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JUSTIFICATION OF POSSIBILITY OF UKRANIAN NPP'S EXPLOITATION TIME ASSESSMENT BY EXPERT METHODS

О.О. Чулкін, В.П. Кравченко, П.Я. Павлишин, В.О. Зотєєв, О.Е. Зотєєв. **Обґрунтування можливості оцінки строку служби АЕС України експертними методами.** Метою роботи є розгляд питань, пов'язаних з продовженням терміну експлуатації АЕС України. Особливу увагу при дослідженні проблеми ресурсу складних об'єктів, таких як АЕС, необхідно приділяти комплексу технічних характеристик обладнання та трубопроводів, що визначають можливість їх експлуатації, і ресурсу експлуатації. З організаційної точки зору, оцінювання ресурсних характеристик складних об'єктів відбувається на базі системного підходу до взаємодіючого, високонадійного, унікального устаткування з обмеженою експлуатаційною інформацією, має істотну особливість. Існують моделі для експертного оцінювання ресурсних характеристик складних об'єктів, що передбачають застосування моделювання предметної області для дослідження динаміки змін ресурсу обладнання критично важливих систем. Зокрема, в атомній енергетиці, існує проблема оцінки реального рівня ресурсу складних об'єктів, схильних до дії процесів старіння при експлуатації, втоми, зносу і деградації. Також слід враховувати вплив людського фактору на їх довговічність. Більшість енергоблоків АЕС України вичерпала свій призначений ресурс, який дорівнює 30 рокам експлуатації. Однак практика експлуатації показує, що енергоблоки АЕС в цілому мають ще достатній запас ресурсу. Таким чином, перед експлуатаційними організаціями стоїть проблема прийняти рішення про продовження терміну служби обладнання АЕС, або про його заміну. Це рішення повинно бути повністю обґрунтованим за вимогами безпеки АЕС, а також економічно виправданим. Підставою для прийняття такого рішення має бути оцінювання та прогнозування реального стану обладнання та його ресурсних характеристик, яке задовольняє науково – обґрунтованим вимогам. Тому системне дослідження ресурсних характеристик компонентів енергоблоків АЕС, виявлення проблем та недоліків в сфері якості оцінювання та прогнозування цих характеристик є актуальним. В роботі розглянуті питання пов'язані з можливістю використання експертних методик для обґрунтування продовження строку експлуатації атомних блоків.
Ключові слова: термін експлуатації АЕС, експертні методи, продовження ресурсу

O. Chulkin, V. Kravchenko, P. Pavlyshin, V. Zotyeyev, O. Zotyeyev. **Justification of possibility of Ukranian NPP's exploitation time assessment by expert methods.** The goal of research is the study of problems, which are connected with Ukrainian NPPs life cycle. Particular attention in the study of the problem of the resource of complex objects, such as nuclear power plants, must be paid to the set of technical characteristics of equipment and pipelines that determine the possibility of their operation, and the resource of operation. From an organizational point of view, the assessment of the resource characteristics of complex objects takes place based on a systematic approach to interacting, highly reliable, unique equipment with limited operational information, which has a significant distinction. Therefore, models have been built for expert evaluation of the resource characteristics of complex objects, involving the use of subject area to study the dynamics of changes in the resource of equipment for critical systems. In particular, in nuclear industry, there is the problem of assessing the real level of the resource of complex objects that are exposed during operation to the effects of aging, fatigue, wear and degradation. The influence of the human factor on their longevity should also be considered. Up to date, a large number of Ukrainian NPP's nuclear blocks are on the verge of exhaustion of the assigned resource, which is equal to 30 years of operation. However, the practice of operation shows that nuclear power units, generally, still have a sufficient resource reserve. Thus, the operating organizations face with the problem of deciding either to extend the life of the equipment of the NPP, or to replace it. This decision should be fully justified by the safety requirements of nuclear power plants, as well as economically. The basis for such a decision should be the assessment and prediction of the real condition of the equipment, its resource characteristics, satisfying scientifically based requirements. Therefore, a systematic study of the resource characteristics of the components of nuclear power units, the identification of problems and deficiencies in the field of the quality of assessment and forecasting of these characteristics is relevant. In this paper, problems, which are connected with justification of possibility of Ukrainian NPP's exploitation time assessment by expert methods, were considered
Keywords: NPP exploitation time, expert methods, resource elongation

Introduction

Particular attention in the study of the problem of the resource of complex objects, such as nuclear power plants (NPP), must be paid to the set of technical characteristics of equipment and pipelines that determine the possibility of their operation, and the resource of operation. From an organizational

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point of view, the assessment of the resource characteristics of complex objects takes place based on a systematic approach to interacting, highly reliable, unique equipment with limited operational information, which has a significant distinction. Therefore, models have been built for expert evaluation of the resource characteristics of complex objects, involving the use of subject area to study the dynamics of changes in the resource of equipment for critical systems. In particular, in nuclear industry, there is the problem of assessing the real level of the resource of complex objects that are exposed during operation to the effects of aging, fatigue, wear and degradation. The influence of the human factor on their longevity should also be considered. To date, a large number of units are on the verge of exhaustion of the assigned resource, which is equal to 30 years of operation. However, the practice of operation shows that nuclear power units, generally, still have a sufficient resource reserve. Thus, the operating organizations are faced with the problem of deciding either to extend the life of the equipment of the NPP, or to replace it immediately. This decision should be fully justified by the safety requirements of nuclear power plants, as well as economically. The basis for such a decision should be the assessment and prediction of the real condition of the equipment, its resource characteristics, satisfying scientifically based requirements. Therefore, a systematic study of the resource characteristics of the components of nuclear power units, the identification of problems and deficiencies in the field of the quality of assessment and forecasting of these characteristics is relevant [1, 2, 3]. To achieve this goal, it is necessary to solve the following scientific problems: analysis and improvement of the regulatory framework in this subject area, modern approaches to managing the aging of nuclear power units, the development of new predictive mathematical models of resource characteristics and methods for estimating and forecasting based on them. The deadlines for the regulated period of operation of the operating power units of Ukrainian NPPs are shown in Fig. 1.

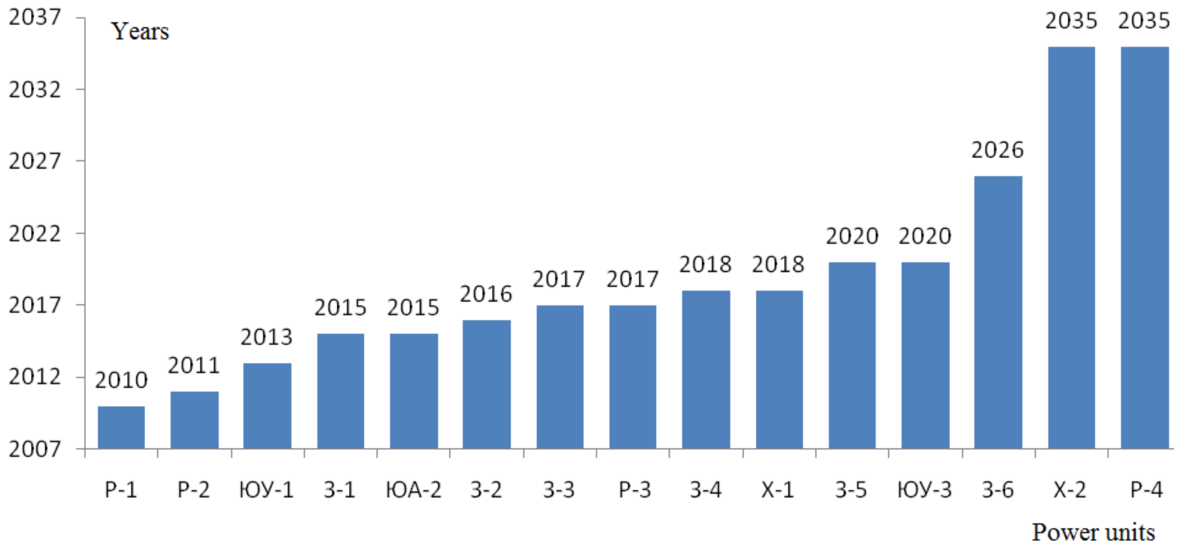

Fig. 1. Deadlines for the regulated period of Ukrainian power units operation

In the United States, more than 80 % of operating nuclear power units have received or are in the process of obtaining a license to extend the life of 40 to 60 years.

Analysis of publications and state of art

In the coming decades, the assessment and prediction of resource characteristics to extend the life of power units are key issues related to the safety analysis of nuclear power plants. The operating organizations are faced with the problem of deciding on the further operation of power units or their withdrawal from economic activity, which is associated with significant material and financial costs. The extension and reassignment of the resource characteristics of nuclear power plants should be theoretically justified and practically confirmed by an examination of the technical condition of the equip-

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ment, as well as calculations that make it possible to predict reliably their behavior in the future, ensuring minimal risks when making appropriate decisions.

To assess the reliability indicators of nuclear power units, systems and equipment, statistical and calculation-experimental methods are used [4, 5, 6]. At the same time, the practice of aging management shows the relevance of developing expert methods for assessing resource characteristics and improving the quality of assessing and predicting the durability of equipment for critical infrastructure, such as nuclear power plants. In many cases, the decision to extend the service life based on the actual condition of the equipment and the accumulated statistics on failures is economically viable and does not lead to a decrease in the level of safety.

It is known that for nuclear power plants, equipment and pipelines are small-batch products. Their destruction during operation is a rare event. Therefore, in most cases it is impossible to obtain reliability characteristics from operating experience. It is also impossible to conduct bench tests of such equipment with adequate modeling of operating conditions (as for electronic systems consisting of a large number of elements whose reliability is known). Therefore, to obtain evaluation of the resource characteristics in such conditions, it is necessary to study the processes of damage, aging, degradation, as well as the construction of physical models, the use of computer modeling and the use of the mathematical apparatus of fuzzy sets. The advantage of this approach, in comparison with standard methods, is proved both theoretically and practically by using it in many critical applications [7]. Thus, the relevance and necessity of developing new expert methods for assessing resource characteristics for the equipment of power units based on fuzzy mathematical models are predetermined. This will improve the existing methodological requirements, and therefore, improve the quality of assessment and prediction of resource characteristics of equipment.

Purpose and objectives of the study

Main goal of the study is investigation of possibility of NPP power units’ operation time assessment by expert methods.

The main tasks of the work.

1. To make comparative analysis of methods for assessment the reliability state of nuclear unit power equipment.

2. To develop expert evaluation technique.

3. The use of evaluated technique for expert inspection of power equipment of NPP.

Comparative analysis of methods for assessment the reliability state of nuclear unit power equipment

The problem of failure-free operation of NPP equipment, or rather, work in conditions of minimal risk of accidents, has been considered from the very moment of its appearance. And practically from the very beginning it was proposed to consider the large scheme of nuclear power plants as uncertain [8, 9, 10]. That is, it was believed that the failure of the circuit is possible, but the probability of failure is not large. By then, probability theory was dominant in resolving reliability issues. It was believed that equipment failure could possibly be predicted using a law that establishes a stochastic relationship between the random development of failure and some of the factors that caused it. However, in a large scheme of factors, there are many factors and not all of them can be controlled. Therefore, it was agreed that the most acceptable measure of equipment reliability could be its trouble-free operation under normal conditions. If the expected time is relatively large, the reliability is high; if relatively small, the reliability is accordingly small.

In other words, if we take into account the high level of achievements of probabilistic methods for assessing the reliability of power equipment that previously was achieved for individual units, and attempt to extend it to modern large systems; we can conclude that we will have to face significant difficulties.

First, large schemes have a significant number of variables. Secondly, these schemes are branched, that is, they differ in complex structures and in the presence of cross and feedback links in them. Thirdly, modern market conditions require equipment to be capable of transformation, that is, rapid organizational transformation. Finally, fourthly, the lack of funds for replacing equipment with new one requires the extension of the life of the existing one without loss of essential reliability qualities.

Fig. 2 explains the difference in statistical and fuzzy approaches to solve uncertain problems. The statistical method can provide an answer to the question of if we take into account only one of the lines (*1 – 3*). Having chosen one of the lines, we should always discard the others (in our example).

$$P(t) = 1 - F(t) = 1 - \frac{1}{\sigma\sqrt{2\pi}} \int_0^\infty e^{\frac{-(t-\mu)^2}{2\sigma^2}} dt,$$

where: t – independent variable (astronomical time), years;

μ – evaluation of average operational time before failure, years;

σ – evaluation of standard deviation of failure time from average (mode), years;

$F(t)$ – Integral function of failures (continuous line in coordinates).

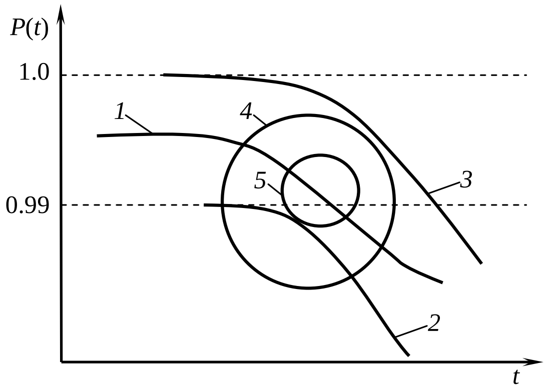

Fig. 2. Illustration of the uncertainty that may arise when applying inaccurately predicted degradation curves $P(t)$: curves *1*, *2*, *3* – indicate various forecasts of reliability; circles *4* and *5* – define fuzzy zones from the forecast of reliability by another method, approach (especially circle with number *5*) to a more accurate estimate of reliability

If we adopt a fuzzy forecast search algorithm, then first accepting an indefinite field of the same width, we will be able to contrast (simplify) the result from a circle of a larger diameter to a circle of a smaller diameter (from circle *4* to circle *5*). At the same time, important information will not be lost, the result will be more accurate, and the search costs will be less. The decision maker will have additional opportunities to continue the confident use of the equipment. If another result is obtained, the decision to terminate the operation will have a proven basis. All these conditions require the search for new effective methods for studying the actual state of power units.

The above mentioned stochastic method for determination of reliability of power equipment has shown that when making the decision only those reliability parameters of the element can be used, that have numeric characteristics.

As for qualitative characteristics, such as failure free operation, reliability, duration of use, etc., then classic method doesn't provide solutions at the moment. That is why to resolve present issues we try to apply the modern theory of fuzzy pluralities or so called "fuzzy logic theory".

This theory is convenient to solve fuzzy tasks.

These qualities are distinguished by expert methods that rely on the theory of fuzzy sets. If, after carrying out all the procedures for expert evaluation of the reliability of power equipment and obtaining the "risk" indicator in a fuzzy environment, we compare the result with statistical data, we will get a graphical interpretation of the difference in approaches. This can be seen in Fig. 2. For example, a statistical analysis of the reliability of the equipment was carried out. As a result there three degradation curves with numbers *1*, *2* and *3* were obtained. Researchers are forced to give preference to one of the curves, discarding the others. Further, for making further decisions, they will rely only on it, and may accumulate a significant error.

Based on fuzzy expert methods, the assessment begins with a circle of a larger diameter, and then this circle narrows to a small diameter. That is, the movement goes from circle *4* to circle *5*. The center of circle *5* will indicate a more accurate and reliable assessment result than a competitive statistical result. However, most importantly, during the next examination, the previous result will be denounced and examined radically again. This, in fact, is the difference between the statistical theory, which notes: "what will happen already will happen" and the theory of possibilities, which states: "it is possible that can happen under the given conditions, and it doesn't matter if it happened before or not".

Expert evaluation technique

The main purpose of conducting an expert assessment with the participation of experienced specialists is the desire to reduce the duration of repairs [11, 12]. Existing planning procedures for the

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repair of power equipment are based on the standard lifetime. A preliminary analysis of the operation of some types of equipment showed that the overhaul periods between overhauls and current repairs also do not fully comply with the recommendations of developers and manufacturers. At the same time, now, reliability-oriented repair (ROR) has become widespread. The principles laid down in the ROR are based on the ranking of equipment according to the degree of influence of possible types of failures on the performance of the basic functions by the systems, taking into account the characteristics of its reliability and establishing for each piece of equipment its own cyclicality and type of repair action. With all the positive qualities of the now "classical" ROR (risk oriented repair) technique, it also has inherent disadvantages. The main disadvantage of the ROR technique is the lack of a quantitative approach to assessing the reliability of the equipment in question. In this regard, work is underway to create a program for optimal repair planning based on a statistical approach that is, using the principles of the ROR technique, but with the specification of quantitative measures of reliability. To date, we improved the main module of methodological and software, which allows to calculate the optimal repair plan for any technological system. This approach is based on a detailed consideration of the structural scheme of the technological system. In this case, the values of reliability indicators of equipment determined before and after the repair are taken into account, and its cost is simultaneously determined. The decision to choose the best repair option is made based on a comparison of the growth of reliability indicators and the costs that are necessary to achieve it. Thus, the virtual restoration of the elements of the structural diagram during the calculations according to the program occurs until the standard value of the probability of failure-free operation (FFO) is reached. As a normative value of FFO, such a value is taken that was observed during the period of the previous trouble-free operation of the equipment. If the manufacturer has data on the reliability indicators of the equipment, they were used taking into account the time of its operation (Fig.3).

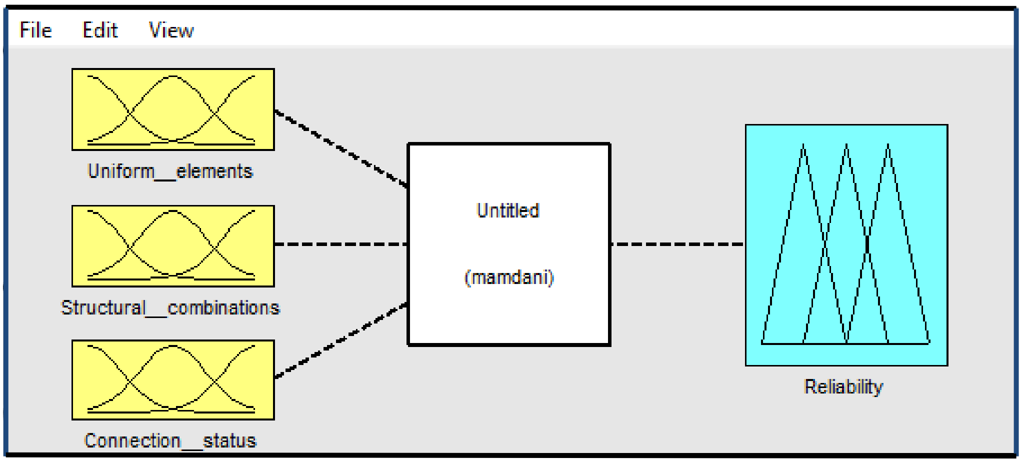

Fig. 3. Simplified scheme of a fuzzy expert system that is recommended to process results of inspection of critical equipment for reliability

Having the law of the probability distribution of uptime, you can use the time scale to determine the numerical value of the probability of uptime. If such data are not available, the estimates obtained from surveys of personnel who for a long time participated in the repair (or operation) of this equipment, are applied. Based on the generally positive experience of using such surveys, a proposal arose to develop this promising approach to solve the problems of optimal repair planning in the conditions of a shortage of production resources. Within the framework of the program, all elements of equipment are conditionally divided into two categories:

– elements whose wear occurs quickly for objective reasons, so that they are subject to restoration (replacement) in the current repair;

– items that wear out slowly and are subject to restoration mainly in major repairs.

Expert assessment as a measurement process

The effectiveness of the initial stages of the development of expert assessment methods (stages of identification and conceptualization) is largely determined by the successful formation of an authoritative group of experts and obtaining of high-quality information from them about the state of power equipment. The essence of the process of identifying knowledge is to organize an expert intuitive logical analysis of the problem area with a quantitative assessment of the judgments formulated by them. At this stage, the experts:

– form objects and concepts of the subject area (goals, decisions, alternative situations, etc.);

– measure characteristics (probability of occurrence of events, significance factors of goals, preference of decisions, etc.).

Expert assessment is a measurement process that can be defined as a procedure for comparing objects according to selected indicators (features). Three attributes appear in this definition: an object, an indicator (feature), and a comparison procedure. Objects can be objects, phenomena, decisions. As indicators of comparison, space-temporal, physical, and other properties and characteristics of objects can be used.

Detection and contrasting of two separate evaluations will give an opportunity to approximate a new forecasted line of reliability degradation. A question which line has to be used for extrapolation of causal relationship link between two conditions of process requires many data for its solution. In the first approximation, it can be assumed that equipment continues operation in the preset operational limits. That is why an approximation of main parameter changes with a section of straight line is possible to consider acceptable (Fig. 4).

Discussions

Analysis of the situation shows that the two survey modes are most natural:

– examination of the state of reliability of equipment in the mode of its normal operation;

– examination, which is carried out after equipment shutdown, i.e. simultaneously with the repair.

The methods for obtaining information in these modes are completely different. Naturally, in the first of them, obtaining information is possible only by:

– external inspection and inspection of equipment with execution of acts;

– data collection from standard instrumentation and information systems;

– collection of measurement information from additionally installed devices;

– collection of records in regular log books and the results of a survey of operating personnel.

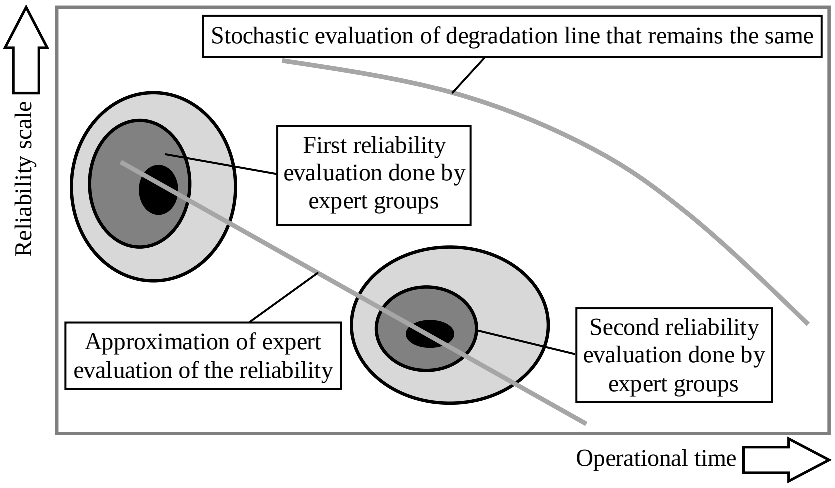

Fig. 4. Explanation of expert groups action strategy to determine reliability resources of the equipment by the application of double inspection

In the second mode, i.e. after stopping the opening of most of the equipment:

– data of instrumental measurements of specific elements;

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– data of visual inspection of elements not subjected to instrumental measurements;

– comparison of specific elements with reference samples for the assessment of degradation (new gasket – old gasket).

Examination of equipment in normal operation, (performed in the period prior to repair):

– the experts, alternately (but not the whole group), which was done in order to obtain independent judgments, get around the existing equipment of this functional group, inspect it, listen to noise, detect leaks of working fluids and make a conclusion about the emerging of problem areas. This solves the problem of the hierarchy of sites in terms of their significance in the upcoming repair. It becomes possible to minimize the cost of repairs;

– experts personally record the values of technological quantities, which give standard devices and record the start time of the examination;

– experts, with the help of employees of special laboratories, install additional measuring instruments in problem areas. By additional instruments we mean vibration monitors, noise sensors, differential pressure gauges, thermometers, qualitative analysis instruments, etc.;

– experts interview operational staff about their observations of equipment status and study entries in log books. Particular attention is paid to the discrepancy between how events are formulated in the notes and how experts present them;

– based on the survey, experts fill out special questionnaires and draw up acts;

– after passing the set time (normalized for each FG), the experts repeat the survey again and again fill out the questionnaires and draw up acts.

– based on the data of questionnaires and acts, each expert individually performs prediction of the equipment fault tolerance of the previously examined FG for the overhaul period. Questionnaires are used to obtain a predicted histogram of the distribution of operating time to failure. Then, the results of the work of all experts are checked, summarized, and then transmitted to system engineers for computer processing;

– based on a synthesis of the results of the forecast made by experts, the NPP management decides on the continuation or termination of operation of the equipment of this FG before the scheduled repair date. The same information can be used to plan the amount of repair and the estimated costs for it.

Conclusions

1. Modern NPP’s can be regarded as big systems, to which expert methods, based on fuzzy logic, may be applied effectively.

2. Expert methods have some advantage compare with standard stochastic procedure of reliability assessment.

3. Presented methods show an updated concept of expert inspection of power equipment of NPP that is focused on increased exploitation period of its safe operation. This methodology makes it possible to achieve substantial savings of all kinds of resources.

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