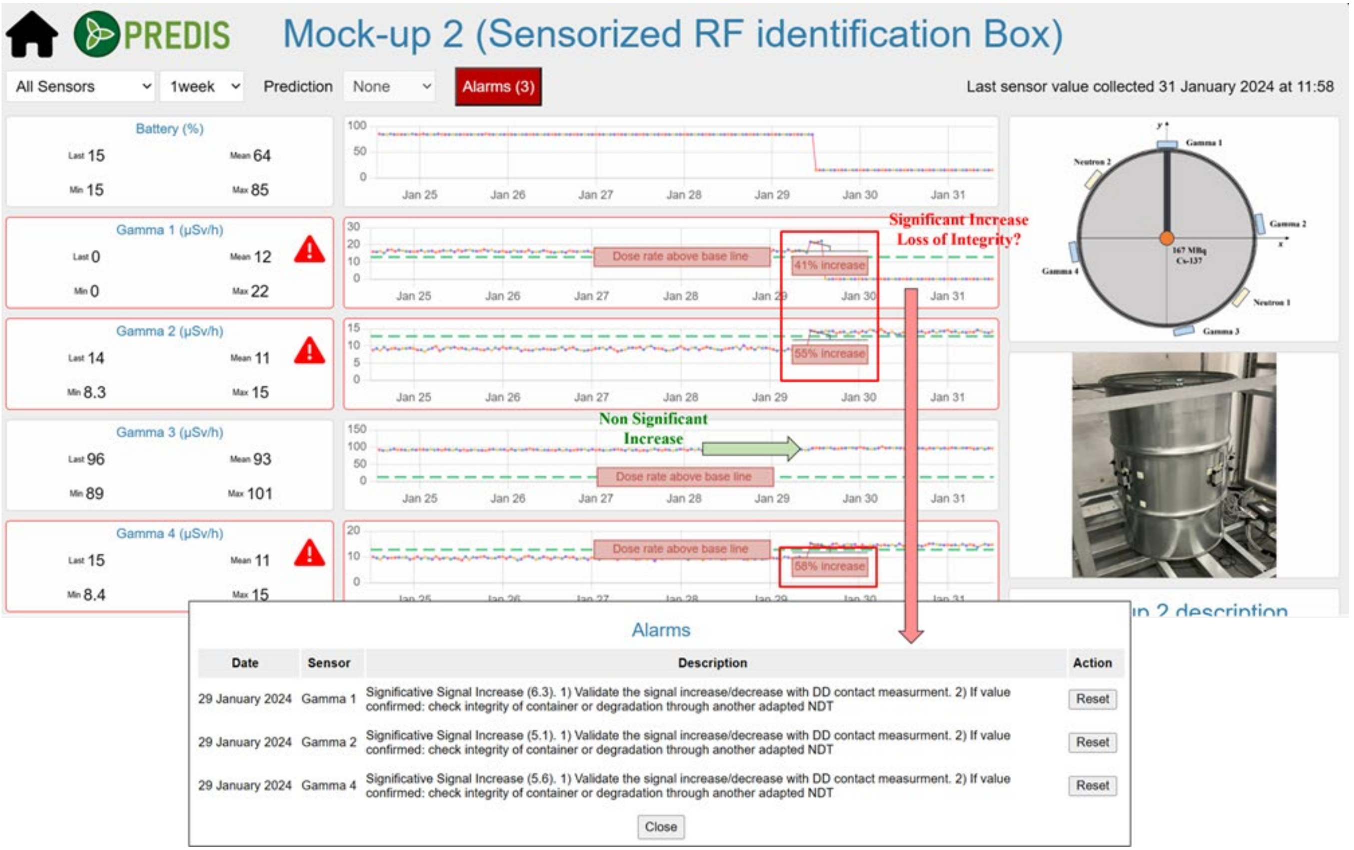
Alarms – Significant Dose Rate Increase



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Task 7.2 State of the Art

Task 7.3 Testing & Monitoring

Task 7.4 Digital Twin

Task 7.5 Data Management

Task 7.6 Demonstration and Implementation

Task 7.7 Dissemination

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

Objectives for task 6

" Test and verify the performance of the selected technologies, developed by task 7.3, by the deployment of an instrumented package at EU facility, possibly within a store environment or realistic environment“

Subtask T7.6.1 Evaluation of technologies and developed systems from an EU perspective

Subtask T7.6.2 Demonstrating systems and methods

Subtask T7.6.3 Definition of potential mitigation actions and design improvements

Outputs	Due date
D7.8 : Report on demonstration and implementation of monitoring, maintenance, and automation/digitalization techniques for improving safety during the storage and handling of cemented waste packages	Month 48
M 7.6 Completion of full-scale trials in a realistic testing environment	Month 48

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

Subtask 7.6.1 Evaluation of technologies

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

Evaluation of technologies

- Task 7.6 has produced a **Comparison table** to evaluate the technologies from an EU perspective
  - 1) First step : Completed by all WP7.3 developers
  - 2) Second step : End users completed the EU criteria during the November workshop
- The table has been revised in the beginning of 2024 to follow-up on new developments of the technologies
- A Value Assessment has been carried out for each technology

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Subtask T7.6.2 : Demonstrating systems and methods

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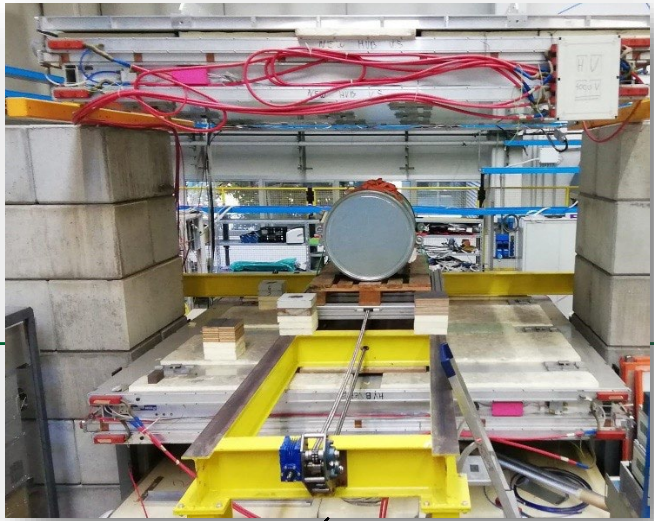
OPI0 : DIFFUSION NORMALE / UNRESTRICTED

Sub-Task 7.6.2



Technology testing at INFN :
- ❖ *Muon Tomography* (INFN)

Demonstration test at UJV :
- ❖ *RFID embedded sensor* (BAM/VTT)
- ❖ *SiLiF / SciFi neutrons and gamma* (INFN)
- ❖ *Sensorized RF identification box for radiation monitoring* (UniPi)

Demonstration test at NNL :
- ❖ *Air-coupled ultrasonic inspection* (NNL)

Technology testing at MAGICS :
- ❖ *Acoustic Emission Wireless* (MAGICS)

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OPI0 : DIFFUSION NORMALE / UNRESTRICTED

PREDIS

DEMO tests interest

- Demonstrate that the technologies, methods, and models developed and identified in Task 2 to 5 can be used in a nuclear environment.
- Test and verifiy the performance of the selected technologies, developped protypes, and models by the deployment of an instrumented package at an end-user facility, possibly within a storage environment

The main aim of the demo test is to demonstrate that technologies are of real interest for monitoring EU packages in storage conditions.

DEMO TEST AT NNL

DEMO TEST AT UJV

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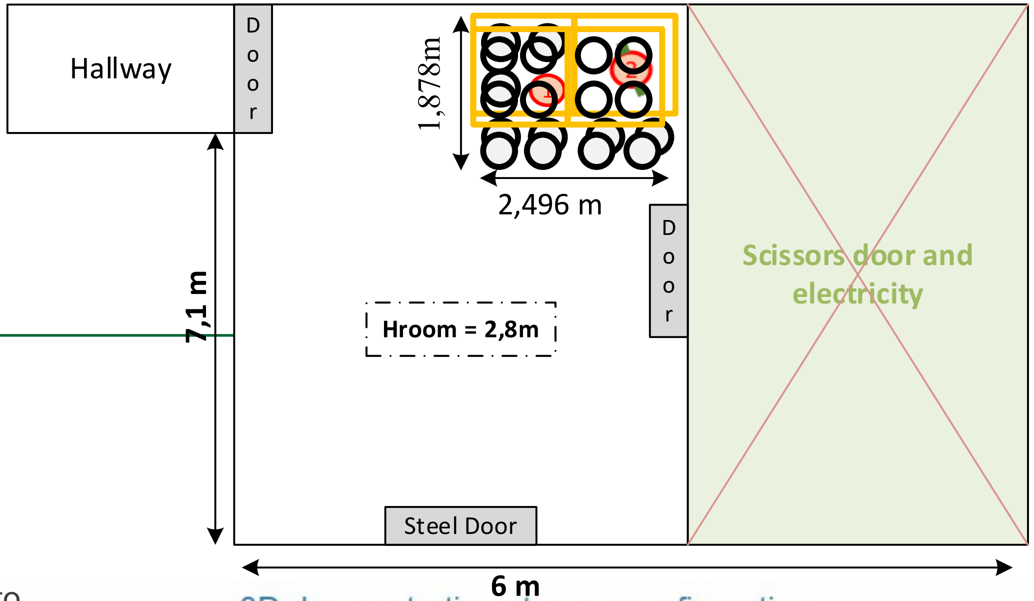
OPI0 : DIFFUSION NORMALE / UNRESTRICTED

Demonstration test at UJV

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

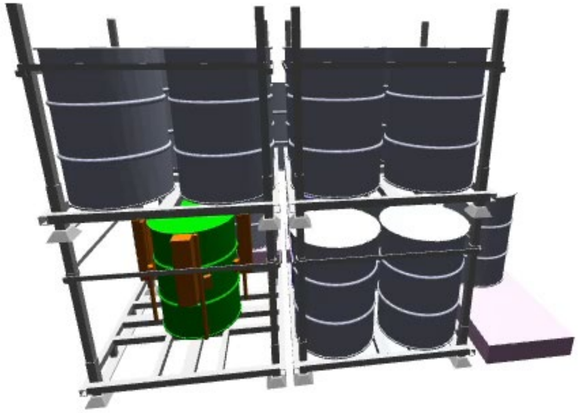
PREDIS

UJV demo test configuration



3D demonstration storage configuration

- *Optimized storage configuration for the demo test is:*
  - 19 cemented packages
  - 2 mock-ups :
    - **Mock-up 1.2 :** Assessing RFID embedded sensor technology using Relative Humidity, Temperature, and pressure sensors, along with Belgoprocess aggregates, to replicate conditions susceptible to Alkali-Silica Reaction (ASR).
    - **Mock-up 2 :** Evaluating radioactivity using a mock-up with a central aperture for a 167 MBq Cs-137 source, facilitating measurement around the mock-up and identifying anomalies or faults within cemented packages.



- *Duration of UJV test:* **3 months** from **October 2023** to **January 2024**
- *During the test:* Each developer was able to **remotely collect data** transmitted by their technology. The data were:
  - First sent to a local server (the Data Equipment Area) located in another room
  - Then uploaded online to the Microsoft Azure platform.
  - Finally gathered in a Dashboard

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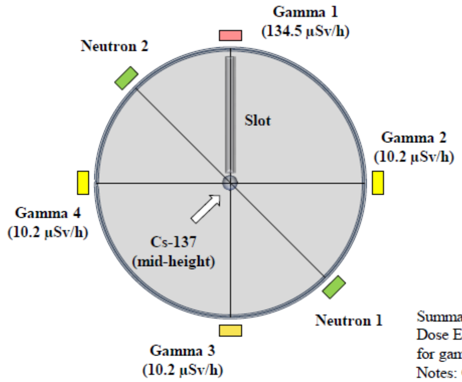
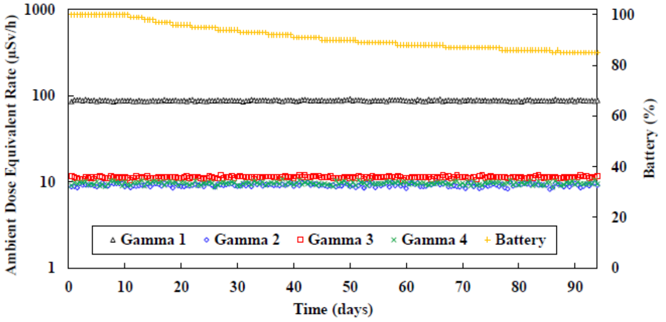
PREDIS

Demonstration test results



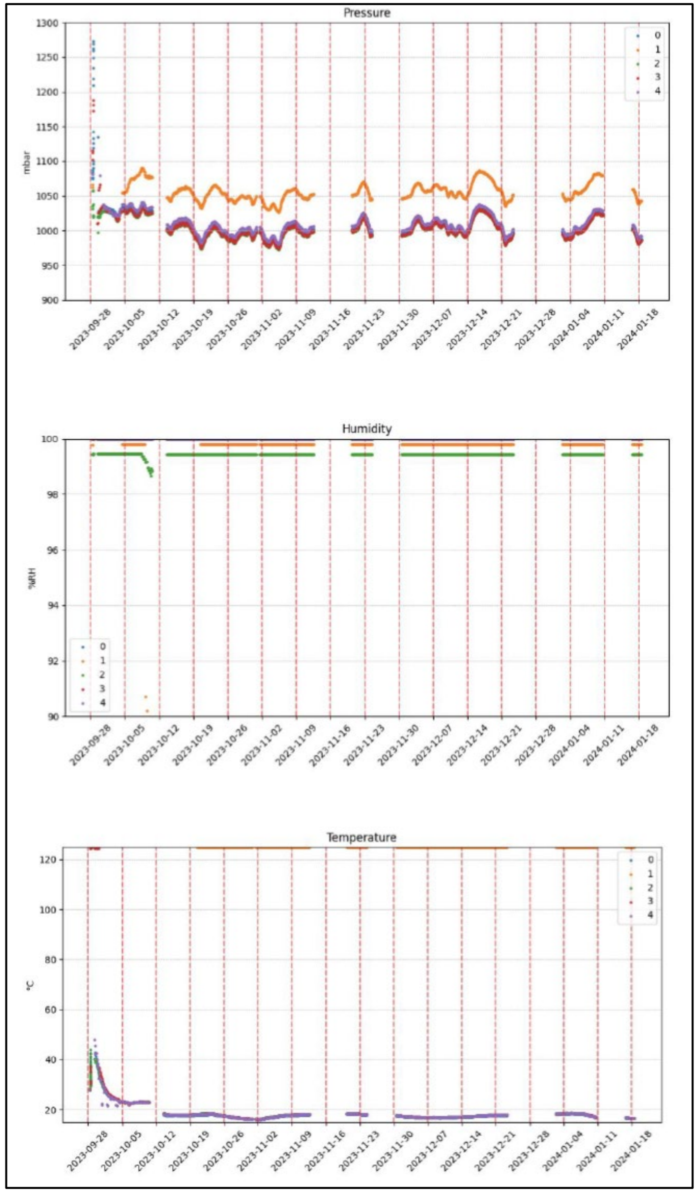


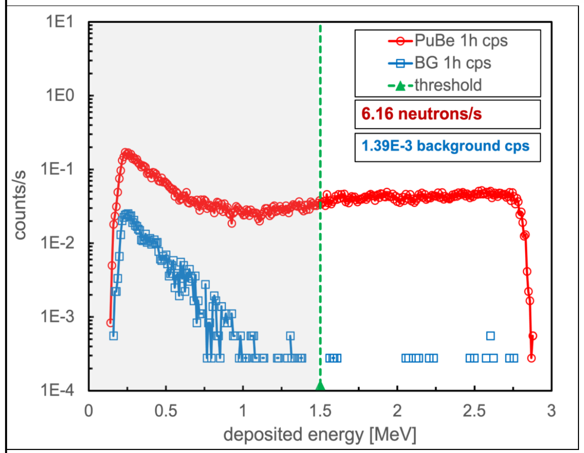
Summary of Count Rate and Ambient Dose Equivalent Rate measurements for gamma detectors.
Notes: CR = Count Rate; ΔCR = Minimum Significative CR Increase (99.7%); ADER = Ambient Dose Equivalent Rate; ΔADER = Minimum Significative ADER Increase (99.7%).

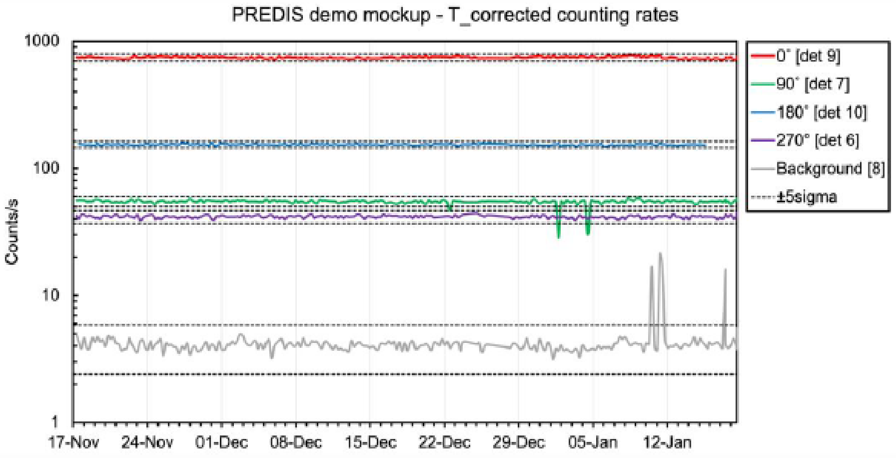
Detector ID	Angular Position	CR (CPM)	ΔCR (CPM)	ADER (µSv/h)	ΔADER (µSv/h)
Gamma 1	0°	440.3 ± 5.9	17.8	88.1 ± 1.2	3.6
Gamma 2	90°	46.0 ± 1.9	5.8	9.2 ± 0.4	1.2
Gamma 3	180°	56.6 ± 2.1	6.4	11.3 ± 0.5	1.5
Gamma 4	270°	48.4 ± 2.0	5.9	9.7 ± 0.4	1.3

UniPi

BAM/VTT





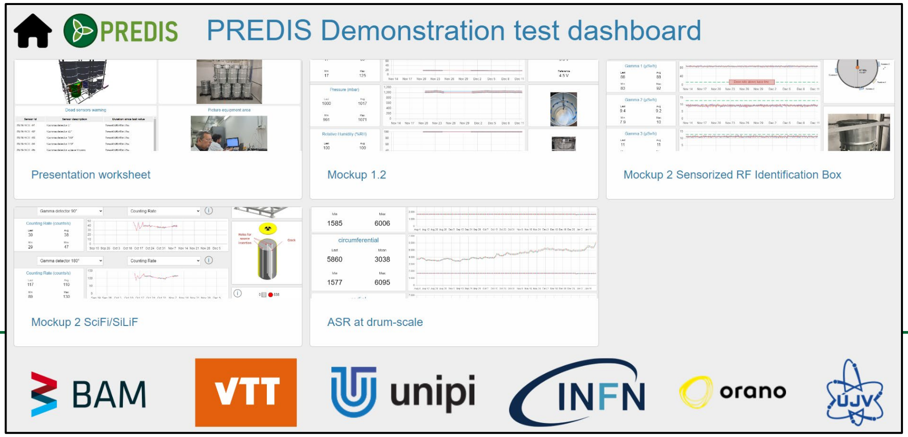


INFN

PREDIS

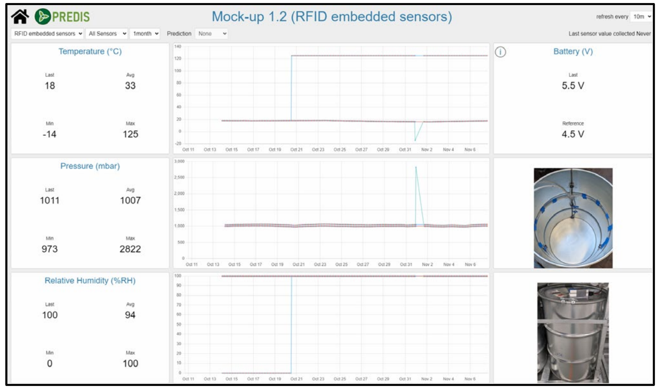
Dashboard

1.



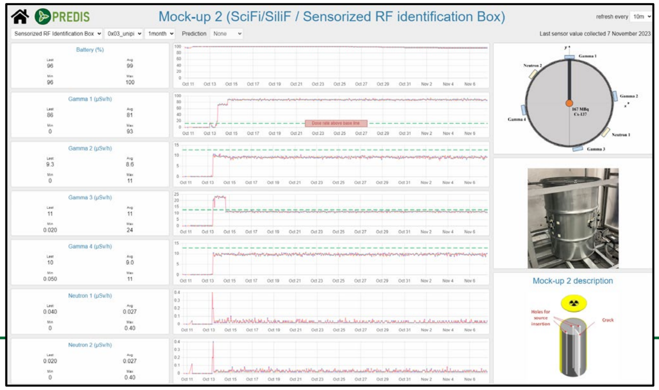
- Implemented as a web page similar to task 7.5 developments
  1. Demo presentation page
     - As if it were an interim storage facility
     - 3D view
     - Dead sensor list
  2. Mock-up 1.2 page
     - RFID embedded sensors from BAM / VTT
     - Time series graphs and summaries for temperature, pressure and humidity sensors
     - Photos and battery status
  3. Mock-up 2 SciFi/SiLiF
     - Time series graphs and summaries for end-user selected parameters among for each sensor (average dose rate, counting rate, read duration, temperature, …)
     - Pictures and illustrations
  4. Mock-up 2 Sensorized RF identification box
     - Sensorized RF identification box for radiation monitoring from UniPi
     - Time series graphs and summaries for battery, 4 gamma and 2 neutron sensors
     - Pictures and illustrations
     - Integration of alarms on sensors failure (detachment), battery low level, lora failure, increase of measured DR

2.



3.

4.



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

Showcase

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PREDIS

Showcase of PREDIS task work

- **How:** Poster to present the different technologies
- **Who** : Every task 3 developpers (BAM, INFN, Unipi, MAgics, NNL)
- **What:** A collection of the results of all tests performed during PREDIS in order to present them
- **Where:** In the poster room

A task 7.6 poster is also available to resume the Demonstration Test in a realistic storage environment at UJV Rez

NNL Poster

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Task 7.2 State of the Art

Task 7.3 Testing & Monitoring

Task 7.4 Digital Twin

Task 7.5 Data Management

Task 7.6 Demonstration and Implementation

Task 7.7 Dissemination

T.7.7 Dissemination and Reporting

- **Key partners**: GSL, BAM, VTT, PSI, Orano, SOGIN (M1-M48)
- **Aim**: ensure dissemination of WP 7 results to wider audience and production of WP7 synthesis report
- **Scope**:
  - Record of WP7 dissemination activities (a log of dissemination activities has been developed)
  - Participation at scientific conferences and workshops
  - Developing a project summary report documenting the outcomes of the project
- Two key deliverables in last year of project
  - **D7.9**: Report on the economic, environmental, and safety impact of the pre-disposal monitoring, modelling, and decision framework activities developed for handling and storage of cemented waste packages (**M45**) - submitted
  - **D7.10**: Final project report on innovations in cemented waste handling and pre-disposal storage, including sections on interaction with end users of cemented waste packages and dissemination of results to the general public (**M48**)

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T7.7 Dissemination Activities

- A total of 28 dissemination activities recorded so far, including:
  - 10 Oral presentations (e.g., DigiDecom conference, several IAEA events)
  - 3 poster presentations (e.g., IGDTP symposium, EURADWASTE conference)
  - 9 journal and other publications
  - 1 webinar on digital twin

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WP7 Value Assessment – Approach

- A form of multi-criteria cost benefit analysis to assess and compare the technical, economic, and environmental performance of alternative waste management options against an established baseline
- Briefing materials produced to explain the assessment process and help technology developers to undertake draft assessments
- Value assessment workshops held with WP7 partners and end users to discuss the draft assessments (Milestone in M43)
- Draft assessments updated and incorporated into Deliverable D7.9 (submitted in M45)

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WP7 Value Assessment – Scope

- All technologies and tools being tested in WP7

Technology	Technology developer(s)	Baseline
SciFi (gamma) radiation monitoring	INFN, Italy	Visual inspection and manual dose rate measurement
SiLiF (neutron) radiation monitoring	INFN, Italy	Visual inspection
Sensorised LoRa wireless sensor network for identification and integrity assessment of radioactive waste drums	UNIPI, Italy	Visual inspection and manual dose rate measurement
Acoustic Emission for measuring ASR	Magics, Belgium	Visual inspection
Non-contact ultrasonic scanning	NNL, UK	
Embedded RFID Sensors	BAM, Germany VTT, Finland	
Muon tomography	INFN, Italy	X-ray imaging
DT, data platform and decision framework tools for predictive modelling, data handling, and data visualisation	PSI, Switzerland VTT, Finland IFE, Norway	Combination of paper records and limited digital archiving of data, but no DT or decision framework used. The baseline also assumes visual package inspection as the monitoring technology. However, the assessment only focuses on the DT, data platform, and decision framework aspects rather than any potential monitoring technologies that might operate concurrently.

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WP7 Value Assessment – Example Summary of Output

Operational and Transport Safety

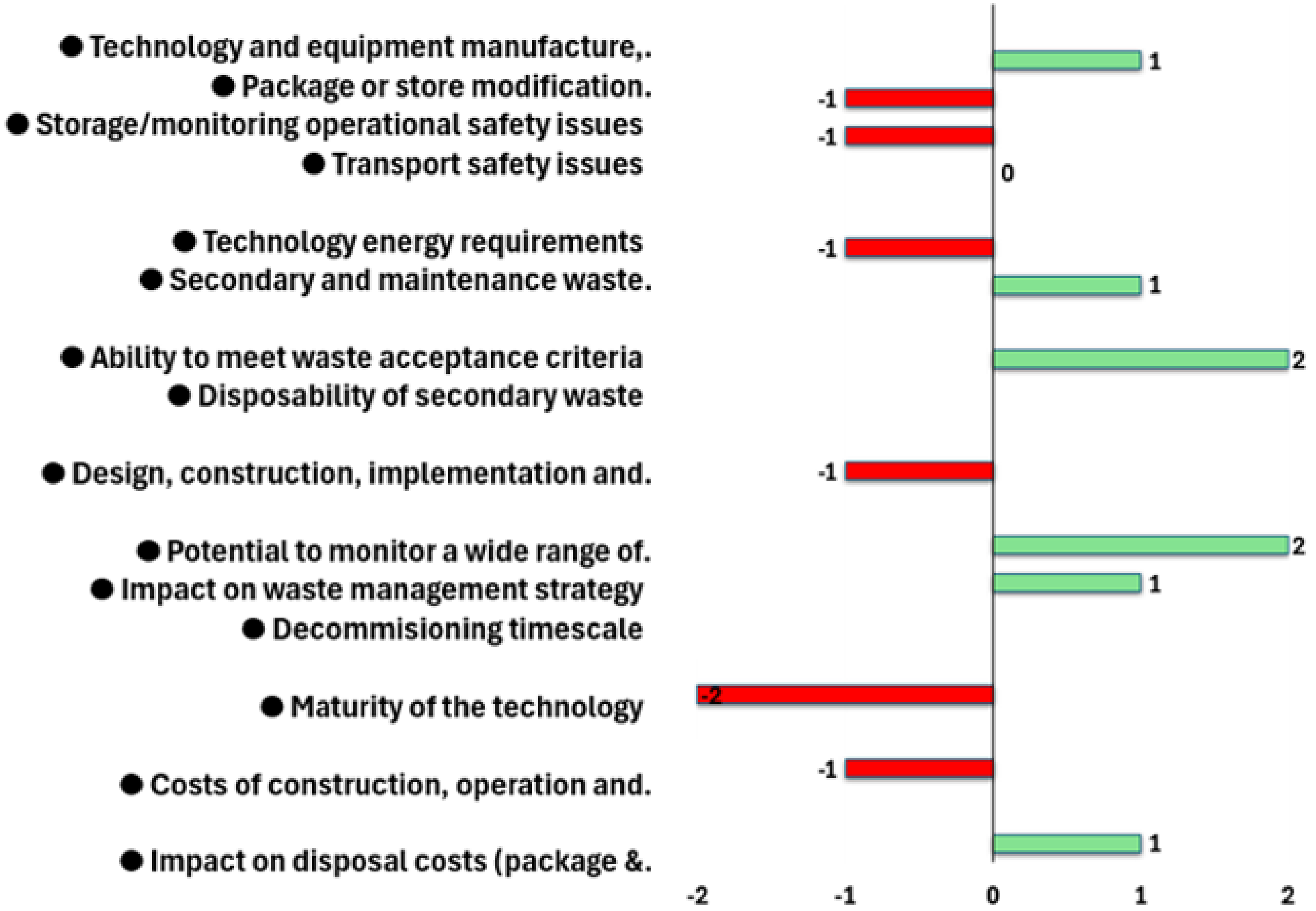
Environmental impact

Impact on disposability / long-term safety

Implementation and timescales

Technical Readiness

Strategic Cost Impact



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Conclusion Objectives vs. Achievements

- Identify, **evaluate and demonstrate** store and package **quality assurance** (NDE) and monitoring technologies

- Developed new technologies for specific challenges.
- Demo test and evaluation.
- Investigate method applicability.
- Continuous evaluation with End User perspective.
- Undertake Value Assessment of all technologies developed in the project.

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Conclusion Objectives vs. Achievements

- Adapt and demonstrate **digital twin technology**

  - Proof of concept of digital twin for cemented waste form pathology (ASR).
  - Demonstration of a machine learning approach for complex cement degradation processes
  - Demonstration of digital twin framework models as a support of decision making

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Conclusion Objectives vs. Achievements

- Develop and demonstrate **methods for data handling**
- Develop and demonstrate a **digital decision framework**

- A data management framework, from sensing to decision-making, was developed.
- Successful integration of all methods/technologies in a realistic environment
- Technologies and practices were demonstrated to help end-users and WMOs to increase their organisational maturity.

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