THE DIGITAL TWIN IN THE NUCLEAR INDUSTRY

AN INTRODUCTION TO ITS USES AND FUNCTIONALITIES:
OPPORTUNITIES AND CHALLENGES
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Executive Summary

Scope.
The objective of this white paper is to present a definition of what we understand at Tecnatom by the term digital twin, analyzing the current context and the different functionalities that it may present for operating nuclear power plants.

Digitalisation.
We are currently immersed in a technological revolution that is changing our way of working, with the goal to increasing productivity and efficiency. In the nuclear field, Digitalisation is key to achieving greater competitiveness and efficiency. Tecnatom offers its clients solutions that improve understanding of the status of the plant and its facilities, providing a better situational awareness, helping to reduce human error and improving safety. We are experts in developing solutions responding to specific challenges and needs arising from the operation of nuclear power plants.

Digital Twin.
Tecnatom’s know-how and experience allow the company to act as a preferential partner in the development, implementation, and operation of a digital twin. Specifically, Tecnatom accompanies the client, contributing value thanks to:

• Its far-reaching knowledge of the plants.
• Knowledge of the NPP’s information systems.
• Previous experience in the development of similar solutions.
• Closeness and flexibility to adapt to the client’s needs. We understand that the available time frames for data acquisition at the plant will be limited, and we will act with the least possible interference of refueling, and other operations and maintenance tasks.
• The possibility of using proprietary SW or providing the client with an autonomous and easily maintainable in-house license free development.
• The possibility of using drones and other robot-operated solutions for data acquisition in confined spaces and radiological areas, under ALARA criteria.
• Its capabilities in the field of process modeling and simulation and expertise in data processing and analysis.
• The capacity to integrate the system with other services rendered by Tecnatom in the areas of training, facility management, and inspection.
• Experience and capacity in the field of human factors engineering for the design of friendly, intuitive and easy to handle user interfaces.
Introduction. What is a digital twin?

The digital twin is a virtual replica of a facility or process that, by combining design information, process data and simulation capacities, allows us to optimize operation throughout its entire life cycle.

In our society, the Digitalisation of processes is increasingly important and relevant for the operation and safety of facilities, and the nuclear industry is fully aware of this.

The Digitalisation of the nuclear industry is still in an early stage, with studies underway on how it might prove to be beneficial in providing value and increasing the competitiveness and safety of the sector. Nevertheless, it has already attracted strong backing and commitment and there are even certain ongoing developments, specifically concerning the concept of digital twin.

Context

- The digital twin is based on a digital image of the facility,
- Which is subsequently provided with a number of layers of information and documentation obtained from the plant systems (SCADA, sensors, meters and other relevant data);
- Furthermore, the digital twin must be connected to the facility in real time;
- Finally, the digital twin must be integrated with simulation models serving to predict the future behavior of the system based on previous data. The more layers of information and the greater degree of detail used in modeling, the higher capacity for the digital twin will be obtained.

The objective of a digital twin is to use these four aspects to facilitate and validate all the phases of a project: design, maintenance, design modifications, etc. The digital twin may be used, for example, to simulate different scenarios based on actual system data and validate what the impact would be, or vice versa, the digital twin may generate new data serving to anticipate a given condition.

It should be pointed out that the use of a digital twin is what mainly determines its “degree of twinning”; for example, it may be possible that having a highly detailed image of the facility is not relevant for our application, or that it might not be necessary to provide the model with predictive capabilities.

The nuclear industry has major challenges ahead, among which are the need to be more efficient and the handover from one generation to the next.

Objective

The objective of a complete nuclear power plant digital twin is as follows:

- Improve safety,
- Increase the efficiency of operations,
- Provide support for decision-making,
- Facilitate design tasks throughout the entire life cycle,
- Reduce maintenance costs,
- And improve the initial and on-going training of the personnel, facilitating generational shift.

Impact during the life cycle of the facility

The digital twin may be applied during the different phases of a facility lifetime; from design through production or manufacturing to operation and even decommissioning.

During the design phase, the digital twin allows us to validate and optimize the design of the process, the materials, and control, checking how it will behave and the impact that different approaches will have on the construction and operation of the facility or process.

During the construction or development phase, the digital twin is a useful tool to optimize logistics, support testing or train the operators who will subsequently be in charge of the operation.

Finally, during the operating phase, the digital twin becomes enriched with actual operating data and its evolution over time, making it possible to address the simulation of processes based on empirical data and applying artificial intelligence or the numerical resolution of fundamental equations.

The present white paper focuses on the use of the digital twin during the operating and decommissioning phase, both currently applicable fields for the operating nuclear power plants.
03

Uses and Functionalities

The digital twin must have a clear purpose, must be reliable and must operate effectively.

Functionalities

The following diagram shows some of the main uses of a digital twin during the operation and future decommissioning of nuclear power plants:

By analyzing each functionality separately, it is possible to determine the attributes of each solution:

- Calculation of Piping Thicknesses
- Condition Monitoring
- Design of DM
- Performance Assessment
- Waste Generation Assessment
- Training of Operative Crew / Field Operators
- Virtual Operation
- Walldown Planification: ALARA criteria

It is concluded that all functionalities require a digital image of the facility to a greater or lesser extent, and at least some associated layers of information. Additionally, there is a wide range of functionalities that would require the digital twin to be provided with capacities for modeling and connection with the plant in real-time.

Let us now go on to analyze each of the functionalities described in greater detail, focusing on the value they provide for the client.
Outage (1/2) Digital Twin Functionalities

**Component Actuation Sequence In-Service Testing**
Tool to assess the status of a system prior to proceeding with an in-service inspection, indicating the steps to be performed and the sequence of component actuation.

**Calculation Piping Thicknesses**
Tool to calculate piping thicknesses on the basis of historical data from past inspections. Hereby anticipating degradation and breakages, allowing to plan upcoming in-service inspections and avoiding service failures.

**Assembly Scaffolding / Auxiliary Structures**
Determining the need for assembling scaffolding or other auxiliary structures during outages. Additional information may be included, such as visual assembly instructions, advice, etc.

**Components / Cubicles Location**
Identification of assets and their location using the digital image of the plant, enabling a faster intervention by field operators, reducing time frames and associated dose.

**Measure / Detect Interferences**
Use of the digital image of an asset to measure distances and detect interferences before executing work in the field, thus determining maneuverability and anticipating potential problems.

**Work Planning**
Use of the digital image of the plant and associated layers of information to plan maintenance, in-service inspection, and other field operations. Use as a tool to support pre-job briefing.

Outage (2/2) Digital Twin Functionalities

**Indication of Work Performance Sequence in the Plant**
Indicating the work sequence of any given work order, consequently improving coordination among different contractors and different disciplines, for instance: scaffolding assembly, pipe lagging insulation removal, radioprotection, mechanical maintenance, etc. Affected personnel receives indications of when is their time to intervene.

**Display of Asset Inspection Reports and Data**
Have a precise, clear and user-friendly visualization in 3D of reports and inspection data. This will help the user have a better knowledge of the status of plant assets and improve decision making.

**Location of Personnel and Evaluation of Work Progress**
Tracking of personnel working throughout the facility, with the possibility of viewing the degree of progress of work orders, and manage the intervention of different contractors and staff assigned to that work order.

**Viewing Radiological Incident and Historical Data of Affected Areas**
Have visual indication of radiological incidents and historical data of high, medium, and low radiation areas.
Design Digital Twin Functionalities

**Decommissioning**
Use of the plant’s digital image and historical operation data to develop decommissioning strategies: radiological characterization and decontamination campaigns, waste management and subsequent dismantling.

**Configuration Management**
Use of field data and historical asset information for maintaining consistency of a product’s performance, functional, and physical attributes with its requirements, design, and operational information throughout its life.

**DM Operation**
Validation of design modifications that have an impact in operation and implies the modification of operation procedures. The digital twin can be used to provide advice and validate all affected parts: setpoints, alarms, Human Machine Interface, etc..

**DM Commissioning**
Mitigation of risks and contingencies coming from the commissioning of new design modification assets, through the use of the digital commissioning features of our digital twin. Performing pre-SAT testing before arriving on-site, directly integrated in the design phase.

**DM Adjustment & Validation**
Validation of design modifications using the digital twin for performing dynamic 3D simulation, verifying workers access area, maneuverability, space for the entrance of new equipment and removal of existing parts, etc; as well as the analysis of equipment control loops.

**Design Modifications**
Develop new design modifications based on the actual plant’s digital image.

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Training Digital Twin Functionalities

**Knowledge Management**
Additional layer of information associated to operating experience and knowledge management. Each asset would have information, such as: videos of how an in-service inspection or regular maintenance are performed, its noise under normal operation, or having training pills related to its operator.

**Contractors Training**
Use of the plant digital image to impart access training, indicating practical tips on places to go to, how to properly wear personal protective equipment, how to use the mask, waste disposal procedures, etc. The training shall include emergency drills, practical instances of emergency sirens, evacuation routes and other training pills of safety culture.

**Operators Training**
Joint training with field operators including links to videos and interactive material obtained from different emergency scenarios and past incidents which occurred at the plant.

**Maintenance Crew Training**
Use of the asset digital image and associated data and documentation to train field workers in its operation and maintenance. The digital twin can be used to train them on a general overview of the plant, the functionality of complex systems and helping them learn where each asset is located and how buildings are distributed.

**Field Operators Training**
Joint training with the operating crew, which would be located at the full scope simulator. Field operators can use the digital twin to complete the tasks being commanded from the simulator.

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**VALUE**

- **SECURITY**
- **TRAINING PERIODS**
- **REDUCE COST**

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**VALUE**

- **REDUCE TIME**
- **LIMIT CONTINGENCIES**
- **EFFICIENCY**
O&M (1/2)

Digital Twin Functionalities

**Performance Assessment & Monitoring**
Analysis of full plant or independent system performance via artificial intelligence, including diagnosis functionality to provide recommendations for improvement.

**Condition Monitoring**
Application of machine learning and data analytics to relevant plant assets in order to identify anomalous operation data in real-time, to infer events before unexpected breakdown.

**Live Video Feeds**
Have our digital twin synchronized with live-video feeds, consequently having a remote supervision of field work while accessing relevant asset information and having an overview of work order progress.

**Asset related Documentation & Data Display**
Asset identification through the use of QR codes. Plant personnel can scan the codes and access to the digital twin’s dataset: documentation, operation data, etc.

**Location & Identification of Components**
Identification of assets and their location using the digital image of the plant, enabling a faster intervention by field operators, reducing time frames and associated dose.

**On the Job Training**
Using virtual reality and the plant’s digital image to provide training solutions focused on the execution of specific work orders, consequently training workers before entering the plant.

**Value**

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<th>REDUCE OPERATING COST</th>
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O&M (2/2)

Digital Twin Functionalities

**Waste Generation Assessment**
Identification of waste generation patterns through the use of machine learning and data analytics. The system predicts the generation of the different waste streams under different operating scenarios, helping to evaluate national waste repository capacity for long term operation.

**Walkdown Optimization**
Embedded application to provide indications to field operators from the control room. Use of wearables for automatic recognition of indicators, detection of anomalies through the use of sound or visual indications, etc.

**Intelligent Identification for Store Management**
Smart identification of assets stored in the warehouse, improving localization, spare parts management, and decreasing response time.

**Virtual Operation**
Virtual verification of Limiting Conditions for Operation (LCO’s) allowing for testing possible solutions upon alteration of normal operating conditions.

**Walkdown Planification**
Calculation and indication of the best paths for walkdowns, and other routinary maintenance activities, in order to reduce execution times and collective worker dose. Emergency evacuation routes are also indicated in case of emergency.

**Value**

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Scope of my Digital Twin

The digital twin must focus on the needs to be covered. It is preferable to carry out this analysis before performing any development.

Now is the moment to ask: of all the functionalities described in the previous section, which interest me the most? And of those that are of interest, which solve my most urgent needs? It is initially important to focus on just a few functionalities, to validate their use and subsequently widen the approach, but without losing sight of the complete range of functionalities desired.

As a result, the steps to be adhered to would be as follows:

01. Determination of the set of functionalities required by the client.
02. Analysis of the characteristics of the digital twin for each functionality, determining the “degree of twinning”.
03. Determination of whether it makes sense to integrate all functionalities in a single solution (digital twin) or whether it would be better to opt for the development of independent solutions responding separately to each problem.
04. If so, overlap the different use cases to determine the characteristics of our digital twin.

In short, the creation of a digital twin is a complex task that requires a complete transformation of processes, methodologies, and functions. Consequently, a preliminary analysis should be carried out to determine the following:

- Which parts of our system or operations might benefit from the development of a digital twin, quantifying the potential savings,
- The critical functionalities to be provided for our model, based on the problems to be addressed thanks to the information obtained from the digital twin,
- The data available in the plant information systems,
- How to connect our model with these fields of information in real-time,
- What simulation capacities and data processing techniques are available, and which should be developed for our purposes.

Therefore, developing functional digital twins tailored to each client’s needs, is an enormous challenge for which the utilities should make use of collaborations with experienced partners. The essential word here is functional; the aim is to develop a tool that creates value, allowing operating costs to be reduced and maintaining, in all cases, a clear view of what the return on investment will be. The aim is not to introduce technology because of being immersed in a technological revolution, but rather to analyze in detail how to do this by determining what improvements will be obtained.

Tecnatom is an engineering company that has been rendering services in the nuclear sector since its creation more than 60 years ago. Tecnatom possesses detailed knowledge of the nuclear power plants, allowing the company to adapt to their needs and understand their problems. We are experts in developing solutions that address specific challenges related to the operation of nuclear power plants. Tecnatom considers that the development of a digital twin should be carried out in a scalable manner, applying agile methodologies during both the prototype and development phase, as well as subsequent validation; making it possible to accompany the client throughout the entire process and ensuring the return on investment.
How is it obtained?

In creating a digital twin, special attention shall be paid to the information available in the plant systems and to determine what data is required to provide it with the functionality sought.

Digital Image of a Facility

As has been pointed out above, the digital twin is based on a digital image of the facility in question, in this case, parts of a nuclear power plant or even the entire plant. In the case of operating nuclear power plants that do not have an initial design based on CAD technology, there are two ways to obtain this image:

• Combination of laser scanning and 360° photography
• 3D survey based on plant isometric drawings

In this case, Tecnatom considers that the isometric drawings may not reflect the actual configuration of the plant and considers the first option to be better. Indeed, laser scanners do not provide 3D models, but these may be obtained through point cloud modeling. It would be sufficient to determine which parts of the facility require 3D viewing and then invest in modeling only those parts. A refined and appropriately processed point cloud is considered enough for most of our installation.

Laser Scanning

The data acquisition procedure followed in the field, as well as the resolution, determines the use cases for the user. A distinction is made here between two possibilities:

1. Scanning / 360° Photography with Topography:
The creation of an accurate plant model for engineering applications requires the scanned items to be geo-referenced to a local or absolute system of coordinates. During this phase it is necessary to develop a topographic network of the plant, allowing for the positioning of scanning stations at points of known orientation. The objective is to be able to relate the scans one to another in a unique and complete association allowing the entire task to be referred to the plant coordinates system.

2. Scanning / 360° Photography:
In this case, the scans are not geo-referenced to a known system of coordinates. Instead, the data are acquired in such a way that there is a 75% overlap between scans. If this is not achieved as a result of physical constraints, a minimum number of 5 common targets visible from each scan are positioned, these being duly identified in sketches and suitably distributed around the space in the room. The positioning and orientation of all the data acquisition stations is tracked to subsequently be able to reference the scans and generate the virtual path.

In both cases, the 360° photograph is obtained at the same time as the scan. On average the latest generation scanner takes a total of 50 seconds to acquire the points cloud. In case of capturing the 360° image as well, the process would take 1 minute 20 seconds.

The data resolution is another aspect that influences the use cases. For example, one might ask: shall component labels have to be distinguishable at a distance of 5 meters? In this respect the following capacities are available for use:

1. State of the Art: scanning: 3 mm @ 10 m photography 360°: indeterminate
2. Industry Standard: scanning: 6 mm @ 10 m photography: 432 megapixels
3. Low Resolution: scanning: 12 mm @ 10 m photography: 100 megapixels

It is thought that working with low resolutions may, in certain cases, complicate the identification of equipment and that it may, therefore, limit the functionality of the model.

The processing phase, which includes: the registration of the points cloud, the generation of files in the formats required by the model, numerical classification in the database, generation of the virtual path and the inclusion of files in the viewing application; is also vitally important. The scanner provides automatic adjustment of the different scanning stations; nevertheless, this must be corrected manually to guarantee that accuracy is maintained during navigation via the different scans.
Layers of information

This is the second property of a digital twin: it must be fed with an enormous amount of information from the plant systems. In this respect, the existing data must be analyzed in detail to prevent the deployment of new sensors and, in keeping with the required functionality, determine which are necessary for our model. If applicable, it is necessary to identify the real-time information needs and address the challenge of transmitting this information in today’s nuclear power plants, where there are major difficulties in deploying cable-free communication networks.

It should be determined what information is parameterized in the plant instrumentation and control systems, how the different systems communicate and how the connectivity of these systems with the digital twin is automated.

Despite attempts to avoid deploying new sensors, this may, in fact, be impossible. In most operating nuclear power plants, the information is scattered and housed in different systems and applications that constitute a fragmented system with different people responsible for information, domains and user profiles. These systems were not designed to operate in a collaborative environment and, therefore, to interact. Consequently, the digital twin will need the information to be transmitted, prepared and consolidated before being used, or complex forms to be developed for consultations with the different sources.

During this phase the question of cybersecurity must also be addressed, guaranteeing the application of the standards, protocols, methods, rules, and tools conceived to minimize vulnerabilities and the possible risks of suffering malicious attacks and the loss of information.

It is once again considered necessary to rely on external partners with far-reaching knowledge of the plant information systems, experience of working with instrumentation and control systems and understanding of the cybersecurity standards.

Modelling

The last characteristic of the digital twin is the capacity to predict the performance of a system, either to anticipate the future or to detect deviations in the present. There are two fundamental ways of addressing this issue:

- Modeling the physical behavior through the numerical resolution of fundamental equations replicating such behavior, making it possible to predict its behavior based on the input conditions. This type of approach is normally used during the early stages (product design) and may be adjusted using empirical models as information is gathered from the facility.

- Empirically through the application of machine learning techniques based on facility or process operating data. This is generally used for processes that have already been started and for which there are enough data for training the model.

In the case of our current nuclear power plants, historical data from existing instrumentation and control systems may be used. However, the history of many parameters is not available. Furthermore, current data processing techniques are not capable, by themselves, of providing all needed functionalities of the digital twin.

The models to be used may be available from other applications and require only integration in the digital twin.

As a specialist in simulation, Tecnatom has in-house technology for the modeling (based on the resolution of equations and machine learning) of electrical, thermohydraulic and logic processes, the data acquisition and the synchronization and coupling of the different models. We also have monitoring technologies that make it possible to analyze actual performance data and the results of “what-if” experiments.

Furthermore, we have specialists in data analytics and artificial intelligence and experts in energy-related and industrial processes.
What does Tecnatom offer?

The implementation of a Digitalisation project like the digital twin requires the support, advice, and assurances that only a partner like Tecnatom can offer.

Tecnatom offers to accompany the client throughout all the phases that encompass the deployment of a digital twin system at a nuclear power plant.

Phase 1: Functionalities

During the first phase, Tecnatom performs a detailed analysis of the client’s needs and determines the minimum configuration of functionalities required to provide value, quantifying the ROI. In this respect we opt for a scalable implementation, determining the uses of the digital twin and the roadmap to be followed for achieving future growth of the model.

As has been pointed out before, the uses of the digital twin determine the appropriate data acquisition technique, the resolution required and the necessary layers of information. The following table, for example, shows an initial analysis for the implementation of a digital twin oriented towards the management of refueling outages.

**Functionalities: Management of Refuelling Outages**

(1): Work planning
(2): Performance of measurements / detection of interferences
(3): Location of components
(4): Location of cubicles
(5): RP analysis: ALARA criterion
(6): Assembly of scaffolding and auxiliary structures

*Note: The use of a model without a basic topography for the detection of interferences and the large-scale acquisition of measurements, beyond the location of a cubicle, may lead to successive measurement errors producing erroneous conclusions. It is also recommended that measurements be taken using 3D points cloud handling SW.*

**Phase 2: Data Acquisition**

The acquisition of data for the development of the digital image must be based on laser scanning and 360° photography techniques, affecting the operation of the facility as little as possible. Tecnatom relies on experts with profound knowledge on the subject, making it possible to obtain the data quickly and accurately. Tecnatom has a far-reaching understanding of the plant, which allows to plan paths, optimize intervention windows and minimize doses in keeping with ALARA criteria.

**Phase 3: SW Application**

Tecnatom may act as an integrator, making use of commercial off-the-shelf software, or develop its own solutions independent from licenses and based on the specific needs of the client. Tecnatom has wide experience in the development of user-friendly modular web interfaces that allow the client to be independent in their subsequent maintenance and scalability.

**Phase 4: Connection with Information Systems**

As a result of the work performed in the fields of inspection, simulation, and training, Tecnatom habitually works with information systems of nuclear power plants. We have a far-reaching understanding of how the plant systems work, of the sensorization of facilities and of how to bring disperse information together in a centralized system.
**Phase 5: Modelling**

Tecnatom is a world leader in simulation in the nuclear field and has available training simulators to provide the system with display, scenario planning, and dynamic simulation capabilities. Tecnatom’s solutions range from the use of best-estimate codes in the numerical resolution of equations to the use of techniques such as machine learning, or analytics to provide functionalities such as self-diagnosis, facilitating decision-making based on the understanding of the plant and components condition.

**Phase 6: Implementation**

Once the digital twin has entered the operating phase, the results obtained should be tracked. Tecnatom is fully aware of the resistance to change that exists within organizations, and we offer to accompany the client during this process, to change processes and working methodologies and allow for the integration of this new technology.

**Added Value**

In addition, Tecnatom has been developing solutions for some time for the digital transformation of operations, supervision, maintenance and inspection tasks that, integrated into a digital twin, provide enhanced situational awareness and help in decision-making. The following are among our solutions:

- **Full Scope Simulators**
  Glass-top simulator developed by Tecnatom for Hitachi-GE Nuclear Energy.

- **System Digital Twin**
  Digital twin developed by Tecnatom to reproduce the performance of one specific plant system of Cofrentes NPP.

- **Computerised Procedures System (PROCEED)**
  Computerised Procedures System (TecOS Proceed) developed by Tecnatom.

- **Plant Analysers**
  Plant simulator developed by Tecnatom for Almaraz NPP for engineering and plant performance analysis.
Dynamic Interactive Diagrams Viewer
Dynamic interactive diagram viewing solution (TecOS VIEW) developed by Tecnatom.

Tracking of Operating Technical Specifications
Technical Specifications monitoring and tracking system (TecOS SPEC) developed by Tecnatom.

High Performance Supervision Displays
High performance supervision display solution (TecOS SUPERVISE) developed by Tecnatom.

Efficiency Monitoring System (TecSOLCEP)
Performance monitoring and optimization suite (TecOS SOLCEP) developed by Tecnatom.

Inspections Management System (WebISI)
Nuclear inspection management solution (TecOS ISI WEB) developed by Tecnatom.

Advanced Condition Monitoring Systems (Predictive)
Predictive monitoring services for detecting early degradation provided by Tecnatom.
Digital twin prototype developed by Tecnatom for equipment location and information for Ascó NPP.