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DIGITAL TECHNOLOGIES IN EUROPEAN NUCLEAR DECOMMISSIONING PROJECTS

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Abstract

Many nuclear facilities around the world are reaching the end of their life cycle and are being shut down, so demand in the nuclear Dismantling and Decommissioning (D&D) market will continue to grow. As the complexity of these tasks involves budgetary constraints, long-term frames, and specific logistical requirements among others, research is encouraged to optimize traditional methods with the help of digital technologies.

The Euratom project PLEIADES (PLatform based on Emerging and Interoperable Applications for enhanced Decommissioning processES) was conducted in the years 2020-2023. The project defined a specific nuclear ontology and developed a central server for combining data, ensuring compatibility and demonstrating its utility in three real nuclear sites.

Starting in September 2024, the project DORADO (Digital twins and Ontology for Robot Assisted Decommissioning Operations) is being carried out by some of the previous partners and new ones. DORADO builds on the work done in the PLEIADES project by creating a holistic digital platform based on an ontology-based data-driven approach and a server with a secured RESTful API Interface to integrate digital tools into a coherent suite customized for decommissioning applications. Once completed, the DORADO platform can be used for preparing and monitoring decommissioning activities. Applications could include e.g. in-situ waste characterization, remote planning of dismantling, robotic and remote inspection, clearance and surface measurements, cost estimation, risk identification, and knowledge management. During the first stage of the project in 2024-2025, the technical requirements and business value analysis were completed. Further analysis regarding the state-of-the-art, data security, risk and safety among others, are allowing the progress of DORADO towards technical implementation. The project will continue until Autumn 2027. Once the technical implementation is complete, the technologies will be demonstrated in three real use cases using accurate digital models of various facilities in Norway, Finland, and Belgium.

KEYWORDS: BIM, COMPLEX, DATA, DECOMMISSIONING, DIGITAL, DIGITAL TWIN, INNOVATION, KNOWLEDGE, NUCLEAR, RESEARCH, SIMULATION, TECHNOLOGY

1. INTRODUCTION

Decommissioning is a necessary step in each building or facility that reaches the end of its lifecycle. This is also true for many nuclear facilities around the world that have been shut down or will be shut down in the next years. Nuclear Power Plants (NPPs) contain industrial technologies within buildings whose configuration is relatively different depending on where they are located and that makes each site unique. As Nuclear Decommissioning Projects (NDPs) were not foreseen at the time of design and construction of most of the existing nuclear facilities, NDPs are complex to manage as they involve budgetary constraints, long-term frames, and specific logistical requirements among others. According to the World Nuclear Industry Status Report [25], only 23 of the 213 closed power reactors in the World have been decommissioned by 2024, while 190 units are being or will be decommissioned. After the U.S., Germany is the second country in the World, and the first in Europe, that has dismantled the most reactors (4), followed by Spain (1). Taking into account that the mean age of the 100 European reactors is 38.3 years [25], decommissioning is a growing market within Europe, so cooperation between European countries is necessary.

In this regard, research is encouraged to optimize traditional methods with the help of digital technologies. BIM (Building Information Modeling) is used in the majority of the steps in large construction projects, and its implementation has even become mandatory for public projects in many countries. But such data needs to be up-to-date and easily accessible for use by the different stakeholders in the project.

2. THE EUROPEAN PROJECT DORADO

The project DORADO (Digital twins and Ontology for Robot Assisted Decommissioning Operations) [1], funded by the Euratom (European Atomic Energy Community) program between 2024 and 2027, brings together 12 Partners from 8 European countries that are joining forces to demonstrate the utilization of emerging digitalization technologies in decommissioning activities. During 36 months, different technologies like robotics, sensor data mapping, data management, voice recognition, BIM, AI (Artificial Intelligence), dose estimation, and mission planning are being combined around a dedicated nuclear decommissioning ontology using the DORADO platform.

Final expectations are to integrate emerging technologies into one coherent platform to support decommissioning planning, extend the decommissioning ontology, transfer data protocols to cover new use cases, and describe an extensible API (Application Programming Interface) to provide standardized data exchange between tools in decommissioning planning.

2.1. Previous steps in the project PLEIADES

The Euratom project PLEIADES (PLatform based on Emerging and Interoperable Applications for enhanced Decommissioning processES) was conducted between 2020 and 2023. Coming from 7 different European countries, the consortium was composed by 14 Partners – of which 7 are currently part of DORADO.

The objectives of PLEIADES were to demonstrate a modular software ecosystem based on interconnection of front-line support tools through a decommissioning specific ontology building upon open BIM and validate it in real use cases. For that, three of the PLEIADES partners provided with information coming from different facilities: Santa María de Garona NPP (SMG) in Spain, from ENRESA; the Halden Research Reactor (HRR) in Norway, from IFE; and the Base Chaude Opérationnelle du Tricastin (BCOT) in France, from EDF.

Data was foreseen following different criteria (cost and planning, radiation exposure estimation, scenario studies, and waste assessment) and 6 different user stories were performed using the PLEIADES platform. Thanks to the creation of an ontology for an international standard of decommissioning with specific

terminology, a common understanding of definition was set, and a common knowledge modeling was achieved by the partners.

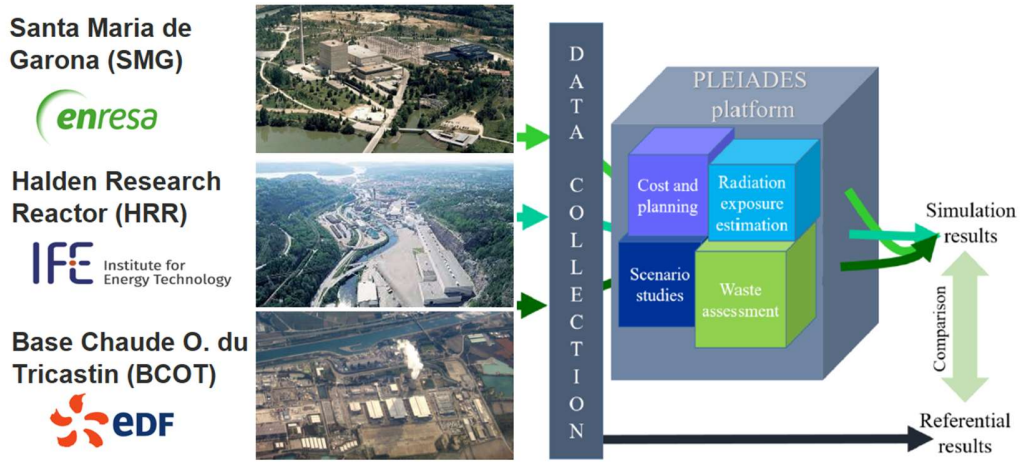


Figure 1. Implementation of PLEIADES on real use cases [6]

2.2. Organization of the DORADO project

The DORADO project consists of five Work Packages (WPs). WP1 (Project management) and WP5 (Dissemination, exploitation, communication, and standardization) run throughout the project, while WPs 2 to 4 are time-limited and interconnected (Figure 4). WP2 focuses on identifying user needs and developing the conceptual design of the DORADO platform. In the first year, the consortium defined potential applications, requirements, and KPIs (Key Performance Indicators), producing outputs on data formats, security, regulations, and user needs that feed into WP3. WP3 uses these inputs to design and implement the platform and its integrated technologies, which in turn support the demonstrations that will be carried in the WP4 from the second year of the project, between September 2025 and January 2027.

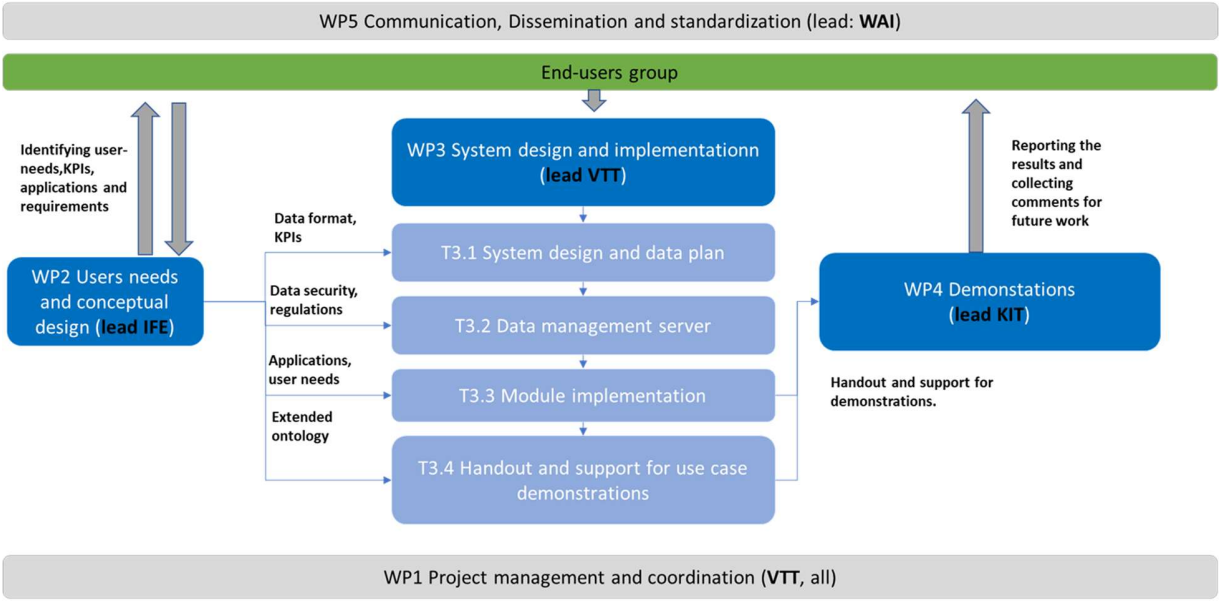


Figure 4. DORADO project flow [10]

3. IMPLEMENTATION IN DORADO

A platform was created in PLEIADES, but software integration just started. Further recommended developments were aimed at extending the coverage of the supported ontology and supporting decommissioning planning activities, as well as continuing the development of the ontology and the API.

DORADO will integrate new technologies into the server. Altogether, eight technologies will be handled:

1) Sensor data mapping with temporal dimension;

2) Environment data comparison against BIM (validation of the BIM model);

3) Point-cloud and 3D model change detection (similar as previous point, but aimed for regular updating of the model);

4) Digital twins based ALARA (As Low As Reasonably Achievable) dose estimation;

5) Server-based integration with IFC (Industry Foundation Classes) file format and extended data queries;

6) Mission control, robot route optimization;

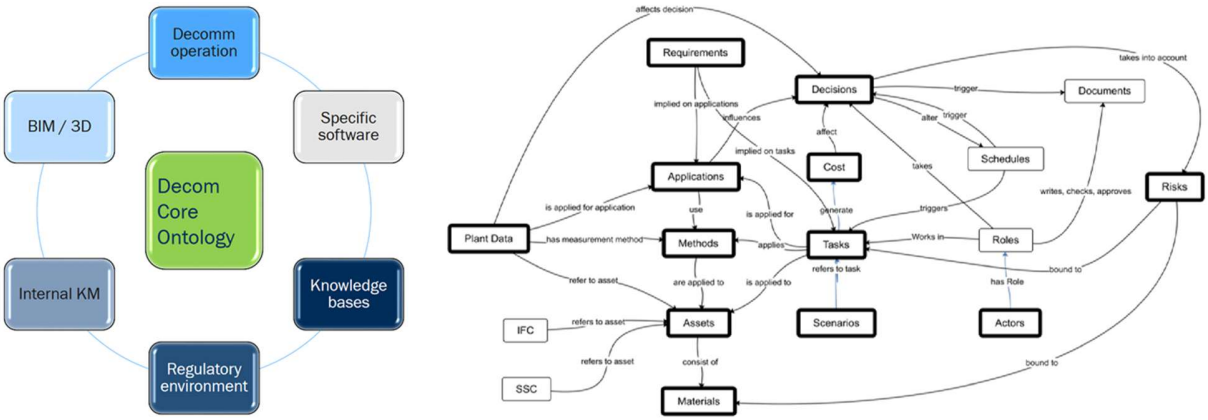
7) Human to System smart voice assistant interface;

8) Standardization using the common ontology.

Many of these are also connected to involve AI (Artificial Intelligence), robotics, and sensor networks are being integrated. Mission planning and feedback part are being added in DORADO as the Decommissioning Core Ontology is being focused on the project. The ultimate goal is to promote the concept for wider use. While the DORADO project is focused on managing the data and the BIM models, other Euratom projects, such as the XS-ABILITY project [24], focus on developing the robotic hardware and mission control. As the synergies between them are obvious, the DORADO project will co-operate with the XS-ABILITY project especially in the later stages of the projects, where joint demonstration cases are planned.

3.1. Ontology based approach

In a NDP, the correct management of interconnected and overlapping roles of active agents (workers, software entities, robots, etc.) are crucial for safety and productivity. Therefore, there is a necessity to maintain a common knowledge representation and data has to be standardized, then stored to be correctly exchanged among these agents. The project PLEIADES defined a specific nuclear ontology and developed a central server for combining data, ensuring compatibility and demonstrating its utility in three real nuclear sites (see chapter 2.1.). The decommissioning core ontology defined in PLEIADES is the basis for data structure development in DORADO, helping to find common definitions and wording.



Figures 2- 3. Decommissioning core ontology [7] [8]

3.2. Sensor data mapping

Current environmental mapping relies on sensors which typically operate independently without a shared temporal or spatial frame of reference. In DORADO, new methods for sensor data mapping are developed to automatically integrate data from multiple sensor types into a unified reference frame. This uses SLAM (Simultaneous Localization And Mapping) based locations tracking and automatic pose detection by comparing photos and LiDAR (Light Detection and Ranging) point clouds.

The approach enables creating a more comprehensive view of the environment and linking data to specific time points. An illustration of the data flow is presented in next figure:

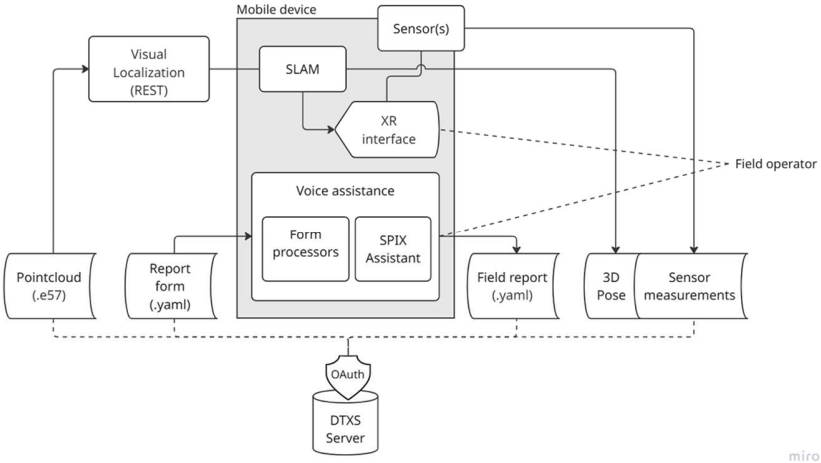


Figure 4: Illustration of data flow between the field operation and the DORADO server [1]

3.3. ALARA dose estimation tool

Digital Twin-based ALARA (As Low as Reasonably Achievable) dose estimation tool uses 3D simulation model to assess radiation dose in hazardous environments. The development work in the DORADO project aims to enable simulating robotic missions by exchanging data between the physics engine used for VRDose ® platform [26], developed by IFE, with ROS2 (Robot Operating System 2). Moreover, the ALARA planning tool (developed by SCK-CEN) will be upgraded to produce more accurate and dynamic rather than static radiation assessments. This entails integrating an AI/ML (Artificial Intelligence / Machine Learning) model to track, predict, and update changes in radioactive sources, ensuring the digital twin remains accurate and identifying when new measurements are needed. By providing real-time, adaptive dose planning, the new tool improves accuracy, supports better decision-making, reduces exposure risks, and optimizes planning and resource use, leading to safer and more cost-efficient decommissioning operations. Integration to the DORADO platform also enables combining the use with other technologies, such as voice assistance.

3.4. Change detection

Current autonomous robotic platforms can perform 3D point cloud scans and photographic imaging, enabling the capture of real-world geometry for creating or updating digital models. Work is underway to extend this by integrating gamma scanning with geometric and radiological data. In DORADO, semi-automatic change detection will be introduced to compare point clouds taken at different times. AI will enhance the efficiency of detecting changes autonomously, enabling the identification of geometric deviations and the generation of heatmaps based on predefined tolerances, among other capabilities.

3.5. Voice assistance

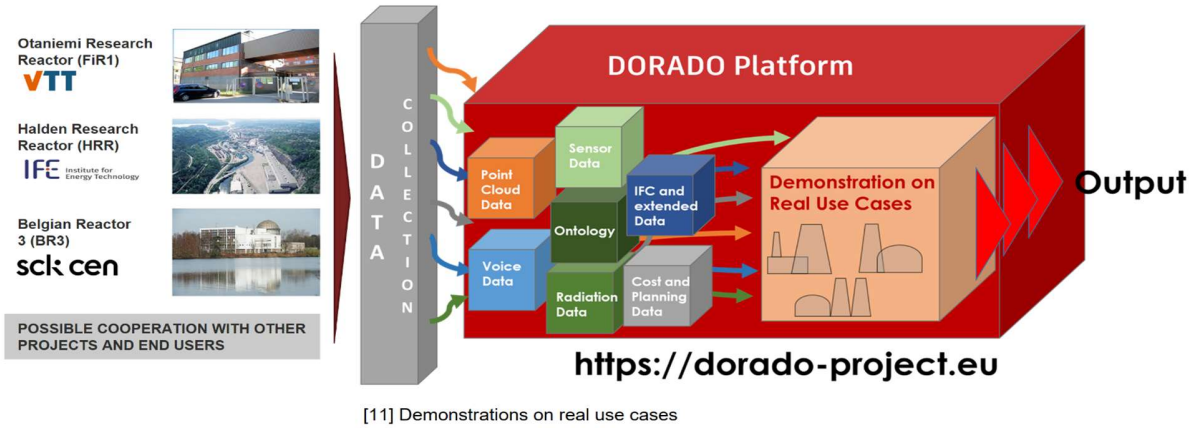
Digital technologies are still difficult for front-line workers to use, and generic voice interfaces are not yet reliable enough for operational deployment due to the lack of business-specific ontologies and integration with industry software like BIM and SSC (Systems, Structures, and Components). In DORADO, voice assistance developed by SPIX Industry will be linked to an ontology database to improve field report generation, traceability, and workplace safety, particularly in hostile environments where PPE is required. Demonstrations will show workers using voice commands to report discrepancies between BIM or SSC models and real-world observations, as well as to instantly log the status or failures of items. Recognition will combine voice tags, optical identification, OCR (Optical Character Recognition) from images, and spatial orientation. Integrating voice assistance to the DORADO platform enables wider use, since it can be used in combination with dose assessment and sensor data mapping tools.

3.6. Robot mission control

In decommissioning, mission control and robot route optimization currently lack ontology-based planning, limiting semantic understanding, knowledge representation, and the effective use of diverse robotic platforms. This results in suboptimal task allocation and reduced adaptability to changing site conditions. DORADO addresses this by using ontological knowledge representation to model spatial relationships and dependencies, enabling context-aware mission planning and dynamic task allocation across a heterogeneous fleet of robots with varying mobility, sensors, and payload capacities. The system incorporates real-time worker safety monitoring and risk assessment through sensory data, semantic mapping, and AI to detect and mitigate hazards. High-level mission planning in a visual BIM environment allows intuitive waypoint and scanpoint definition, which can be transferred into detailed technical planning.

4. Demonstration on real use cases

In the WP4, technologies will be linked to demonstrations using data from real use cases. The DORADO platform will use different data formats as point clouds, historical photogrammetry, dose rate survey, 3D models, robot data as LiDAR, RGB-D (Red Green Blue-Depth), SLAM, inventory data, etc. This data may come from the Halden Research Reactor (HRR) in Norway, the Otaniemi Research Reactor (FiR1) in Finland, and the Belgian Reactor 3 (BR3) in Belgium, among others. Further data like dose rate mapping and spectrometry is being collected or completed, in particular from the XS-Ability project [24], aiming at extending robotics and radiological sensors integration.



[11] Demonstrations on real use cases

Figure 5. Demonstrations on real use cases [10]

Next demonstrations will be performed: Creation of a parametric 3D model; Detecting the changes in the 3D models over time; Comparison of plans vs. reality; Decommissioning safety and risk/hazards assessment. Although they are defined separately and independently, they can partially benefit from the data from other demonstration cases.

The technical development will be demonstrated with four use case scenarios:

1. Intelligent mission planning and BIM integration. In this scenario, a high-level mission plan for surveying part of a legacy nuclear facility is transformed into detailed robotic and manual tasks using ontology-based reasoning. These tasks are visualized within an existing BIM model, or alternatively, robots equipped with LiDAR or handheld scanners generate spatial data if the BIM is missing or outdated. SLAM algorithms assist with real-time navigation and map generation, while radiation simulation tools use the point cloud data to highlight safety-relevant areas. Voice-assisted annotations enrich the semantic understanding of the site. This use case reduces human exposure and improves survey efficiency.
2. Precise scan localization and detecting changes over time. Multiple point cloud scans captured from different viewpoints are registered using advanced mapping techniques, ensuring spatial consistency. The platform compares current and historical scans to detect structural or environmental changes, such as equipment removal, unexpected object placement, or abnormal radiation levels. These changes are categorized using the ontology, allowing for meaningful analysis within the context of the facility's configuration. This enables ongoing, automated monitoring with minimal manual oversight.
3. Ontology-driven reporting and AI-enhanced hazard assessment. Personnel can generate detailed reports using voice assistance, and the platform cross-references these inputs with the BIM data to ensure accuracy and identify inconsistencies. AI algorithms assess the risk of hazards based on known facility conditions and component data. If risks or data gaps are detected, robots can be remotely directed to collect additional information through inspections or radiation scans. This process streamlines reporting, ensures consistent documentation, and introduces a proactive layer of safety evaluation.
4. Autonomous monitoring of nuclear waste drums stored within the facility. Robots are deployed to predefined or optimally selected scan points to measure radiation levels and assess drum integrity. These readings are compared to expected values derived from BIM and ontology-informed data. Significant deviations trigger alerts for further investigation. This approach reduces the need for manual inspections in hazardous areas and enables early detection of potential issues with waste containment.

5. END-USERS GROUP INTERACTION

The DORADO Consortium is inviting all interested stakeholders in Nuclear Decommissioning Projects to join the End-users group of the project. They can be operators, regulators, technological experts, or any other interested Stakeholders. End users are invited to follow the project via webinars, newsletters and other publications.

The value for the end users is the opportunity to increase their understanding on each technology and hence, gain a better understanding on how these technologies can be used in their own business. This may include the use of the technologies, benefits, applications, and many other aspects in order to support Nuclear Decommissioning Projects (NDPs).

6. CONCLUSIONS

The DORADO platform is continuing and improving a part of the work that was previously achieved in PLEIADES by integrating more technologies to the server and extending the ontology for new applications. From a holistic approach, these technologies emphasize, among others, the use of BIM and AI by taking care of data compatibility. The work developed in DORADO may benefit from experiences in other fields of industry where the level of implementation of digital technologies is higher. New members are welcomed to the users group in order to join forces and create and added value.

7. ACKNOWLEDGEMENTS

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The authors also thank the Spanish Nuclear Society (SNE) for this opportunity to present DORADO in the 51st Annual Meeting of the SNE in Cáceres. The activities and the results of the DORADO project will be very beneficial for the different stakeholders working in projects related to nuclear decommissioning and other transversal areas.

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