Increasing the efficiency of nuclear power plant equipment at the design stage

Mikle Egorov^{1,2,*}, Anastasiya Ukolova², Ivan Kovalenko², Irina Krectunova², Nataliya Lavrovskaya², and Nadezhda Litvinova²

¹Peter the Great St. Petersburg Polytechnic University, Russia, 195251 Saint-Petersburg, Polytechnicheskaya 29

²St. Petersburg State University of Aerospace Instrumentation, Russia, 190000 Saint Petersburg, Bolshaya Morskaya st. 67

Abstract. It is possible to increase the efficiency of the nuclear power plants equipment in various ways. In particular, one of the most relevant is the active use of computer modeling at different stages of work. The effectiveness the software package used directly affects the quality of the installation equipment. Depending on the stage at which the software package is used, it has various priority properties for the most effective application.

1 Introduction

It is difficult to overestimate the importance nuclear facilities in modern industry. The development of nuclear energy began with the launch on June 27, 1954 in the USSR in Obninsk at the First NPP with a capacity of 5000 kW. Its operation convincingly proved the technical feasibility of converting nuclear energy into electrical energy on an industrial scale [1].

Work with nuclear energy requires the most accurate calculations when designing and working with facilities [2-8], because in the event of an accident the consequences will be catastrophic for people, especially for the economy — the restoration of the surrounding territories and the development of other energy sources after an accident at a nuclear power plant requires huge costs and not always completely possible, which was proved by the experience of the infamous Chernobyl nuclear power plant [9].

It should be noted that at present there is a variety of existing complex technological systems, during the implementation of which the parameters of their functioning and the structure of the technological cycle can change, as well as the complexity of practical tasks that arise when assessing the level of reliability and safety of functioning of potentially dangerous industrial facilities, approaches and new technical decisions in optimizing the structure of production require the development of specific systems at the stage of their design modeling [10, 11].

With the development of computer technology software has also appeared for modeling, designing and evaluating the operation of various nuclear power plants. This significantly increased their efficiency - the automation of many calculations and technological processes allowed minimizing the influence the human

factor, as well as accelerating some processes at the stage of modeling and design of installations.

The main life stages of any nuclear power unit (NPU) are design, modeling, analysis work taking into account environmental factors and direct operation. Since the construction of such an installation is an extremely expensive process, at the above stages the installation concept is tested and all its parameters are calculated with high accuracy.

A feature of solving the problems planning and production management is the need to take into account, when solving them, many variables that characterize constantly changing external conditions.

One of the most promising areas of the tasks being solved is simulation, which allows one to obtain qualitative and quantitative estimates of the possible consequences of managed decisions. Simulation methods are the most common means of management theory and operations research in the management of industrial enterprises and organizations.

This is due to the fact that they provide instrumental support for the analysis of functioning in order to improve production and management processes, coordinated and controlled work of all subsystems [12].

2 Materials and methods

Using computer simulation can improve the efficiency of nuclear power plants in the following ways:

- Error reduction through intelligent modeling of piping and equipment elements;
- Reduced costs for the design and testing of both equipment and installations in general;
- Modeling of installations and processes in them, allowing to identify the most vulnerable places and establish ways out of emergency situations.

* Corresponding author: mikhail.yu.egorov@gmail.com

Traditional approaches to the development of production systems and the adoption of design decisions are based, as a rule, on engineering methods for substantiating and calculating the design of technical equipment, their kinematics, the strength of individual components and elements, as well as the technological aspects of the operation of such systems. Such methods do not take into account the high structural and organizational complexity of modern production, which significantly reduces the quality of design and the accuracy of the resulting solutions.

This is unacceptable, given the high cost of implementing such projects. Therefore, a necessary prerequisite for the successful design, research and implementation of technological systems in modern conditions is a strategy in which the main technical decisions at the early stages of development are made, first of all, on the basis of scientific approaches using previous modeling and computer-aided design [13].

Intelligent modeling (for an example see Figure 1) is the most time-consuming stage of work on industrial facilities and equipment. The design of nuclear power plants, in particular, requires the use of non-trivial templates and the consideration of many factors, for which far from all automatic design systems are suitable.

Fig. 1. AXSYS. Engine, CAD for modeling an object and its components.

For example, SolidWorks does not allow modeling complex installations taking into account all physical factors, including many properties of materials. That is why when working with nuclear power plants, software is used to design industrial facilities.

Software tools for the intelligent modeling of industrial facilities are distinguished by large volumes of processed information, in contrast to software systems for the development, for example, of small parts. Also significant differences are powerful graphical tools used when working with three-dimensional models and libraries, which often contain many rare templates and models, which affects the amount of computer memory used by the program.

Modern intelligent modeling programs also allow the analysis of large data sets to also simulate the behavior

of equipment in certain conditions, for example, weather or emergency.

Modeling of production processes is carried out by various methods, divided into two classes: analytical and simulation modeling. In this case, simulation models are more optimal, since simulation allows you to work with more complex models of greater dimension, taking into account the greater number of factors influencing the functioning of the object [14].

Similar software tools used when working with nuclear power plants can improve the efficiency of model development, as well as avoid the influence of the human factor at the design stage. However, in the case when the software package is unstable or incomplete (in particular, if the process of connecting the necessary libraries is complicated), the efficiency decreases, which affects the quality of the final equipment.

The main difficulty in creating such a software product can be called ensuring the rational use of computer resources and the stability of the software complex. In modern programming, this is solved through quality testing of the software product and its components, as well as regular code refactoring.

Depending on the required level of abstraction to simulate production systems, various paradigms of simulation modeling can be applied. For example, at the level of global interconnections, an approach to the study of system dynamics is used. To simulate production processes, we apply an approach that explores specific processes separately. Using a mixed approach allows us to study the system at several levels of abstraction [15].

Conceptual design is a mandatory stage in the development of any installation and equipment. The most effective software is one that simplifies work according to standards and allows the use of more libraries with components, Figure 2.

Fig. 2. AXSYS.Process, CAD for 2D object design.

The main purpose of using such programs is to create drawings according to various standards, which requires providing the user with a comfortable interface and easy access to libraries.

A well-constructed model allows you to reduce risks during the operation of the installation, and computer

simulation significantly reduces the influence of the human factor.

3 Results and Discussion

One of the most important aspects of the operation of a nuclear power unit is a probabilistic safety analysis, taking into account the probability of failure of technological equipment. This avoids many malfunctions, which significantly affects the overall efficiency of the installation.

When it comes to the nuclear industry, computer simulation is imperative, since real experiments are impossible. The development and improvement of the accuracy of computer simulation programs makes it possible to improve the quality of real installations.

Realistic assessment software is most relevant for nuclear power plants - it allows you to assess the vulnerability of the entire installation or equipment and to design emergency escape routes

This software works with accurate calculations and constantly updated data, but does not require powerful hardware and is fast enough.

It can be assumed that currently relevant areas of information technology Big Data and Data Science will find application, including in realistic assessment programs [16].

Figure 3 shows a comparative diagram of the average requirements of software systems to the hardware of a computer, depending on their area of application.

The diagram shows that the programs for intelligent modeling are most effective on powerful computers, which is primarily due to graphical tools and a large number of libraries used.

These programs, however, do not require a high processor frequency, since they process a relatively small amount of data.

The vast majority of modern software systems for simulation use a graphical interface and a graphical representation of the simulation model. This allows you to visually assess the functioning of the relationships between the objects of the simulation model. In addition, the visual graphical interface simplifies the work with a complex of simulation modeling, which allows even a poorly trained person to develop a simulation model. This is especially important when creating a model by a person who has extensive practical experience working with a real system but does not have modeling experience [17].

Conceptual design requires significantly less hardware resources, however, for the correct and effective work it is necessary to correctly organize the interaction of the template libraries, as well as their compliance with the standards of graphic symbols [18, 19]. In this case, it is important to update the software products when a new GOST or ISO standards are released.

Fig. 3. Diagram of requirements for the hardware of a computer for the operation of various types of software systems: (blue – average power requirements (RAM, GB); orange – average speed requirements (processor frequency, GHz; gray – average memory requirements (hard drive, GB)).

Realistic Evaluation Programs, as it might seem at first glance, have the lowest hardware requirements on average. However, if you pay attention, the most demanding on the processor frequency, due to the need to process a large amount of data in a minimum amount of time. For example, this can be data for the installation itself, in particular, the dynamics of its various indicators in normal and emergency operation modes, and data on external factors - weather conditions, the condition of the rest of the equipment, and others [20-22].

The main goal of realistic assessment programs is to evaluate the efficiency and safety of the installation and equipment both in normal operation and in emergency mode, taking into account all external and internal factors. In such programs, most often, graphical tools are not used and sets of numbers act as output or just brief answers about whether the results are within normal values.

Nevertheless, in the development of realistic assessment programs, the most optimized mathematical and physical calculations play an important role, which allows minimizing or eliminating the risks at all during the operation of the analyzed product [23, 24].

Determining the priority sides of software systems is an extremely important stage of their development when working with industrial nuclear installations, since this is precisely the area where risks of incorrect execution of instructions by a computer are enormous. Good-planned development of software products in the field of nuclear energy is ensured, first of all, due to the high-quality technical specifications and the availability of at least a superficial understanding of the scope of work.

This is necessary because, taking into account the constraints imposed by the economy and business, development is often limited in time and resources, which often leads to a poor-quality product, which, subsequently, reduces the efficiency of plants and equipment, and in some cases seriously increases risks

when working with nuclear power on specific equipment.

Depending on the design stage of the nuclear power plant, for maximum efficiency, the software should have some of the following properties:

- Extensive library of objects;
- Powerful graphical tool for visualizing models;
- Ability to work with databases;
- Ability to conduct highly accurate calculations with constant updating of input data;
- Strict adherence to equipment design standards.

4 Conclusion

1. Computer modeling, in particular, intellectual and conceptual modeling, is quite common at the stage of development of directly installations and equipment. Realistic assessment programs, in turn, must be applied with a ready-made model of the entire enterprise using the developed nuclear power plants.

2. Modern nuclear power can't go without partial or full automation at any stage of work.

3. The development of computer simulation is the safest and most promising way to improve the efficiency of equipment and nuclear power plants in general.

References

- [1] B.G. Ganchev, L.L. Kalishevsky, R.S. Lemeshev, E.B. Kolosov, L.A. Kuznetsov, N.F. Rekshnia, S.V. Selikhovkin, *Nuclear Power Plants* (Energoatomizdat, Moscow, 1990)
- [2] G. Li, Ch. Yan, J. Wang, *Annals of Nuclear Energy* **73** (2014)
- [3] M. Le, J. Kim, J. Kim, H. Do, J. Lee, *Nondestructive Testing and Evaluation* **33**, 1 (2018)
- [4] R. Rafee, H. Rahimzadeh, *Iranian Journal of Chemistry and Chemical Engineering* **29**, 3 (2010)
- [5] E. Narimani, S. Shahhoseini, *Applied Thermal Engineering* **31**, 2 (2011)
- [6] H. Zhang, Q. Liu, B. Qin, H. Bo, *Annals of Nuclear Energy* **75** (2015)
- [7] X. Wang, P. Cheng, J. Xie, Z. Zhou, *Journal of Mechanical Science and Technology* **29**, 8 (2015)
- [8] F. Kavousi, Ya. Behjat, Sh. Shahhosseini, *Chemical Engineering Research and Design* **91** (2013)
- [9] D.S. Pashkevich, E.D. Fedorovich, V.V. Kapustin, *Atomic Energy* **123**, 6 (2018)
- [10] V.S. Smorodin, *Mathematical machines and systems* **2** (2012)
- [11] V.S. Smorodin, A.V. Klimenko, E.I. Sukach, O.A. Shimchik, *Problems of Physics, Mathematics and Technics* **1**, 26 (2016)
- [12] T.V. Mikheeva, *Izvestia Altai State University* **1**, 61 (2009)
- [13] A.R. Rott, S.Ya. Alibekov, A.V. Maryashev, A.V. Medvedev, R.S. Salmanov, *Bulletin of Kazan Technological University* **1** (2014)
- [14] V.G. Martynov, *Dynamics of systems, mechanisms and machines* **2** (2014)
- [15] S.S. Zhuravlev, *Problems of Informatics* **3** (2009)
- [16] *The Big Data Phenomenon* (Age of Quality, 2014)
- [17] M.I. Chizhov, Yu.S. Skripchenko, P.Yu. Gusev, *Computer Research and Modeling* **6**, 2 (2014)
- [18] K.N. Malovik, *East European Journal of Advanced Technologies* **1** (2012)
- [19] V.K. Semenov, M.A. Wolman, *Global Nuclear Safety* **4** (2012)
- [20] S.F. Sandu, *Geo-Resource Engineering* **2** (2003)
- [21] A.R. Belozerova, B.F. Melnikov, *Izvestiya Vysshikh Uchebnykh Zavedenii. Physics and mathematics* **1** (2014)
- [22] N.N. Chernyshov, *Radioelectronics and Informatics* **3** (2013)
- [23] I.I. Ovchinnikov, I.G. Ovchinnikov, M.Yu. Bogina, A.V. Matora, *Bulletin of Eurasian Science* **4** (2013)
- [24] Yu.I. Dimitrienko, Yu.V. Yurin, S.V. Europine, *News of higher educational institutions, Engineering* **6** (2013)