POTENTIAL OF A "DIGITAL TWIN" TECHNOLOGY FOR THE PURPOSES OF RESEARCH IN THE NIZHNEKANSKIY ROCK MASS UNDERGROUND RESEARCH LABORATORY

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The paper highlights key aspects associated with the introduction of advanced digital technologies under the development of large complex industrial facilities. It considers the applicability of a "digital twin" technology in the development of an underground research facility in the Nizhnekanškiy massif (Krasnoyarsk territory) (URF NKM).

Keywords: radioactive waste, information model, digital twin, underground research laboratory, life cycle.

Introduction

In keeping with the Strategy on the Development of a Deep RW Disposal Facility (RWDF) of March 28, 2018 [1], as well as based on the international best practices and IAEA recommendations, establishment of an underground research laboratory (URL) is viewed as the initial construction stage of deep disposal facilities for HLW. The key role played by URL is explained by the fact that under deep geological RW disposal concept the processes of safety demonstration, site characterization and design development are inextricably linked (which is schematically shown in Figure 1).

Thus, early in the development, preliminary models of the disposal system may to a certain extent affect the siting process. Further on, site characterization data and findings of URL experiments will allow to precise these models. Preliminary safety assessments can affect the choice of a disposal

Safe disposal

- Long-term isolation and containment
  - Favorable near-field
  - Proved technical quality of EBS

- Containment, retention and dilution by all barriers
  - Slow geosphere transfer
  - Slow leaching from RW
  - Slow transfer in EBS

- Favorable and predictable geological conditions
  - Well studied material properties

- Robust structure of the disposal system (insensitive to defects)

Figure 1. Relationship between various aspects in DDF RW development (based on [2])
concept out of several possible, then the characteristics of the designed engineered barrier system are used in the next stages of the safety assessment and the results of the latter one, in turn, are used to produce a set of detailed technical design requirements [3].

Moreover, despite the fact that long-term safety is believed to be the main challenge in DDF RW planning, operational safety and engineering feasibility are no less important for the successful implementation of such projects [4]. This means that all phases of URL establishment (and subsequently of DDF RW), starting from the preparatory work and ending with the operation, require a highly effective tool for managing and maintaining current processes.

Based on the above, effective exchange of information between various aspects of activities appears to be crucial under DDF RW development.

Under PULSE information system providing scientific support under the development of URL and DDF RW in the Nizhnekansk rock mass [5], information concerning all engineering feasibility aspects will be aggregated into a digital information model (DIM). Figure 2 schematically shows the data flows between the DIM and other information subsystems (knowledge base for long-term safety demonstration, system of computer codes and models, source data bases). Integration of DIM provides such opportunities as, for example, the use of up-to-date characteristics of EBS elements in calculations, verification of technical solutions and optimization of engineering processes by means of simulation modeling.

“Digital twin” technology and the advantages of its implementation during the development of complex industrial facilities

Regardless of the type of industry, life cycle management at large industrial enterprises, support provided to all ongoing processes, as well as necessary compliance with requirements associated with reliability, safety and economic efficiency indicators, the feasibility of decision-making regarding both the managerial and engineering aspects challenge all the interested parties with complex tasks with modern digital technologies helping to address them.

“Digital twin” or digital information model is a prototype of an actual facility, a group of facilities or processes, where each element is linked to a database, in which attributive information is stored and updated at all stages of the life cycle: starting from conceptualization and the development of design, engineering and technological solutions to industrial operation and further decommissioning.

The variety of “digital twins” is usually categorized into three types: Digital Twin Prototype (DTP), Digital Twin Instance (DTI) and Digital Twin Aggregate (DTA) [6, 7].

DTP (Digital Twin Prototype) is a virtual prototype of an actual physical object, which includes various data allowing comprehensive model
characterization (dimensions and structure of the facility, technical requirements and conditions, technological characteristics, etc.).

DTI (Digital Twin Instance) is created based on a DTP twin and additionally provides production and operational data (data on manufacturing, materials and components used, failure statistics, repairs, monitoring parameters, etc.).

DTA (Digital Twin Aggregate) is an information management system that has access to all twins and allows the user to collect and share the data.

Digital twin technology allows to implement PLM systems (Product Lifecycle Management).

The need of introducing advanced digital technologies in the initial development stages of technically and technologically sophisticated industrial facilities is prompted by a number of factors with the key ones summarized below:

- a large amount of heterogeneous data needs to be arranged into a single source to allow further complex analytical processing;
- up-to-date data associated with various aspects should be obtained to make optimal design, technological and managerial decisions;
- errors/collisions caused by human factor should be kept to minimum;
- collisions should be identified and addressed in a timely manner;
- efficiency of management and control system overseeing ongoing processes at all stages of the life cycle should be increased;
- information about the facility, regardless of the duration of its life cycle or its individual stage should be recorded and maintained.

The use of digital twins is currently considered by a number of countries implementing DDF RW disposal projects, namely, Japan [8], UK [9], Sweden [10], Finland [11], Switzerland [12], France [13], Germany [14] and others.

It should be noted that DDF RW development is a lengthy process and now, when the “digital twin” technology has become mature enough, they are at different stages of the life cycle. At the same time, data and documents accumulated during the implementation of such projects, as well as the IT used appear to be diverse and heterogeneous. Due to these factors, the place of “digital twin” in the IT infrastructure of such projects in different countries and the approaches applied can vary significantly.

Thus, for example, German “digital twin” VIR-TUS is based on geological modeling software and not on CAD (Figure 3). In the IT infrastructure of a Japanese project, a large number of knowledge management tools were developed at early stages to solve various problems. Therefore, digital information model included in the iSRE design system is not central, but is synchronized with these information systems (Figure 4). In the French project, the use of information modeling tools is inextricably linked with the Product Lifecycle Management concept (PLM).

Capabilities of digital information model for managing URL design development and construction in the Nizhnekansk rock mass

In 2017, IBRAE RAS has started implementing its joint efforts with JSC NEOLANT on the integration of “digital twin” technology into Russian DDF RW development project. The aim is to model the main production processes [5] enabling their subsequent analysis and optimization. These efforts are being implemented under a contract on the Development of an Information Model Enabling the Evaluation of Design and Technical Solutions under DDF RW NKM Construction. The information model was developed based on the NEOSYNTHESIS engineering data management system. This work resulted in an enlarged three-dimensional information model of the DDF RW, including the submountain part (allowing to display rock excavations), the above-ground part (buildings and structures of the industrial site), as well as animation models of most important sections associated with the main production processes for subsequent demonstration and confirmation of their feasibility and optimality.

The above efforts served a basis for the digital twin development including the following key areas that are currently being worked out:
Figure 4. Basic structure of iSRE and interaction with other systems [8]
• classification and coding of building information for subsequent automation of engineering survey processes, design, construction, operation;
• three-dimensional modeling;
• integration of information model into the knowledge base in part of relevant documentation and data;
• development of a monitoring system for project cost indicators;
• digital verification of decisions on the transport and engineering flow chart providing RW management;
• development of a distributed IT infrastructure supporting digital twin operation and a construction support center on the site.

Coding standard for design, engineering and estimated items and technical documentation evolving during URL NKM development is considered as the primary project standard. The code structure is developed based on principles of KKS universal coding classification system [15] and relevant experience in code implementation under NPP-2006 and WWER-TOI projects, which will ensure the implementation of a monitoring system for cost indicators and, in addition, provide an effective accounting and control system for facility operation. Purpose-designed add-ons for existing types of software used in the design estimates development (Word, Excel, AutoCAD, Grand Estimate) are provided for as part of the encoding standard development aimed at practical implementation and partial automation of the encoding process. These will allow to assign a code to relevant project item in a semi-automatic mode providing optimization of resources and time expenditures.

A detailed three-dimensional URL NKM model based on the developed operational and design documentation (OD and DD) provides not only a visual representation of the facility, but also serves a basis for verification of design and engineering RW management solutions, as well as a visual tool applied to identify possible collisions. Structure of the three-dimensional model of the URL NKM objects, inter alia, ensures the interconnection of data on material items (building, structure, system, utilities, equipment, etc.) and data on information items (cost, time, resource and other design and actual design and construction performance indicators associated with material item’s CIW (construction and installation work)) with an electronic archive of documentation as part of the URL NKM DIM.

DIM electronic archive is a tree-like hierarchical structure of documentation developed during URL NKM development process and formed in accordance with the grouping by types and species, brands and sections, ensuring versioning and interconnections with the elements of the three-dimensional model.

The system of monitoring cost indicators implements additional DIM capabilities allowing to compare cost indicators of the project according to the documentation concerning stages “R” and “P”, as well as a planned indicator with actual CIW cost based on primary accounting documents, including digitalization of the estimate documentation in the DIM URL NKM environment and customization of automatically generated reports.

In addition to the purchase, installation and configuration of necessary software and hardware, implementation of a distributed IT infrastructure supporting DIM URL NKM operation, involves some measures providing for the information security and organization of a protective circuit for the information exchange under the DIM, user training and technical support of DIM URL NKM operation.

Digital support center for construction at CIW site provides:
• collection of factual information directly at the construction site using laser scanning technologies, spherical photography, photo-video shooting from an unmanned aerial vehicles (UAV) providing visual monitoring of the construction process (virtual headquarters);
• support and control of construction and installation operations by means of maintaining and updating the desired construction schedules (4D model), delivery schedules and installation of equipment purchased and manufactured under the project;
• field supervision via a maintained digital journal;
• DIM updating and its filling with data on the field activities, executive documentation. Figure 5 presents DIM structure and the layout of relevant internal interactions within the DIM.

Digital information model should be a structured set of electronic data on URL NKM design and construction providing a spatial description of URL elements, including engineering and technical, structural, engineering and other solutions, thereby providing a single consolidated source of data required for URL NKM construction and its subsequent operation.

Key performance indicators for digital twin technology development and application

Key performance indicators for digital twin technology development and application at each stage of facility’s life cycle can be summarized as follows:

**Design development stage:**
• reducing time and improving the quality of design documentation development (DDD);
• timely identification of design conflicts;
• optimization and verification of design and engineering solutions;
• enhancing the performance of DDD control and analysis;
• development of a monitoring system for DDD/CIW cost indicator.

Construction stage:
• improving CIW quality by introducing planning, management and control tools, including: material requirement and human resources distribution planning, reducing equipment and personnel downtime;
• identification of construction conflicts and CIW quality control (laser scanning, photo-panning);
• quality control of executive documentation;
• designer’s technical supervision;
• arranging for remote headquarters and meetings;
• monitoring system for OD/DD cost indicators;
• development of an executive “as built” model.

Operation stage:
• as built model corresponding to the actual state of the facility at the time of its commissioning considered as the basis of the digital environment supporting facility operation;
• availability of comprehensive engineering and technical information;
• optimized planning of equipment maintenance and repairs;
• operational efficiency of personnel involved in facility operation;
• reduction of training time for operating and maintenance personnel prior to the execution of some complex operations.

All stages of the life cycle:
• reduced time for information search (various search criteria);
• preservation of information for the entire lifespan of the facility.

Machine learning methods using neural networks, development of online monitoring systems and establishment of self-learning intelligent digital model on the whole enabling highly accurate predictive assessments and multivariate designs accounting for various restrictions is viewed as potential trends for the development of the described technology.

Conclusion

Development and application of a fully-fledged DIM as a base for the implementation of a digital twin approach will provide the following opportunities under URL NKM development:
Potential of a "Digital Twin" Technology for the Purposes of Research in the Nizhnekanskiy Rock Mass Underground Research Laboratory

- a single source of up-to-date information and technological data corresponding to the actual current state of the facility;
- an effective analytical tool, also providing predictive analytical capabilities for optimal decision-making;
- an effective tool for monitoring design, research, construction and installation processes, including monitoring of cost indicators.

Moreover, based on completed design development & survey efforts, as well as CIW, DIM will allow to form a basis for the development of a digital environment supporting the industrial operation of URL NKM.

DIM integration with the system of calculation and prognostic complexes viewed as a cornerstone of DDF RW long-term safety still remains a big challenge to be addressed. Such a successful integration will enable the development of URL digital twin not only being able to support design and construction activities, but also the modeling of safety-important processes (Figure 6).

Current maturity level of high-performance computing technologies is sufficient enough not only to theorize, but also to build practical plans. Not least of all, this is evidenced by the fact that similar tasks are posed in the adjacent field of NPP life cycle management [16–18].

Introduction of advanced digital technologies into the existing concept of managing sets of interrelated processes of design, construction, operation and closure will allow the transition to a qualitatively new modern level of life cycle management for such technically sophisticated facilities as URLs and DDF RW [18].

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Bibliographic description