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ARCHITECTURE OF THE DIGITAL TWIN FOR THE NEW SAFE CONFINEMENT OF THE ChNPP

The paper presents the construction of a digital twin architecture for the New Safe Confinement (NSC) of the Chernobyl Nuclear Power Plant (ChNPP), which was built to ensure the protection of people and the surrounding environment from nuclear and radioactive hazards and to provide the opportunity to remove radioactive materials and carry out other measures to transform the «Shelter» facility into an ecological safe system. The need for effective management of thermogasdynamic processes and assessment of the radiation state in the NSC under non-stationary weather conditions requires the availability of specialized information technologies. An analysis of the functionality and structure of the existing integrated management system of the NSC was carried out, and it was proposed to supplement its functionality with visualization and forecasting capabilities through the development of a digital twin, with the help of which it will be possible to effectively solve the tasks of monitoring and forecasting the state of the object and making management decisions, which in general will ensure physical nuclear safety of the facility and radiation safety of personnel. An overview of the main types of digital twins and available approaches to the construction of their architecture was performed, the choice of the architecture of the NSC digital twin was substantiated. Based on the analysis of the characteristics of the NSC as a complex multi-level system, the main requirements for the digital twin were formed and its generalized structure was developed based on them. The proposed architecture of the digital twin is multi-level and built according to the modular principle, which allows it to be flexibly supplemented depending on needs. To develop the components of a digital twin, it is recommended to use a microservice architecture based on secure information transfer protocols. The results of the work can be used in the creation of the software for the digital twin of the ChNPP NSC.

Keywords: digital double; new safe confinement of ChNPP; software architecture.

Introduction

As you know, in April 1986, one of the greatest man-made disasters of mankind took place — the accident at the Chernobyl nuclear power plant (ChNPP). During the liquidation of the accident, a temporary structure was built above the destroyed power unit, which was called the «Shelter Object» (SO). The term of use of this object was 30 years, therefore, in 2007, with foreign financial support, the construction of a new protective structure, which was named «New Safe Confinement» (NSC), began. Schematic cross-section of NSC and SO is shown in fig. 1 [1]. As you can see at fig. 1, this structure was supposed to isolate the destroyed reactor of the ChNPP and the SO, ensuring the protection of the personnel of the ChNPP, the population and the surrounding environment from nuclear and radioactive dangers by controlling the leakage of radioactive dust and making it possible to remove radioactive materials from them to transform the SO into an environmentally safe system [2; 3]. In 2019, the ChNPP NSC was put into operation. The term of use of the NSC is 100 years, provided that certain air humidity characteristics are maintained in the main volume, which is achieved through ventilation management.

In addition to humidity, NSC require the control and management of a large number of other parameters to improve radiation, nuclear, industrial and

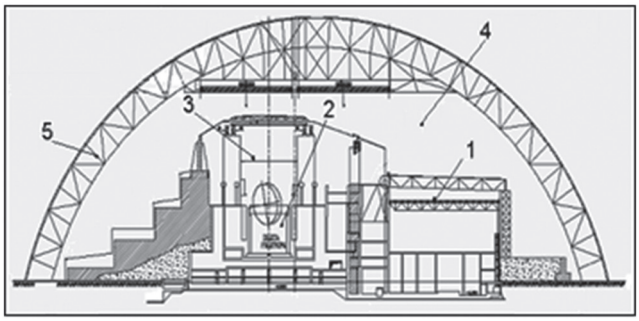

**Fig. 1. Scheme of NIC and IIIЦ in cross section:
1 — turbine hall; 2 — destroyed reactor; 3 — central hall;
4 — main volume; 5 — annular space of NSC**

environmental safety. For this purpose, the so-called integrated management system (IMS) of the NSC was designed and put into operation [2]. The main problem of the NSC is the dangerous impact of the increased radiation background in the main volume on the personnel who will work there. The roof and walls of the SO have a large number of cracks through which air and radioactive aerosols penetrate into the main volume of the NSC, and from there into the environment. Non-stationary thermo-gasodynamic processes of heat convection and air movement occur due to temperature differences inside the NSC, which depend on the season and the mode of work of the personnel during the dismantling of rubble, various heat emissions inside the NSC [2]. In addition,

the need to effectively maintain certain humidity indicators in the NSC under non-stationary weather conditions requires the availability of information technologies for forecasting the condition and making decisions on the management of the NSC, which are not available in the IMS.

Analysis of recent research and publications. It is possible to monitor the state of the NSC using modern computer modeling methods based on CFD (Computational Fluid Dynamics) models that adequately describe the necessary physical processes occurring in the NSC in various conditions [2]. For example, models were built, which, with the help of operational measurements, made it possible to determine the continuous unorganized flow of air with radioactive aerosols outside the NSC into the surrounding environment with arbitrary wind directions and speeds [1], the issue of developing special mathematical software for controlling NSC ventilation units was considered [4]. Approaches to the construction of the information technology architecture of the NSC are proposed, taking into account the subsystem of forecasting forecasts of locations and concentrations of radioactive aerosols based on modern approaches to software life cycle management [5].

The need to combine the storage and processing of historical data regarding the NSC, their visualization, the solution of forecasting and management problems determines the feasibility of using the technology of digital twins for further improvement of information systems of the NSC.

The purpose and objectives of the study. The purpose of this work is the development of a multi-level architecture of the digital double of the NSC ChNPP, on the basis of which it will be possible to effectively solve the problems of monitoring and forecasting the state of the facility and making management decisions, which will generally ensure the physical nuclear safety of the facility and the radiation safety of personnel. To achieve the goal, it is necessary to conduct an analysis of existing approaches to the construction of digital twins, formulate requirements for a digital twin, develop a multi-level architecture of a digital double and provide its description.

The main part

A digital twin is generally referred to as a virtual prototype of a real physical object, product, group of products or a process that collects and reuses digital information [6]. The digital twin consists of two parts: a visual model of the control object and a behavioral model, which includes the corresponding mathematical and data models. According to their purpose, digital twins are divided into digital twin prototypes (digital twin prototype), digital twin instances (digital twin instance) and digital twin aggregates (digital twin aggregate), which combine several digital twin instances [7]. According to the nature of the connection between the digital twin and the real object, they are divided into a digital model (there is no automated data exchange), a digital shadow (the twin only receives data from the object) and, in fact, a digital twin (there is a two-way data exchange between the twin and object) [8]. In our opinion, the most effective type for NSC management is a digital twin with two-way data exchange. There are several approaches to building the architecture of such digital twins. As a rule, a digital twin has a multi-level architecture, which contains mechanisms for measuring and exchanging data with a real object, a local database and data storage, modeling, processing and data analysis tools [9-11]. However, the NSC is a complex system with a multilevel structure, which must be taken into account when solving monitoring and management tasks, which is not taken into account in existing works and requires the development of new approaches to the construction of a digital twin architecture.

The purpose of developing a digital twin is to provide an effective solution to the tasks of monitoring and forecasting the state of the NSC and making decisions about its management. Based on this goal and taking into account the specifics of the automation object, it is possible to formulate the main requirements for the architecture of the digital twin.

The information that will be collected and processed by the digital twin is of a closed nature, which creates restrictions on the use of various cloud services for its processing, storage and analysis. Considering the high complexity of the automation object, in order to take into account the risks of the project, the development and implementation of the digital twin should be based on the model of the evolutionary life cycle [4], using the advantages of the microservice architecture to implement the functional modules of the system. The modules of the digital twin must implement the functions of visualization, forecasting, analysis and decision-making support for the main subsystems of the IMS of the NSC (the list of functions depends on the features of the functional subsystems).

Based on the above requirements, the proposed architecture of the digital twin of the ChNPP NSC is shown in the form of a structural diagram in fig. 2.

As can be seen in fig. 2, the architecture of the digital twin of the NSC contains five levels. At the first, lower level, the basic management of technological processes of NSC is carried out using the existing integrated management system. The system is responsible for the collection and accumulation of primary data on the functioning of the NSC, control and management of its current state using sensors, programmable logic controllers, etc.

In order to transfer from the IMS database the information necessary for analysis, forecasting and decision-making, it is proposed to implement a communication server at the second level, the API of which will ensure the formation of the necessary data samples. Currently, the architecture of the NSC IMS does not provide for the receipt of control commands from other systems, so the transmission for the implementation of decisions made at the upper levels of the digital twin is carried out by users using the existing interface in the NSC IMS.

The basis of the operation of the digital twin is the basic subsystems presented at the third level: library of models, library of algorithms, databases and knowledge, data storage, versioning system and software change management system.

The library of digital twin models should contain micro-level computer models of NSC phenomena and objects, means of identifying their parameters and assessing adequacy. These models are used as components of macro-level models for forecasting and decision-making regarding certain aspects of the functioning of the NSC, which are presented at the fourth level.

The library of algorithms should provide data processing, their intellectual analysis and decision-making.

Databases and knowledge bases are designed to store information about the results of forecasting and decision-making, production rules and other components for intelligent analysis of information. Their structure is determined when solving specific tasks of analysis and management of the NSC.

The data storage is designed to store processed, unified and prepared data for analysis, which consists of both information from databases of the current level of the hierarchy and data received from the IMS of the NSC.

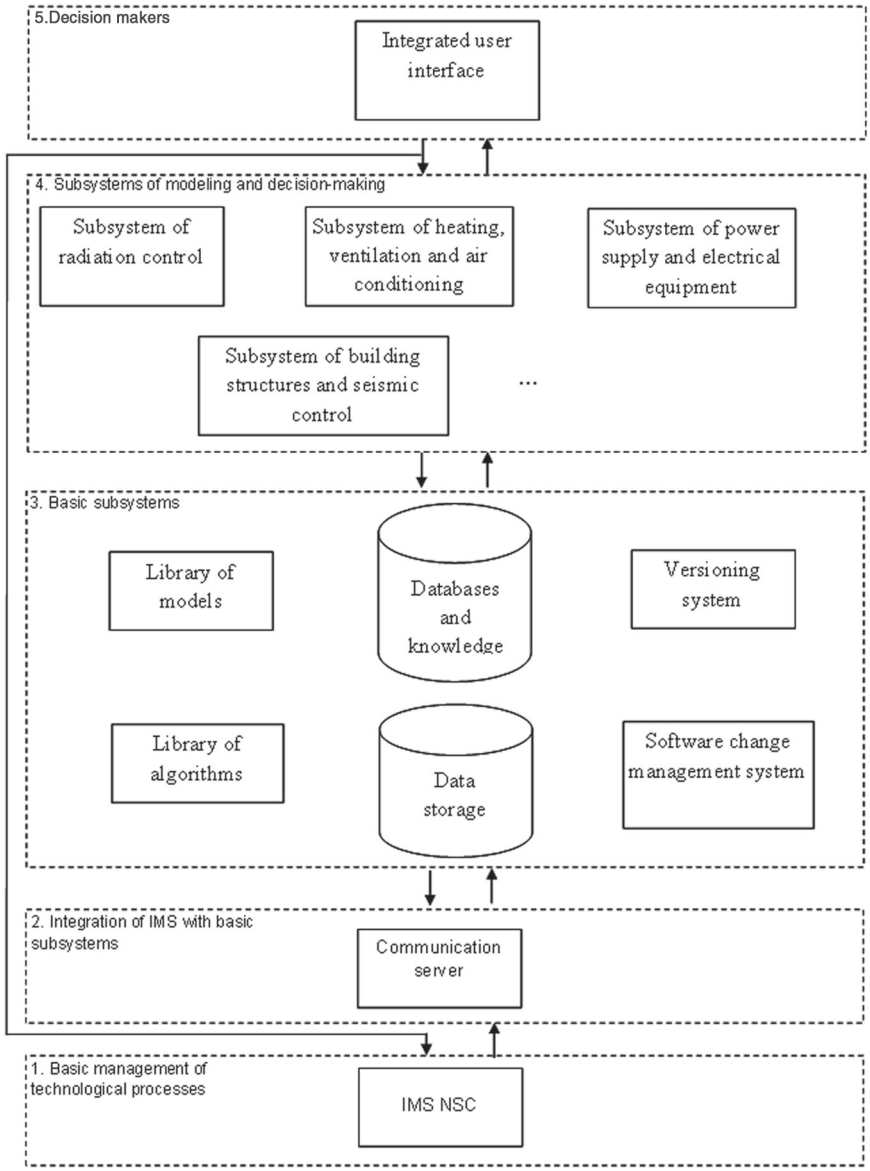

Fig. 2. Generalized architecture of the digital twin of the ChNPP NSC

The versioning system is designed to track changes in key data and model parameters, store the history of forecast results, decisions made, electronic documents created, etc.

A software change management system should enable project management of digital twin modifications, test automation, integration control, and deployment.

These basic subsystems are used in the work of the modeling and decision-making subsystems presented at the fourth level of the digital twin architecture.

We propose to include the following subsystems of modeling and decision-making of the digital counterpart of the NSC:

- radiation control subsystem;
- subsystem of heating, ventilation and air conditioning;
- power supply subsystem and electrical equipment;
- subsystem of building structures and seismic control.

The set of these subsystems can be expanded based on the requirements for solving NSC management tasks and requirements for ensuring radiation safety.

Modeling and decision-making subsystems can have a modular structure, which includes modules:

- visualization of the current and forecast state;
- analysis and reporting;
- classification and prognosis;
- formation of recommendations and assessment of the decisions made;
- approval of decisions made in the hierarchical structure of management and monitoring.

The list of these modules can be changed and expanded depending on their specifics. It is recommended to implement the modules of the modeling and decision-making subsystems, other components of the digital twin, based on the architecture of microservices using secure data exchange protocols between them. At the top level of the digital twin is an integrated user interface for decision makers that should provide work with subsystems depending on the settings of user access rights.

In order to increase the level of cyber security, a closed local information network should be used for the functioning of the digital counterpart of the NSC of Chernobyl NPP.

Conclusions

In this work, it is proposed to use the technology of digital twins to expand the functions of the existing information management systems of the NSC with the possibilities of information visualization and forecasting of its state. The main requirements for the digital twin of the NSC have been formulated and based on them, its generalized structure has been developed, which provides the opportunity to solve the tasks of monitoring and forecasting the state of the NSC, making decisions on process management.

The proposed architecture of the digital twin is multi-level and built according to the modular principle, which allows it to be flexibly supplemented depending on needs. To develop the components of a digital twin, it is recommended to use a microservice architecture based on secure information transfer protocols. The results of the work can be used in the creation of software for the digital twin of the ChNPP NSC.

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АРХІТЕКТУРА ЦИФРОВОГО ДВІЙНИКА НОВОГО БЕЗПЕЧНОГО КОНФАЙНМЕНТУ ЧАЕС

Розглянуто проєктування архітектури цифрового двійника нового безпечного конфайнменту (НБК) ЧАЕС, який було збудовано для забезпечення захисту людей та навколишнього середовища від ядерної та радіоактивної небезпеки і надання можливості вилучати радіоактивні матеріали та здійснювати інші заходи щодо перетворення об'єкта «Укриття» в екологічно безпечну систему. Потреба в ефективному керуванні термогазодинамічними процесами та оцінюванні радіаційного стану в НБК під час нестаціонарних погодних умов вимагає наявності спеціалізованих інформаційних технологій. Проведено аналіз функціональних можливостей та структури сучасної інтегрованої системи керування НБК і було запропоновано доповнити її функціональність можливостями візуалізації та прогнозування через розроблення цифрового двійника, за допомогою якого буде можливе ефективне вирішення задач моніторингу та прогнозування стану об'єкта й ухвалення керувальних рішень, що в цілому забезпечить фізичну ядерну безпеку об'єкту і радіаційну безпеку персоналу. Виконано огляд основних типів цифрових двійників та наявних підходів до побудови їх архітектури, обгрунтовано вибір архітектури цифрового двійника НБК. Ґрунтуючись на аналізі характеристик НБК як складної багаторівневої системи сформовано головні вимоги до цифрового двійника і на їх основі розроблено його узагальнену структуру. Запропонована архітектура цифрового двійника є багаторівневою і побудована за модульним принципом, що дає змогу гнучко її доповнювати залежно від потреб. Вона містить рівні базового керування процесами, інтеграції з наявною системою керування, базових підсистем, підсистем моделювання та ухвалення рішень та інтегрований інтерфейс для взаємодії з особами, що ухвалюють рішення. Для розроблення складових цифрового двійника рекомендується використати мікросервісну архітектуру на основі захищених протоколів передавання інформації.

Ключові слова: цифровий двійник; новий безпечний конфайнмент ЧАЕС; архітектура програмного забезпечення.