

Model-based system engineering, an industrialization path for decommissioning projects by ASSYSTEM

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Abstract. Dismantling projects (dismantling of the high activity tanks of the UP1 plant, treatment of residual sodium from the Rapsodie facility, recovery of bitumen drums from the STEL Marcoule case-mates, ...) are complex because of budgets constraints, no return on investment, and characterized by an environment with great uncertainty (NEA OCDE, The decommissioning and dismantling of nuclear facilities, status, approaches, challenges 2020 [1]). This is particularly true for fuel cycle facilities, which are mainly all first-of-a-kind; but it is also valid for commercial NPP (notably on the budget constraints). The main challenges are to (i) conciliate the cost control & risks of uncertainties due to technical subjects, which is the hard skills of the system, and (ii) manage the interfaces between the product owner, engineering, technology provider, operators, & regulators, which is the soft skills of the system. These projects do not progress as much as everyone would like, with a reluctance to move into execution, stuck into several “rounds” of re-engineering studies leading to additional delays and costs. It is necessary to treat the subject as a complex system. The DEMOLOGIST suite is one answer that we implemented to treat these complex projects as systems by deploying a method based on system engineering management of data while developing adapted digital plug-in software to collect, organize and harmonize the data at every stage (archives, regulators requirements, field operations) to feed the method. This is notably the case on a project aiming at studying the best option to deal with sodium management in France.

1 Introduction

1.1 Context of decommissioning and legacy management projects

A common characteristic of legacy sites is that their “initial stage”, meaning their radiological characterization, is broadly unknown because records have been lost, former site operators with knowledge of the sites are unavailable, and/or site owners have changed. On top of these poorly characterized chemical and physical hazards and other operational challenges may also appear over time. Among the most impacting ones, we can mention the increasing cost of regulatory constraints. Decommissioning a facility often comes with significant challenges, in direct relation to their ages:

- inadequate storage facilities:
 - both in volume and in capacity to deal with a new type of waste to be managed
 - aging, up to 50 years or even longer
- large and uncertain inventories
- miscellaneous material conditions

- working conditions range from difficult to extremely challenging
- extended time for hazard reduction:
 - complex tasks required to remove or recover wastes in a safe manner
 - variable confidence in the schedule.

Current legacy-related challenges include:

- legacy ponds and silos
- old waste drums.

Many decommissioning projects are delayed by several years due to a lack of adequate planning and management infrastructure, inevitably leading to increased costs. In such situations, funds usually set up for decommissioning are spent to maintain the facility in an “on hold” state depleting the financial resources required to terminate the project.

“Design and build” and/or also “design, build and operate” contracts are commonly used in this market. For projects facing important uncertainties, commercial risks can be limited by separating design from implementation.

The feedback around success factors is numerous in the literature. Key parameters to address the improvement of decommissioning contracts are:

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- a good understanding of the work as a contribution to risk management
- the development of the safety culture including through the deployment of daily “safety minute” for operators
- planning
- client contribution
- staff competence and training
- important project management lessons were:
 - encourage best use of client/contractor skills
 - establish performance monitors
 - regular management audits
 - full documentation of records.

In this context, the role of the supply chain, and in particular of engineering, is to define solutions that enable us to make progress in the management of risks and, where possible, to achieve economies of scale through industrialization.

1.2 Role and place of engineering

To control the risk of complex and lengthy decommissioning projects, it appears necessary to have the appropriate technical skills in all engineering fields such as mechanics, ventilation, and processes. However, although this is a necessary condition, it is not sufficient. For evidence, the conventional engineering development cycles are too linear to accommodate the uncertainties inherent to decommissioning and waste retrieval projects, leading to costly problems detection.

The mastery of complex projects over long periods requires the management of data and requirements over time, the ability to trace their evolution, and to make choices. It is in this context that ASSYSTEM has developed the digital suite DEMOLOGIST relying on:

- The implementation of the model-based system-engineering method
- The development of digital software to recover, analyze and make reliable data across the whole project.

2 Project management methodology based on systems engineering

Lessons learned have shown that instability in requirement definition and/or management is a major, if not the main root cause of scope creep on projects that are complex because each time a requirement is altered, it affects the technical baseline and likely the project baseline as well. The change of the requirements will often have cost, schedule, and risk exposure concerns that must be addressed. It is always beneficial to perform a cost, schedule, and technical impact analysis on any proposed change before committing to an engineering and/or contract change proposal. Any captured risks that are affected, or new or secondary risks that are created, must be noted in the risk registry. For example, if the technical complexity is increased, this will pose a direct risk to the cost and schedule baselines. In addition, the more the requirement changes come late in the project life cycle, the more it

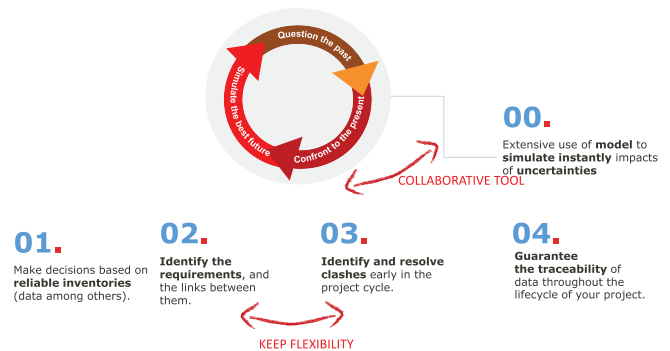


Fig. 1. Decision-making process.

will negatively affect the cost and schedule risk. The first challenge is to strongly build the decision-making process (Fig. 1).

The fact is that sequential engineering methods based on documents are no longer sufficient, each change requires starting from the beginning and going through each step of the process.

3 What system engineering does?

System engineering is a method, a way to organize the project. It allows to:

- Keep the objective to keep linking the requirements with the design $\Rightarrow$ define the set of desired outcomes and justify decisions
- Involve the strategic partnerships $\Rightarrow$ collective intelligence – bringing stakeholders together around a tool: product owner, engineering workforces & operators
- Define the problem before hypothesizing a solution, which allows to identify several alternatives and choose the most appropriate solution $\Rightarrow$ represent and divide the problem into several parts “A picture is worth a thousand words”
- Manage the interfaces between the parts $\Rightarrow$ “The devil is on the interfaces”
- Help large teams to collaborate and manage changes $\Rightarrow$ delay choices on technology as much as possible so as not to impose a technology that would block the system
- Manage complexity through models – test early, test often $\Rightarrow$ interface modeling allows you to test whether the system has solutions and to identify blockages due to excess or conflicting requirements.

System engineering appears essential in identifying technical risks, managing and deriving requirements, aligning the technical baseline with the project baseline, deriving the system architecture framework, and translating technical issues into actionable business cases that the project manager can use to make critical business decisions.

The mastery of complex projects over long periods requires the management of data and requirements over time, the ability to trace their evolution, and to make choices.

It is in this context that ASSYSTEM has developed the digital suite DEMOLOGIST (Fig. 2) relying on:

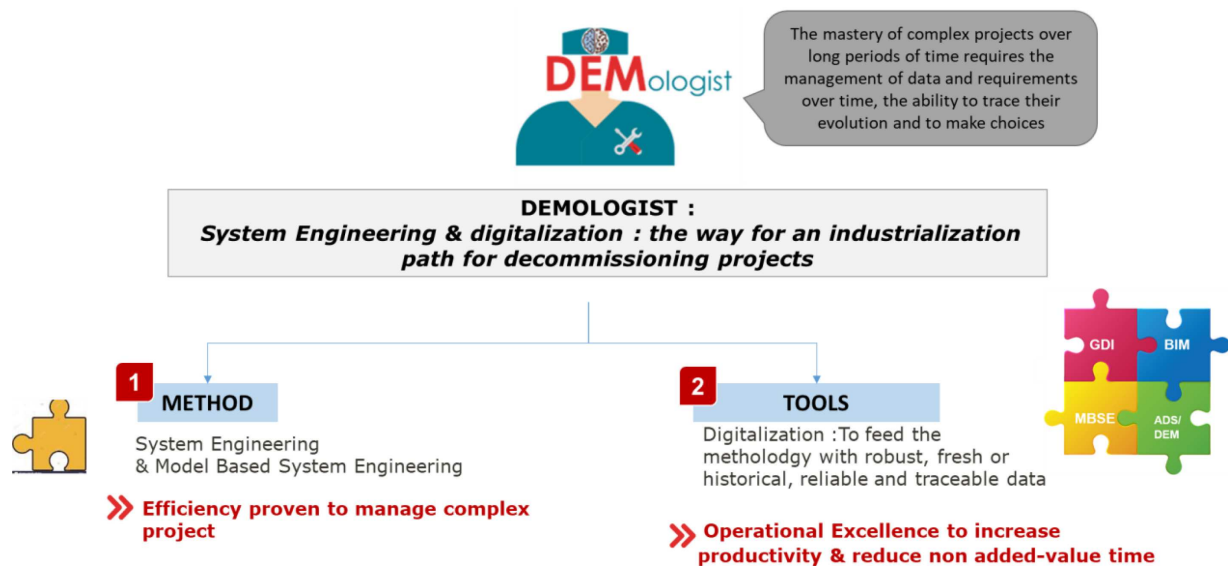


Fig. 2. DEMOLOGIST principle.

- The implementation of the Model-Based System Engineering (MBSE) methodology, which has proven its ability to deal with complex projects in space sector, notably by the NASA
- The development of digital tools is able to recover, analyze and make reliable data across the whole project. These tools, developed for and with users, will allow to feed the methodology with robust, fresh or historical, reliable, and traceable data while contributing to Operational Excellence to increase productivity & reduce non-added-value time

Figure 2 – Puzzle legend:

- GDI: Global Direct Inquire; an AI-based software fully engineered by ASSYSTEM acting like Google, but indexed with project-related engineering documentation
- BIM: Building Information Model
- MBSE/Model-Based System Engineering
- ADS-DEM: software fully engineered by ASSYSTEM aiming at defining the best decommissioning scenario.

4 MBSE methodology

Based on requirements, among other considerations, this methodology ensures that the identified requirements are documented and written in such a manner that they can be verified and validated.

From our experience, the design of a facility in the context of dismantling and legacy waste retrieval is based on three factors:

- Firstly, the synthesis of complex input data spread over documents, their compilation, and follow-up during project development phases, without any loss of information, redundancy, or ambiguity,
- Secondly, the definition of a structured, traced, and ordered requirements referential to facilitate safety and compliance demonstrations,

- Thirdly, the identification of all the functions of the facility, and in particular the interfaces and flows to optimize the layout of the facility housing the process.

To achieve all these objectives and enables all the players to be brought together around a decision tool ASSYSTEM is using model-based system engineering methods in order to:

- Rationalize the needs of the project owner,
- Identify data and requirements throughout the life of the project. In design phase, the management of the requirements is placed at the heart of the design and used to guide its development, assess its progress and progressively validate it.
- Adapt the architecture of the solution
- Manage its optimization through a quick and self-coherent follow-up of modifications.

Model-Based Systems Engineering is the formalized application of modeling to support system requirements, design, analysis, verification and validation, beginning in the conceptual design phase and continuing throughout development and later life cycle phases [3]. MBSE is known as a standard method in other industries (aeronautics, defense, etc.) and can be adapted to meet the specificities of the nuclear industry.

As a leading engineering company in nuclear, we always implement MBSE methodology starting from processes, needs, and practices in a very pragmatic way based on existing tools such as the open-source model Capella [2,4].

Modeling allows the relationships between the different elements of the projects to be described (actors, interfaces, sub-systems, processes, etc.) and all the requirements to be structured at different levels of abstraction (from the needs down to the solution) and over the entire project lifetime that can be particularly long in the context of dismantling. The approach can be deployed partially or

over the entire project scope, depending on its progress and priorities.

The strength of modeling lies in the fact that it links data together, which implies being able to manage the resulting cascades of changes and analyze the consequences quickly.

5 Feed of the method by digital tools

In addition to that, one of the key features of DEMOLOGIST is relying on digital software specially developed to manage and work around data at different stages of the project (Fig. 3), not only for design but also at the operator levels.

Capture data from the archives: ASSYSTEM has developed a solution called Global Data Inquire (GDI), able to read, understand and structure disparate and scattered data in technical archives including handwritten.

This solution, based on optical character recognition and artificial intelligence processing, allows to build-up a set of ordered data, whereas a human analysis would focus on a limited number of documents.

Capture the requirements: the Rectify tool can capture the requirements from technical documents and is used to manage the requirements among the projects.

Capture data from the field: dismantling projects will last between 10 and 50 years and will generate a significant volume of data. The intermittent nature of decommissioning projects requires monitoring facility data to adjust the scenario as needed.

Data coming from the operations: ASSYSTEM developed a solution to monitor data coming from the operation. This module called “Field Studio” eases the dematerialization of on-site activities. The stakes are clear: save time, secure data, and reliability.

Data coming from BIM or scan to BIM

Data coming from scenario: ASSYSTEM compiles its technical background on dismantling and a new facility for waste retrieval in a digital application called ADS-DEM which is a tool to evaluate and optimize cost. This tool allows qualifying and quantifying the impact of the choices, on waste, costs, safety, or deadlines and supports the demonstration of the design choices to the safety authorities.

All these data are structured and then coupled into a digital twin [5] which becomes the nerve center of the project data and facilitates the configuration management.

6 Use cases

6.1 Design study for a sorting and conditioning facility for low- and medium-radioactive waste

As already said, managing requirements is considered a key success factor for the project. The definition of the

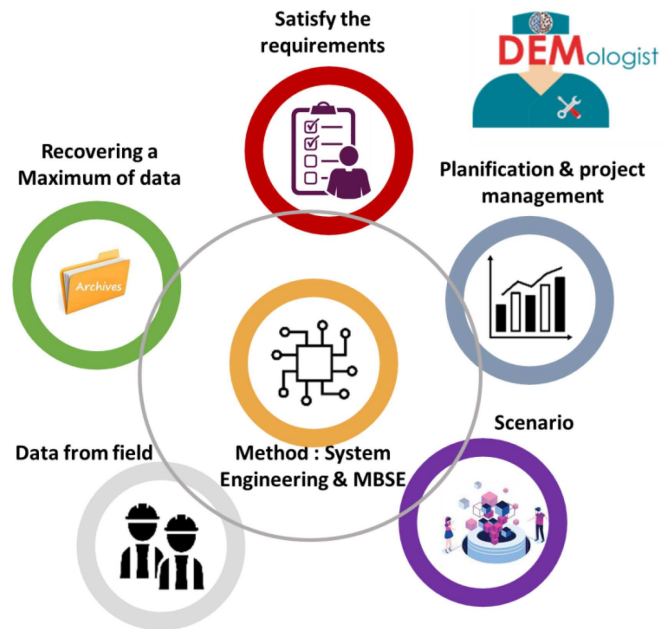


Fig. 3. Digital tools feeding the engineering method.

Stakeholder Needs and Requirements is key, and it is the reason why the MBSE is very useful to drive the project.

A referential of all the requirements have been created (Fig. 4). Then these requirements are specified by means of attributes to distinguish functional, safety, or operational requirements. At the design stage, technical costs are defined to satisfy the required performance. These provisions are described in the engineering documents which provide the justification for their correct integration into the design.

These requirements referential is successively used to feed the design, assess its maturity and evaluate its progress through reviews or indicators provided by the requirements management tool.

The benefits of modeling are numerous:

- A structured view with links helps manage traceability
- A centralized, structured, synthetic glossary
- Visual support for configuration definition
- Different views complete in one model: several focuses but global consistency
- A model, which can be used as the reference for marketing data and can be completed to drive decisions (cost, risk, ...).

In addition to requirements management, system modeling, when implemented, supports the animation and efficiency of design. Indeed, correlated with functional breakdowns, it is possible to highlight the functional chains of a process required. Associated with a geographical breakdown and a layout of the facility, this type of modeling offers support to explain the organization of the facility and its operation. This type of support (Fig. 5) is used to share information within the project team as well as for the appropriation of the facility and its operation by the design actors (e.g. exchanges between technical and safety teams) or for the animation of reviews.

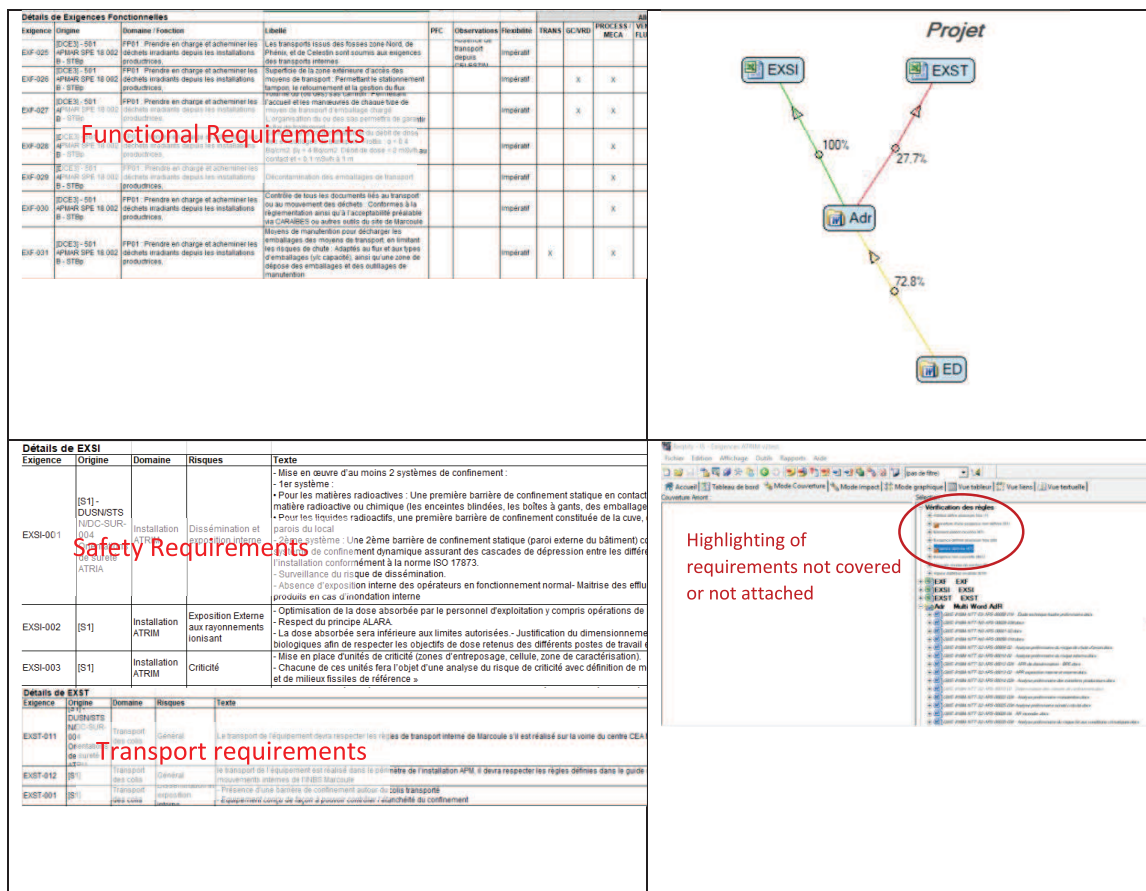


Fig. 4. Examples of baseline and requirements management indicators.

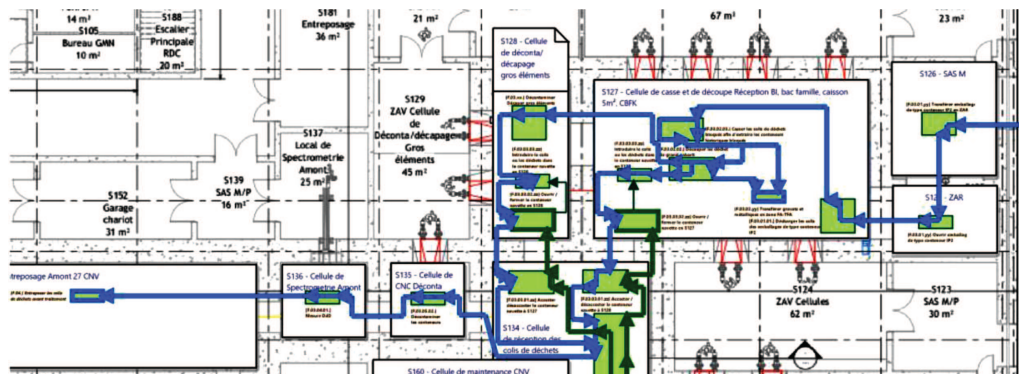


Fig. 5. Geographical and functional representation of the facility with, highlighted, the optimum path for the waste to be produced depending on some criteria such as nature, flow, radiological characteristics.

6.2 Digital twin for the operation & maintenance of facilities under decommissioning

This project consists of creating a digital twin to boost and simplify the monitoring of the operation and maintenance of a nuclear facility under decommissioning. This digital twin is composed of interconnected micro-services, with the objective to:

- Contribute to operational excellence in the preparation, supervision, and monitoring of operations at the facility,

- Improve the traceability/quality/reliability of data acquired at the work site, their exploitation, and their diffusion,
- Increase productivity.

The originality and success of the development of the digital twin lie in the understanding of the business processes of the operations on one hand and the knowledge and capacity to develop or adapt digital tools on the other. This digital twin was developed based on a combination

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Fig. 6. Extract from the Field Studio tool – summary view of the visits carried out and in this case the findings made.

of software bricks, workflow modeling methodology, and business expertise (nuclear and digital).

In addition, the digital twin allows the operator to:

- Define the bricks of the facility being dismantled
- Bring together all the players (owner, industrial operators) around a shared collaborative space that allows access to the data acquired on-site.

After six months of using the digital twin, it has been shown that the automatic generation of reports reduces the duration of field visits, inspections, and inventories by a factor of 2 to 2.5. For inventories, this is an order of magnitude that depends on the completeness and complexity of the inventory. For inspection operations, the duration is effectively reduced by a factor of 2. For monitoring visits, the time spent on site is multiplied by 2. These orders of magnitude are valid for all types of work sites.

Other potential gains are emerging, including

The shared and collaborative space. The digital twin allows bringing together ASSYSTEM, the customer, and the operator around the same tool. Although difficult to evaluate in terms of quantitative gains, everyone knows that one of the major difficulties of projects lies in the management of interfaces and the capitalization of information.

The contribution to operational excellence

- Configuration control for the preparation of operations: configuration control is achieved when the operator anticipates and plans for future documentary changes (based on the planned physical changes to the facility). For a facility undergoing dismantling which, by nature, is constantly changing, this is a major challenge.
- Optimizing the monitoring of operations: progress and organization of operations, monitoring of operational findings (Fig. 6), etc.,
- Planning management: control of deadlines, anticipation of risks, and mitigation of causes (prevention) rather than limitation of consequences (correction).

- Productivity improvement including:
 - Control of waste produced: in a decommissioning facility, most of the operations lead to the production of nuclear waste. Controlling the waste produced includes
 - The inventory of waste produced: typology, volume,
 - Compliance of packages with specifications.

Gain in quality, traceability, and reliability

Reconstituting the facility's operating documentation: the documentation and associated processes were designed and structured according to the reference system at that time. The search for the best possible level of safety, regarding the techniques and knowledge at that time, requires restructuring and reverse engineering in the middle of the operation and dismantling phase.

Keep the operating documentation repository up to date and consistent with the physical state of the facility in the context of configuration control:

- Centralizing and securing the operational data acquired, as well as the flows of dissemination and use of this data, in the context of monitoring operations, reinforcing Safety & Security, managing the planning and controlling the waste produced (see below).
- Through in addition, it allows the improvement of the robustness of processes, by reducing the possibility of errors and by improving the quality, traceability, and processing time of information.
- Reinforcement of safety and security: acquisition and capitalization of weak signals (Fig. 7), monitoring, under the Quality Order of 10 August 1984, of compliance with the safety requirements set out in the standard.

7 Conclusion

The challenge concerning the dismantling & waste management project is to answer the complexity while derisk-

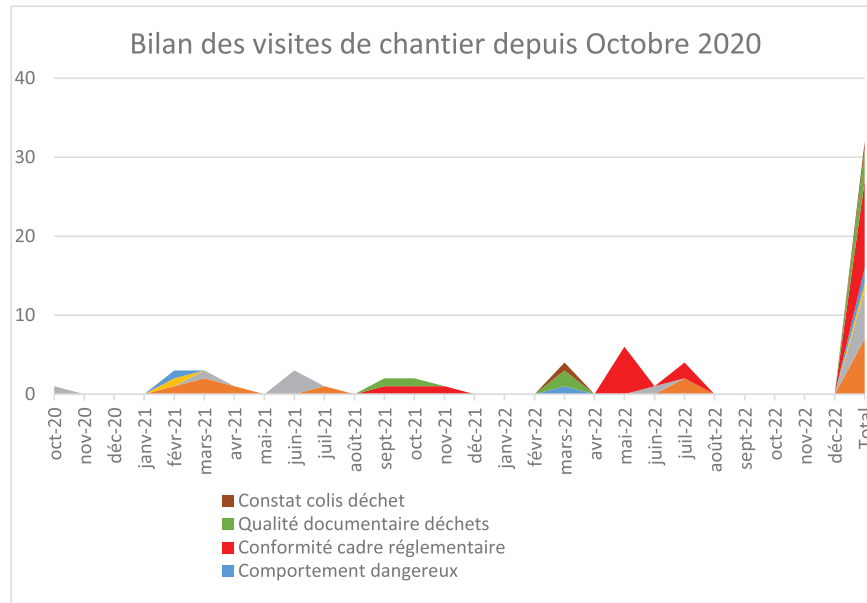


Fig. 7. Example of indicators from monitoring visits carried out with the Field Studio tool listing the weak signals acquired during dismantling operations at CEA Marcoule (average of 20 monitoring visits per month).

ing the operations. Firstly, there are challenges based on technical subjects such as the incomplete initial state, radiological, physical, regulatory requirements, availability and maturity of technologies, and skills that we could compare to hard skills.

However, there are also challenges due to the organization & management of the interfaces between all the stakeholders, the product owner, engineering, technology provider, operators, & regulators, and sometimes the final disposal operators what we could compare to soft skills.

Unfortunately, engineering is solicited on a case-by-case basis to produce studies. Engineering companies produce good studies, but we all know that the projects do not progress as much as everyone would like, with a reluctance to move the projects into execution. Engineering must play the role of integration through the development of tools that allow to do so and to maintain the vision and the overall coherence of the project; this is the goal of the DEMOLOGIST digital suite, which will be regularly enriched with new developments able to industrialize dismantling, and waste management projects activities.

Conflict of interests

The authors declare that they have no competing interests to report.

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Data availability statement

This article has no associated data generated.

Author contribution statement

Olivier and Christine established the general concept based on the acquired experience, Pauline, Mihaela, and Brice specified, tested, and implemented the concept in their activities.

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