ELECTRIC POWER RESEARCH INSTITUTE

Quick Insight Brief: Digital Twin Activities at EPRI

The purpose of this quick insight is to inform the nuclear industry about the current EPRI research activities on Digital Twin (DT) technology.

RESEARCH QUESTION

The following summarizes the research questions EPRI is planning to address in order to help the nuclear industry understand the potential use cases of DT technology.

- What impact do DT applications have on nuclear power plant construction, operation, maintenance and decommissioning?
- What DT applications are deployable in the near future?
- How can DT optimize the life cycle of nuclear assets?
- What research is needed for the nuclear industry to advance the use of DTs?

KEY POINTS

- DT processes enable real-time data exchange and provide the ability for smarter and more informed decision making
- DT can be integrated through innovative construction management tools such as the Building Information Model (BIM) to ensure a closer adherence to cost and schedule
- DT can track and manage the nuclear power plant lifecycle from construction to operation to license extension and beyond to minimize cost, increase efficiency and ensure the availability of long-term safe and reliable energy.

WHAT IS A DIGITAL TWIN?

DT is a digital replica of physical and functional characteristics of the assets that provides information to systems or personnel to make tactical or strategic operations decisions. A DT can be developed when there is a key interactive connection between a physical system and the corresponding virtual model. When measured data from the physical system is provided to a virtual model, a DT is formed, and this enables the DT output to be much more tuned to the physical systems' performance and can be used to adjust operations or inform future decisions.

EPRI RESEARCH ON DIGITAL TWIN

EPRI participated in the "Innovation for the Future of Nuclear Energy – A Global Forum" on June 10–12, 2019 in Gyeongju, South Korea. Delegates representing industry stakeholders around the globe prioritized the most critical innovation technologies or processes that could make a positive difference and advance the current fleet of nuclear reactors. One of the Top 4 Innovations identified from the Global Forum was DT technology.

EPRI has recognized the potential benefits of DT technology for the nuclear industry. Accordingly, EPRI has assembled an internal cross-cutting team to collaborate on DT research and launched two DT related projects. The first project is in the Advanced Nuclear Technology (ANT) program and the second in the Water Chemistry Program. These projects are summarized below.

Digital Twin Applications for Advanced Reactors

EPRI is working on a study to document best practices and establish recommendations for leveraging DT technologies to optimize advanced reactors (ARs). The study explores the benefits and identifies current limitations and challenges of the DT technology in design, construction, operation and maintenance of ARs. The project will investigate:

- **Informed designs:** How can the data interaction between the physical asset and its DT be used to inform optimized operations?
- **Design optimization:** How does the ability of assessing various what -if scenarios using DT technology help optimize the design of the nuclear assets?
- **Health Monitoring:** How can DT technology be used to monitor the health of the asset to assist in planning the next maintenance schedule?
- **Configuration management:** How can DT technology help in managing the next generation of nuclear power plants construction projects by providing a holistic view of on-going and planned activities?

The outcome of this project will assist AR developers and utilities evaluate options for implementing DT technology in their next generation of nuclear power plants.

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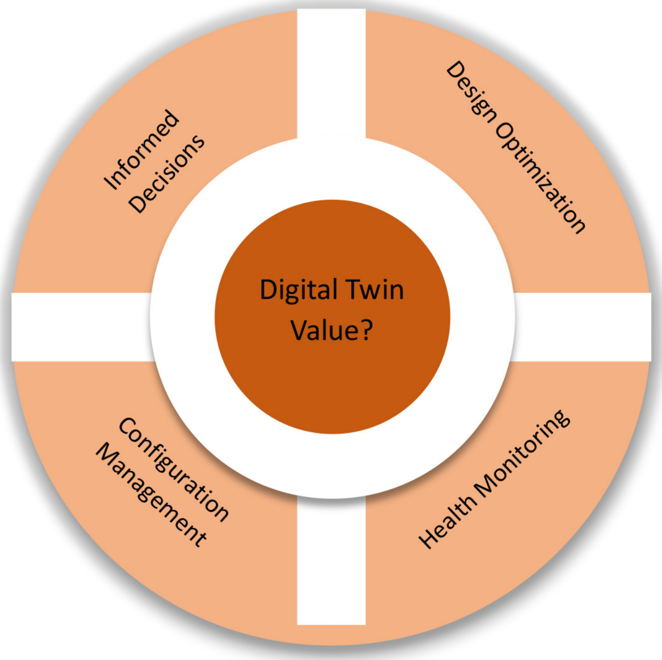

Figure 1. Digital Twin use for Life Cycle Management of Nuclear Assets

Digital Twin Tools within EPRI Water Chemistry

EPRI is working to update the current water chemistry tools for achieving more realistic and accurate physical model of the plant secondary chemistry controls. The project aims at updating and combining two existing EPRI tools, the Plant Chemistry Simulator (PCS) and SMART Plants Works (SPW). The PCS simulator provided the ability to model plant chemistry conditions based on a plant specific heat balance, or a physical model, with chemistry parameters and impurity / chemical injection rates. The simulator output can then be evaluated to optimize operating chemistry controls. The current version of the PCS is limited to a static heat balance model and one-time data entry by plant staff (i.e., it is not automated). Changes to the plant equipment flow, pressure, and temperatures require manual update to the physical model. The SPW was recently introduced by the water chemistry group. It has the capabilities for importing near-real time data from plant systems and includes a primary to secondary leak rate calculator, trend analyzer and other modules to evaluate plant chemistry. Through the application of more real time data into the PCS module combined with the numerous advancements in data modeling and research, an updated SPW would provide the ability to model the plant steam cycle heat balance that represents exact plant conditions.

The combined tool will serve as a DT for a plants' secondary chemistry system using the plant specific heat balance that is or can be continuously updated from the plant data historians with near-real time chemistry data. The utilization of near real-time data provides plant staff with the ability to evaluate and optimize chemistry controls considering current plant conditions based on simulation of the secondary steam cycle. Analyzing plant and chemistry data together allows for better secondary chemistry control, earlier detection of adverse trends and improved long-term asset protection. The tools could also be expanded into multiple additional areas of the plant including heat exchangers and flow accelerated corrosion modeling that has the potential to predict and represent transients, which in turn, allows operators, engineers, and chemists to optimize plant performance.

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POTENTIAL DIGITAL TWIN USE IN NUCLEAR INDUSTRY:

Other departments at EPRI are exploring the potential uses of DT technology. The following summarize two additional potential near-term DT applications.

DT on Steam Generator Performance

EPRI is reviewing DT capabilities to predict the future steam generator (SG) performance, investigate risks to tube integrity, and aid in timing of chemical cleaning activities. The performance and integrity of a SG are key aspects for overall PWR plant performance and health. SG performance changes over time are partly driven by transport of iron-based corrosion deposits from the secondary circuit to the steam generator. These deposits affect steam production inside the steam generator and can have other long term negative effects such as blocking of broached flow holes which can result in redirection of flow within the SG resulting in problems like water level oscillation. Deposit management activities, especially chemical cleaning, can be very expensive and require significant advanced planning. Additionally, plugging of tubes due to wear or corrosion degradation can result in significant changes to the local heat flux conditions, especially if a large number of tubes in a single region need to be plugged. A digital twin of a steam generator would allow for performance estimates into the future to trend and better predict the lifetime performance and optimize scheduling and implementation of expensive inspections and chemical cleanings.

A digital twin of an SG allows using the actual data from the operating and water chemistry conditions to predict deposit buildup and identifying specific regions that could be most as risk for degradation or excess deposit build-up. By using this measured plant data, the SG digital twin would allow precise predictions based on the actual characteristics of importance since design and operating parameters often differ between units. An SG digital twin is a longer-term project, but one key start to the project is taking place now as the SGMP is developing an SG Performance Database for SGs. The data in the SG Performance Database will serve as the basis for future predictions of performance. Use of the DT will allow for estimating the impact of not only steady state operation, but predicting performance changes due to such activities as chemical cleaning, change of the secondary side chemistry control program, or the impact of having to plug a large number of tubes. The SG digital twin tool would allow plants to optimize scheduling of maintenance activities reducing service costs while ensuring high performance and maintaining integrity.

Électricité de France (EdF) is also pursuing a project on a digital twin for steam generators. EdF's approach is to target predicting the changes in broached hole blockage to prevent unwanted flow patterns in the SG and also understanding tube degradation to optimize plugging of the SG tubes. For example, EdF is building off research to understand how the blockage builds up over time, which is a non-linear function, and this will improve the decisions on chemical cleaning. EPRI and the SGMP will engage with EdF to follow development of the SG digital twin to understand the potential return for investing in this technology.

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Fuel Example: CASL VERA

Utilizing existing state of the art simulation technologies provides the foundation for further developments in digital twin technology for use in the nuclear industry. EPRI is working with the DOE's consortium for the Advanced Simulation of Light Water Reactors (CASL) to develop VERA—the Virtual Environment for Reactor Applications. VERA is composed of several physics-based models that are all coupled to provide an all-in-one solution for the simulation of the reactor core. Figure 2 shows the coupling relationships between the physics models within VERA.

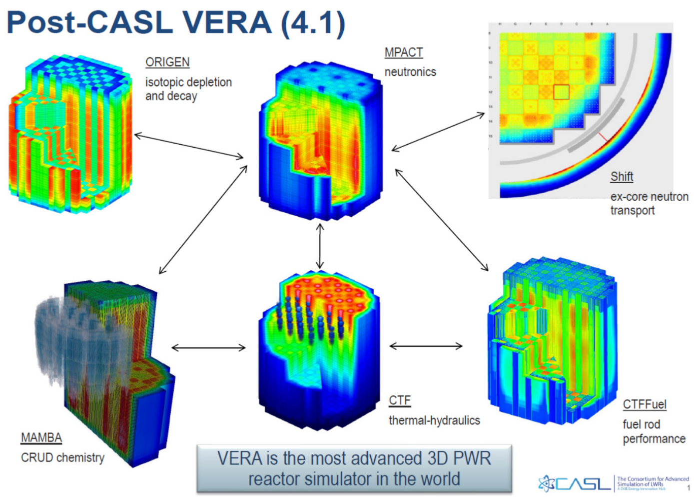

Figure 2. Interrelationships between VERA physics sub-models (Courtesy of CASL)

Any phenomena one wishes to evaluate in any part of the plant ultimately obtains initial/boundary conditions derived from the state of the reactor core. There have been many previous industry applications of VERA to real-world challenges. Some examples include:

- VERA has been applied to the first eight operating cycles of Watts Bar Unit 1, including cycles that experienced Crud Induced Power Shift (CIPS).
- Duke Energy applied VERA for a Monte Carlo-based analysis of shutdown margin and a core design cost analysis to choose the most economic option that met risk constraints.
- TVA applied VERA to analyze their usage of secondary source assemblies and evaluate potential core design changes capable of reducing fuel costs.

EPRI is licensed to use VERA and is currently developing strategies to use its simulation capabilities for a variety of applications. The advanced 3D modeling of VERA may lay the groundwork for development of a digital twin that could optimize reactor engineering and operations decision-making.

A digital twin could simultaneously learn from the core data and inform the reactor operations team using iterative data transfer methods integrated into the simulation. Combining the predictive modeling capabilities of VERA with plant data acquired during the cycle provides utilities with consistently improving technical, cost, and risk-based analysis.

Active EPRI work using VERA's unique capabilities include:

- Evaluating the effects of flexible operating strategies by simulating xenon transients (important for ensuring technical specifications are being met) and calculating pellet cladding interaction margin (necessary to ensure a safe, failure-free return to full power). These simulations have the potential to be modeled in real-time.
- Evaluating neutron fluence levels in the extended beltline region to support reactor life extensions and to enhance materials aging management strategies.
- High resolution rod-level analysis of high burnup fuel during reactivity insertion accidents (RIA) to evaluate margin to regulatory limits.
- Developing detailed core power distribution information to inform high fidelity BOA (Boron-induced Offset Anomaly, a Fuel Reliability Program code) crud analysis.

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DIGITAL TWIN AND MACHINE LEARNING

The interaction between the physical asset and its digital twin through their lifecycle generates a large amount of data. The data are full of useful information that can be used alongside machine learning (ML) algorithms to provide the basis for updating and continuous learning of the predictive model. AI algorithms coupled with DT have the potential for more accurate DT performance as they enable the ability to rapidly gain valuable insights from the monitored parameters and provide the ability of a deeper understanding of the underlining issues that may not be easily detected without machine learning. The following example shows how machine learning and DT can be used for optimizing the maintenance activities of rotating equipment.

There is a lot of interest in the industry for using advanced technologies like digital twin to help in predictive maintenance modeling. Rotating equipment, such as pumps and motors, can be quite difficult to model using physics. While some modeling parameters are easily known or measured, there are many other factors affecting the response the equipment that are often unknown like underlining manufacturing errors, misalignments during assembly or latent engineering or materials defects. The lack of detailed knowledge significantly impacts the accuracy of physics-based models. ML and artificial intelligence algorithms can be used to detect these underlining conditions that are difficult to be modeled mathematically, adapt and learn from the actual data to improve predictions. Accordingly, ML can strengthen the prediction capabilities of the simulation part of the digital twin to better match the actual response, which leads to more effective digital twin utilization and more accurate lifecycle management of the equipment.

EPRI has active research in data analytics, artificial intelligence and data driven decision making (3DM). The advancement in these research areas will be leveraged within the DT research activities to identify more use cases of DT technology for the nuclear industry.

For more information please visit AI.EPRI.com

SUMMARY

DT technology has the potential to optimize construction, commissioning, operations, maintenance and increase the reliability of nuclear assets. Utilities, vendors, and advanced reactor developers recognize the potential benefits of DT technology and are researching its capabilities. This research would not have been possible without the advancement in monitoring systems, 3D modeling and artificial intelligence.

If you would like to get involved with EPRI on the digital twin topic or have some ideas and feedback for the digital twin team, please contact Hasan Charkas at hcharkas@epri.com.

EPRI RESOURCE

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Advanced Nuclear Technology

Note

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

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