A contribution to Commissioning as enabler of nuclear infrastructure delivery: Tests and trials program elaboration and management

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Conference Paper · October 2020

DOI: 10.1109/ISSE49799.2020.9272027

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***Abstract*— This paper proposes a new methodology to conduct commissioning activities for Basic Nuclear Facility (BNF) based on the implementation of a Model Based System Engineering (MBSE) approach coupled with theoretical foundations concerning the commissioning processes and the feedback of experience inherited from previous projects.**

The methodology illustrates the benefits of the MBSE to take into account the interfaces between the stakeholders, the building, equipment and processes and the different constraints related to the type of facility (safety and security requirements).

The methodology is supported by two industrial nuclear projects and has allowed the elaboration of an innovative tests and trials program that will open the route to the early V&V applications that turn into a significant reduction of extra costs occurring in the case of commissioning projects.

Keywords— Commissioning, MBSE, Nuclear facility, Model, Test, Trial, Validation, Verification, Integration, Qualification

I. INTRODUCTION

« In its simplest form, commissioning is the confirmation that an installed system functions as per its requirements ». This confirmation consists in proofs results and justifications allowing to demonstrate that the system meets the requirements. For this purpose, commissioning requests to prepare then manage various activities involving both business and technical resources, and to provide, share and manage multiple data, information and knowledge from different streams. It is hereafter question of commissioning in nuclear field, focusing particularly on operation, performance, safety, and security requirements [16], [18]. Indeed, commissioning must assume the respect of different safety and security criteria required to authorize the running of a Basic Nuclear Facility (BNF) by the safety authorities (e.g. French Nuclear Safety Authority NSA

Commissioning must therefore deal with several factors of complexity related to the BNF [16], to the multiplicity and heterogeneity of concerned domains (civil engineering, mechanical engineering, HVAC, computer sciences, electronical, automation and control command engineering, etc.). In addition, it must consider the multiple interactions that have to be managed all along the commissioning between the stakeholders, each one having eventually a specific vocabulary for each stream involved. Particularly, the exchange, traceability, consistency and availability of data, information and knowledge between these stakeholders is crucial to allow and facilitate these interactions. So, interoperability at different levels (processes, activities, data, and tools) is of a great relevance. Finally, commissioning must evolve in a dependent manner and be fed with the results of the activities that are part of the engineering processes.

This article introduces the basis of a methodology aiming first, to guide the preparation, to manage and to control commissioning activities that are from various natures and often common with other processes. Second, it aims then to promote, formalize, trust and trace results expected for a given BNF commissioning. Third, this methodology must allow reducing the costs and timelines of these activities. To do so, we will first introduce this methodology and the scientific approach used to establish it. Secondly, we will describe the two projects that have been studied and used as a basis for this work, third we will present how the commissioning is developed on those projects and which issues were observed. Finally, we will focus on how the methodology presented here has been used on those projects and what findings can be established.

II. SCIENTIFIC APPROACH

A. *Scientific approach and working hypotheses*

To elaborate this methodology, the scientific approach used hereafter consisted to compare the elements of definition from the literature [6], [14] (top-down approach) and the background accumulated by ASSYSTEM in various commissioning projects (referred to as bottom-up approach). In this case, modelling activities are mandatories for many reasons [12] allowing key players to describe levels of abstraction of a system through various types of models. In addition, here are five principles and working hypothesis around which our reflection is based:

- This methodology implies the use of MBSE principles [5], [7] (presented above). In this case, modelling activities, are to be in accordance with system engineering practices and processes, with commissioning objectives (performance, safety and security), and considering both risks and other milestones identified on the global engineering project of the targeted BNF.

- Modelling activities must use languages and tools that allow working using a set of models that are understood by everyone involved into the project. Furthermore, these modelling means are to be consistent and compliant with commissioning concepts.

- Concerning the used tools, they will be chosen being as much as possible interoperable, then may be eventually interchanged in a specific way to manage different activities (modelling, simulating, scheduling, approving, etc.).

- Commissioning has to be considered as a whole focusing on the mission that aim to orchestrate several processes from System Engineering gaining confidence in the results all along the BNF's life cycle.

- Finally, it has to be outlined that good practices, modelling patterns and experiences inspired from previous projects are considered as knowledge resources used for eventually revisiting and enriching the methodology.

B. Bottom-up approach

Two projects are hereafter used to illustrate the scientific bottom-up approach.

The first project consists of modelling a given perimeter of an effluent treatment facility and the development of a 4D schedule for test visualization. This modelling therefore requires the interconnection of several tools for the logical as well as temporal and physical modelling of the commissioning process.

For the second project we'll first introduce the Test and Trials Program (TTP), it is hereafter defined with respect to the enterprise best practices (bottom-up approach) and information from IAEA guides (top-down approach), it is the definition and set up of all the tests and trials needed to verify and validate that the BNF functions and requirements are respected. The second project consists of the definition of a TTP and requirements management within a Molybdenum99 production project. Molybdenum-99 is a radioisotope of molybdenum. It is used in industry as a precursor to 99mTc (nuclear medicine). It is obtained by the irradiation of targets enriched in uranium235.

Among other, REX from these projects show different issues. Particularly, contract holders often plan to manufacture, program, assemble, test and complete their contracts. Doing that, they build plans according to their scope of supply and omit requested interfaces between resources. Therefore, it remains complicated even impossible to orchestrate efficiently all contract holders to work in harmony.

C. Issues

The study of these projects and literature allows us highlighting different issues:

- **Conceptual issues**:

- A shared vocabulary is needed to move towards better understanding and interoperability among stakeholders when they need to exchange and collaborate. What would then be this universal language of commissioning, at least in the nuclear field?

- Modelling is a key activity in this process. Models must be easily and quickly shared throughout the System Engineering (SE) processes all along a project. This allows the complexity factors mentioned above to be taken into account and then reported on. Which models can or should be adopted? What would be the way of proceeding (or operational approach) adequate to answer the needs of commissioning? This article will focus on needs addressing tests and trials description and formalization in TTP?

- **Technical issue**:

The business actors are inclined to use their own business tools (methodological and IT tools), while unfortunately disregarding the needs to collaborate and therefore interoperate with other business actors. What tools should be used to model, transform models, verify, analyze, simulate and trace data, information and business knowledge in increasingly complex repositories (e.g. best practice REX, modelling patterns, normative documents, ...)?

D. Methodology

Considering these investigations and issues, the proposed methodology that is summarized in Figure 1 must allow commissioning responsible to:

- Improve the coordination and the articulation of the different activities of all stakeholders involved in the commissioning.

- Orchestrate the design but also the running phase of the tests and trials:

- Establish the tests and trials needed to verify the requirements that are not always all considered (security, safety …)

- Check the wholeness and the pertinence of the tests and trials established by the system engineering processes.

- Bridge the gap between MBSE practitioners who are involved in SE processes, each focusing on own objectives (e.g. requirements engineering or architectural design of the BNF, integration or verification of the BNF). The methodology is composed of five elements schematized in Figure 1.

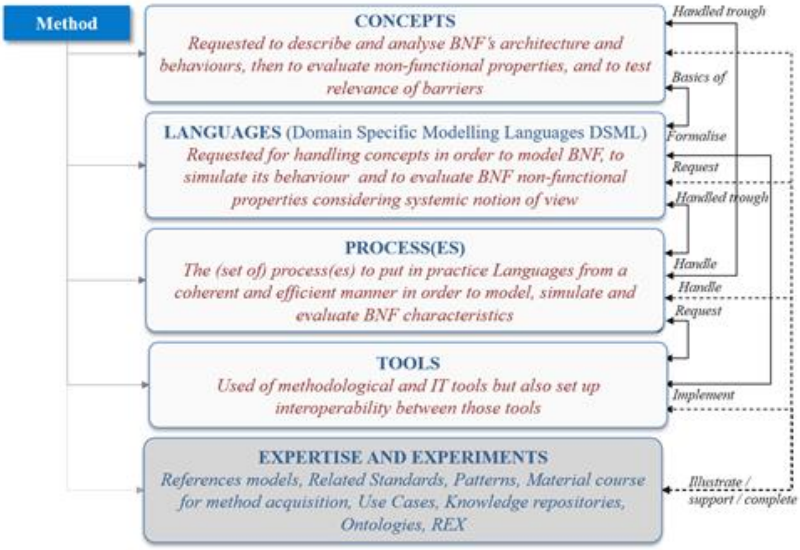

Figure 1: Methodology proposed

III. MBSE APPROACH FOR COMMISSIONING

A. Semantic data model

After we established the methodology, it is needed to setup a semantic data model [3] allowing the description of all the concepts and processes involved in the commissioning [15]. The requested concepts and relations between concepts to be handled then modelled during commissioning phases are therefore summarized in the semantic data model (Figure 2). It highlights the main concepts and relations between the commissioning project, the commissioning process and subsequent activities and entities. All those activities must be in accordance with all the stakeholders and system requirements within the planned BNF design phase. It ensures that all the concepts and processes involving different stakeholders are well defined and that the dialogue between those stakeholders become more straightforward. Thanks to this data model, the commissioning project can easily set up and orchestrate all the actions entangled in the commissioning process whether they occur during the design or the run time.

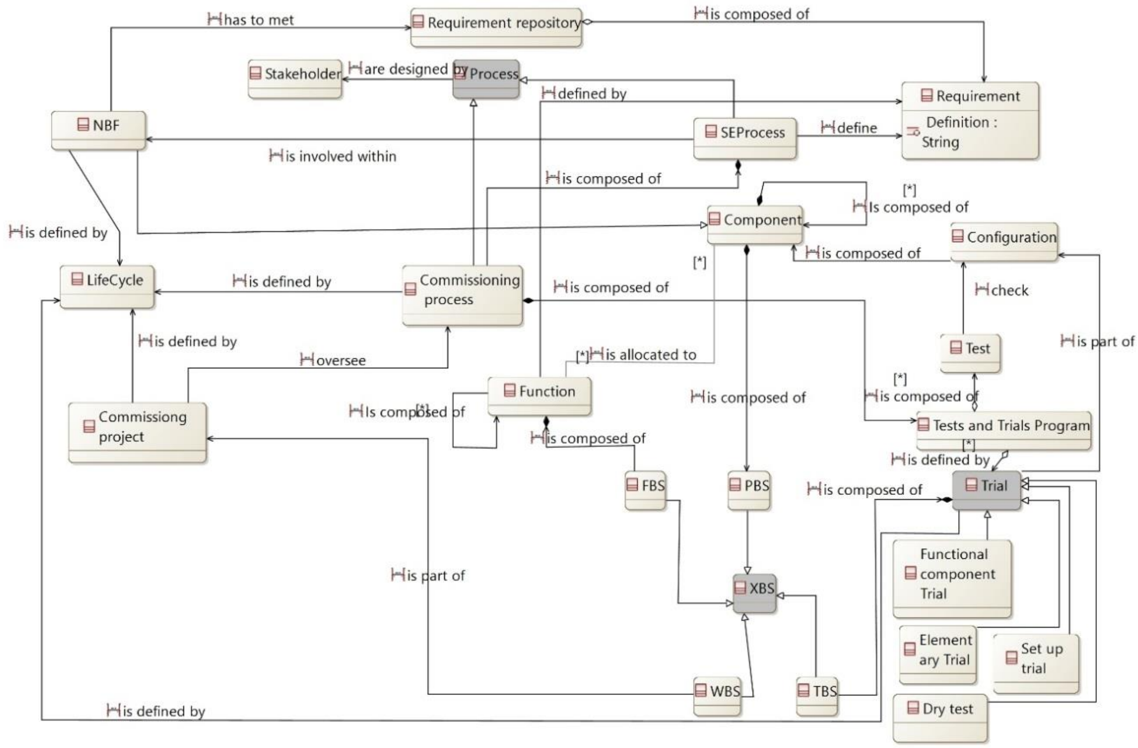

Figure 2: Semantic Data model

B. Commissioning strategy

The next phase will be related to the commissioning strategy that will be implemented. It will be organized as follows:

- the commissioning process: Commissioning process is considered as a System of Interest (SoI) [2] closely linked to the BNF itself and interacting with the SE processes.

- the commissioning project: Commissioning project is considered as a System Used To Do (SUTD) that ensures the commissioning process design and management.

The commissioning process (SoI) gains in maturity consequently and in parallel with the design progress, gaining details in modelling of the BNF. In parallel, the commissioning project (SUTD) is defined as a system of systems [8] for several reasons. Particularly, the specific business activities require autonomy in terms of decision and evolution of the teams or even of the companies that are to be involved for instance in terms of availability or skills. So, the SUTD evolves continuously due to numerous interactions and orchestration as synthesized in Figure 2. In addition, the commissioning project is characterized by a life cycle composed of two phases:

- Design phase (referred further as Commissioning Design Time - CDT): the commissioning process is defined in a first way then validated a priori by specifying commissioning activities, resources, objectives, constraints, and expectations. The CDT therefore starts at the BNF's design stage, which must feed (in terms of feasibility, regulatory, or deployment constraints, for example) and irrigate itself (in terms of needs and testing, trial, and justification activities).
- Execution phase (referred further as Commissioning Run Time - CRT): the commissioning process is then implemented and is to be adapted as needed according to the various events or situations encountered during the IVTV phase of the targeted BNF. Indeed, commissioning process encompasses the IVTV processes:
  - Integration i.e. realization, production, assembly, construction ... of the BNF;
  - Verification of this integration on an ongoing basis to ensure its quality in relation to the established design;
  - Transition to the customer (a priori partially concerned for some of the components manufactured at a separate production site and transferred for integration at the customer's site);
  - Validation with the stakeholder's representatives of the BNF development project, including the client.

All those activities related or in phase with commissioning objectives and purpose must consequently be defined then planned, considering the different schedules of all other processes (see Figure 3).

They must follow a clear commissioning strategy defined by a set of main activities listed below. For the commissioning project:

- The TTP set up i.e. Test and Trials Program to be done, expected results, and alternative solution in case of defect. This multi-trade and multi-point of view organization must therefore also highlight relations of trust which are difficult to establish on a lasting basis.
- The setup of a commissioning team with an approved distribution of roles and responsibilities.
- Milestones, reviews and stakeholders' meeting from various kinds that clock the commissioning run time;
- Establishment of the requirements which need to be tested;
- Trace the models of the NBF and enrich them for test and trial purpose;
- Define various and potential alternatives (in terms of activities and planning particularly) allowing to anticipate when possible the hazards and constraints encountered during NBF realization phase;
- Verify and validate the commissioning process elements (TTP, planning, resources availability …) by using various technics (sensibility analysis, dependence analysis and simulation.

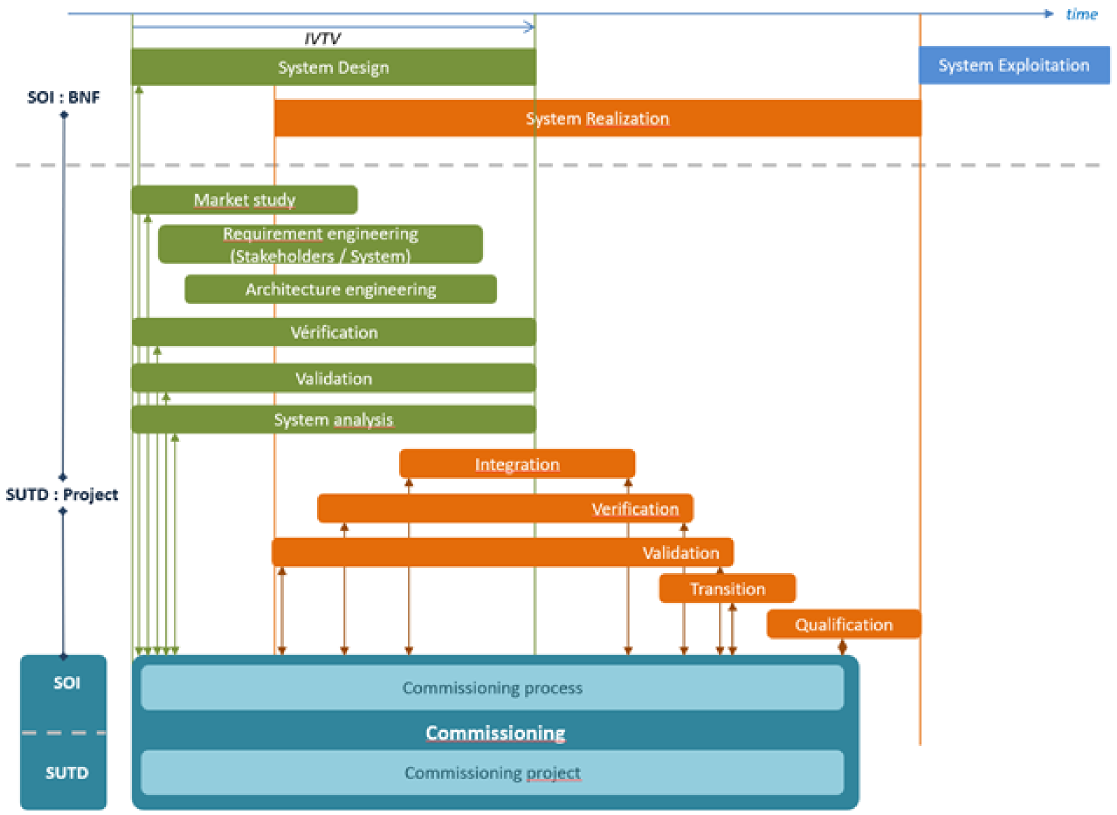

Figure 3: Commissioning: interaction and orchestration relations

For the commissioning process:
- For each test or trial:
    - The setup resources (human, material and tools) needed for the TPP realization.
    - To check the NBF configuration for each test
    - To verify that the results fit with expected ones
    - If fails, then establish corrective actions
    - Communicate results to responsible in charge of the commissioning
    - Restore NBF configuration
    - Release resources
    - To formalize the test or trial REX
- Synthetize the results
- Check of the results and of the wholeness of the TTP
- If fails, then establish corrective actions
- Communicate results to responsible in charge of the commissioning
- To formalize the TTP global REX
- of the results and of the wholeness of the TTP
- If fails, then establish corrective actions
- Communicate results to responsible in charge of the commissioning
- To formalize the TTP global REX

As stated in the main activities a commissioning organization is needed to ensure those activities orchestration. The commissioning organization is usually a composite team, consisting of Procurement and Construction Management Engineers (PMCI), but also equipment suppliers, business line managers (construction, networks, hydraulics, fluids, etc.) and a representative of the operator in the role of the client of the BNF construction project. The operation of the various components of the BNF, and of the BNF during its commissioning, is carried out by suitably trained and qualified operating personnel provided by the operating body. These personnel must in fact be integrated in the team in charge of the organization of the TTP. This multi-trade and multi-point of view organization must therefore also highlight relations of trust which are difficult to establish on a lasting basis.

C. Tests and trials program

Among these activities, let's focus in the following on the development of the Test and Trials Program (TTP). The TTP of a BNF is defined since the beginning of its design. It gathers requested tests and trial procedures that will gradually mature during the design and implementation phases. These will be finally approved a few months before use. So, it covers equipment's testing prior to on-site installation (tests and tests related to the verification before and during integration), testing of installed components and systems, and general installation testing (tests and trials related to the Functional Verification). It includes also, when its relevant, tests and trials requested for the Transition and by the BNF Validation as performed. From the point of view of its design and its piloting for the needs of the commissioning process, the TTP is jointly implemented by and with the means and professions of the project manager and the client. From the point of view of content, the tests and trials are defined here with a vision and experience from the enterprise, which is completely in line with the definition given by the IAEA [14]:

Tests Phase 0: Off-site
- Phase 0.1: At Factory, with the objective of anticipating site trials. Factory demonstration is considered to have been completed if:
    - The execution context is representative of the operating context,
    - The non-regression between the factory trial and the site is demonstrated,
    - They do not concern a functional test relevant to safety, in which case they are systematically re-run on site.
- Phase 0.2: Platform recipe, with the following objectives:
    - To minimize the time of site test by verifying the functional aspects of the platform software, the operational part of the process being simulated.
    - To validate the architecture and its behavior on incidents.

Tests Phase 1: Off-power site tests. These tests consist in verifying the correct assembly of the equipment once it is installed on site. They are often considered to be outside the scope of the TTP, as evidence is collected during construction and assembly operations.

Tests Phase 2 tests: Functional tests.
- Phase 2.1: Basic or integration tests:
    - Energy upgrades.
    - Software loading.
    - Synchronizations and instrumentation.
    - Elementary and unit tests.
    - Dismantling tests - maintainability.
    - Tests of blank automatisms.
- Phase 2.2: Testing of functional assemblies:
    - Verification of operation in normal mode
    - Verification of operation in degraded mode.

Tests Phase 3: Overall tests in inactive mode

These tests must make it possible to check the simultaneous operation of all the units constituting the installation in normal and degraded operation and the performance of the installation.
- Phase 3.1: reaction to general incidents, verification of the behavior of the installation to general incidents:
    - Loss of electricity.
    - Loss of utilities (compressed air, raw water, etc.).
- Phase 3.2: performance tests in idle mode:
    - Overall operation of the installation and all systems and functionalities;
    - Processable product flows.

After this, it is envisaged to model the tests and trials that make up the TTP.

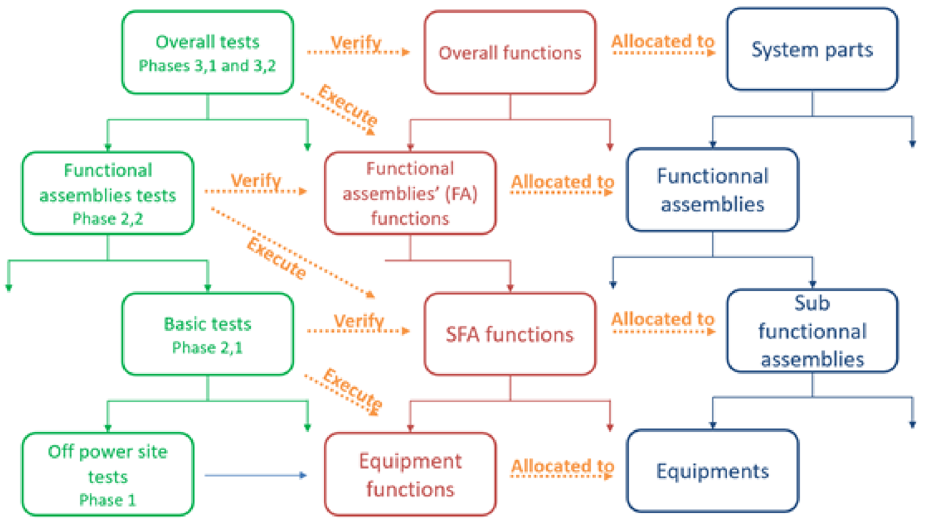

Figure 4: Links and relations between the three breakdown structures

A tree structure is proposed in parallel of the two XBS (namely Functional Breakdown Structure (FBS) and Product Breakdown Structure (PBS)), both results of the BNF design. Figure 4 defines the logical links between these trees. We decided to link the tests tree elements with the functional one, indeed we defined the tests as the execution of subfunctions that will ensure the proof that the function composed of those subfunctions is verified. Thanks to the semantic model and the tree structure established above and the model of the NBF, the tests and trials models can now be built and will be briefly illustrated in the following part.

IV. Modelling examples

The two projects previously and briefly presented where not fully in phase with MBSE expectations, principles and practices, particularly concerning modelling and models handling activities. As stated as a working hypothesis, the proposed methodology aims to follow these principles. It requests to promote the role and relevance of various models. For both projects, we then demonstrated the benefits of the MBSE approach that has structured both the commissioning processes and the commissioning project as well as the different interfaces exhibited. This has been used to improve the communication of the various stakeholders and to make easier the setting up of tests and trials allowing the validation of the requirements. More precisely, the first project made it possible to insist on the necessary interoperability of various tools (for modelling but also for project monitoring, etc.) when the second project has been used to validate the elaboration and management of the Tests and Trials program.

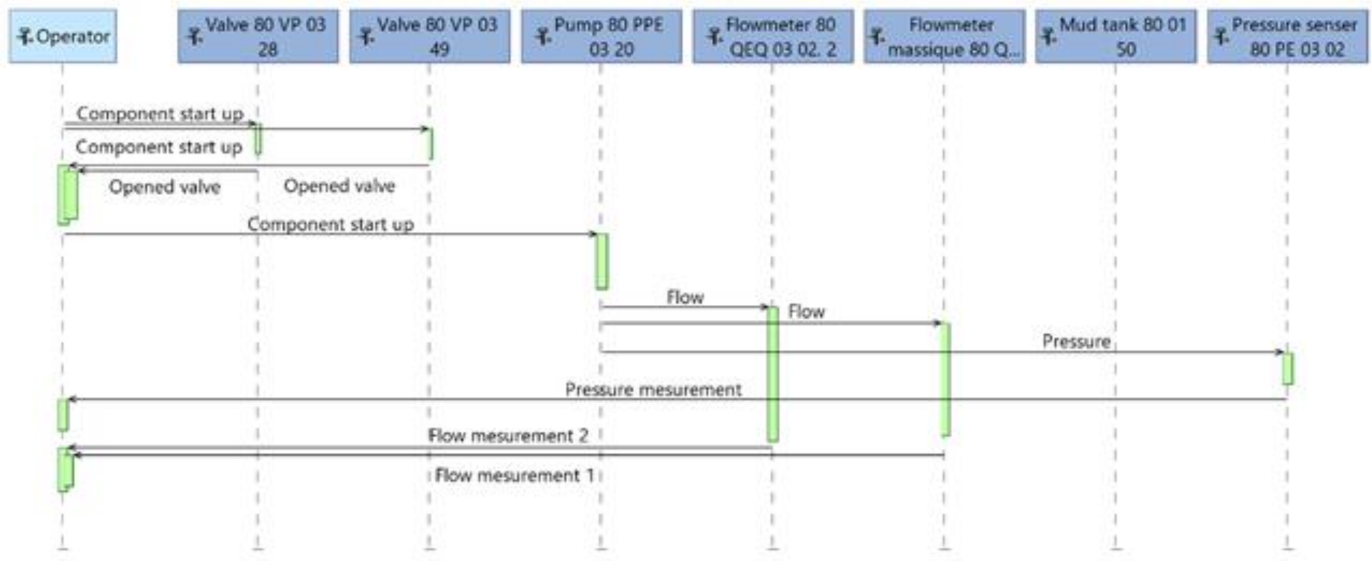

Figure 5: Test scenario model

Figure 5 illustrates the modeling of one trial, as we can see it shows the functions executed, the stakeholders and the components involved in the trial. Thanks to this modeling process, it has therefore been easier to set up the test in its environment. It is important to notice that whether it concerns overall or basic tests, this modelling process ensure the traceability of information and a better understanding of the test process for all the stakeholders involved.

V. Conclusion and perspectives

This paper presents a methodology encompassing the MBSE approach coupled with theoretical requirements concerning commissioning and feedback of experience coming from ASSYSTEM background on previous commissioning projects in the field of nuclear.

The System modeling approach is allowing to aggregate different solutions to accommodate with the legacy of the facility owner and to integrate the commissioning phase in the whole life cycle of the Nuclear Facility. This will facilitate the interface modelling, the traceability of changes, the introduction of commissioning requirements at the design phase to anticipate potential issues.

The approach proposed is supported through two industrial projects in the nuclear field.

The MBSE and the data model that has been built translated into the elaboration of an innovative tests and trials program. It constitutes a part of a broader commissioning methodology to be proposed, as well as an enabler for significant value. This methodology will open the route to the early V&V [9] applications that are very important in the context of improvement [4] of the project delivery and commissioning activities. It may imply a digital twin establishment, in order to optimize the implementation of relevant processes.

More data and results will be shared during the conference and included in the extended version of this paper.

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