PROBABILISTIC METHODS OF STRENGTH RELIABILITY AND THEIR APPLICATION FOR OPTIMUM NUCLEAR POWER PLANT LIFE MANAGEMENT

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ABSTRACT

The presentation the new book "**Probabilistic safety assessment for optimum nuclear power plant life management (PLiM)"** published in Russia in 2010 Energoatomizdat and in England in 2011 Woodhead Publishing house is given. The monography is prepared within the framework of the international European program "Ageing and PSA" by VNIIAES (Moscow) and IRSN (Paris) experts.

This book reviews the theory and application of probabilistic safety assessment methods used to calculate nuclear power plant (NPP) durability and lifetime. These methods are reviewed in their application to NPP components and pipelines ageing, which are critical elements in the forecasting of NPP resource lifetime and safety.

Special attention is given to probabilistic safety analysis, optimization of the operations through in-service inspection (ISI) utilising non-destructive testing, and maintenance, service and repair approaches. Practical application of probabilistic methods are considered for:

• optimisation of ISI volumes and periodicity;
• optimisation of hydraulic tests periodicity and conditions;
• optimisation of periodicity and technology of NPP component technical survey;
• optimisation of structure and scheduled of NPP preventive maintenance.

This important book includes examples of the application of these methods in the ageing and reliability analysis and maintenance of pressurised water reactors and their components, from both the Russian-designed WWER and Western-designed PWR, including for instance steam-generator tube integrity assessment methods. The book will be a valuable reference for all nuclear plant designers, operators, nuclear safety engineers and managers, as well as academics and researchers in this field.

About the authors:

Dr. Gennadij V. Arkadov and Prof. Alexander F. Getman of the All-Russia Scientific Research Institute for Nuclear Power Plants Operation (VNIIAES), Moscow, Russia, and Dr Anderi N. Rodionov of Institute for Radiological Protection and Nuclear Safety (IRSN), Paris, France, are noted for their research into nuclear power plant operation and safety issues.

1. INTRODUCTION

In the presentation the table of contents of the monography is below given. At the end of presentation the example of complex application of the methods described in the monography for maintenance of integrity of steam generators tubes is given.

2. TABLE OF CONTENTS OF THE MONOGRAPHY

In the part I are discussed probabilistic Methods Reliability prediction for NPP components, namely:
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1.2 Basic terms and formulas of reliability theory, probability theory and mathematical statistics
1.3 Safety of nuclear plants. Active and passive elements of safety.
1.4 Strength reliability and its relation to NPP safety and lifetime.
1.5 Aging as a process NPP components lifetime and safety determining. Ageing which has been taken into account in the project and not design ageing .

1.6 Quantitative reliability characteristics and their value for the safety analysis and optimization of operational expenses.
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Chapter 4. Physical-statistical approach taking into account the defects and the use of the binomial distribution.
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4.2.2 Development of 4.2.1 methods.
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5.1.4 Methods of studying the reliability of NDT
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5.3 Probabilistic methods for assessing the strength and lifetime, taking into account the residual defects of structural elements.
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5.3.4 Methods of definition in operation of quantity indicators of reliability by criteria of destruction, leak or revealing of defect with use of results of nondestructive testing.
5.3.5 The influence of statistical nature of strength properties and loading on the probability of destruction. Generalized method.
5.3.6 Example: Comparison of results of calculation by methods of section 5.3.5 and section 3.1
5.3.7 Changes of steels strength properties due aging in operation.
5.3.8 Initial data for probability destruction calculating.

Part II PRACTICAL APPLICATION OF THE PROBABILISTIC METHODS OF STRENGTH RELIABILITY
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Appendix: Software PN-1.1: The strength reliability. Definition of probability of failure, leaks and defects in components of nuclear power plant, optimization of their non-destructive testing and maintenance during the operation.
Literature - 154 References.

An exampl taken from the discussed monography are below given. Are considered also results of application new probabilistic methods for the decision of a problem of maintenance of integrity of steam generators tubes.

3. STEAM GENERATORS TUBES INTEGRITY MAINTENANCE OF the VVER-440 and VVER-1000 NUCLEAR POWER PLANTS

The problem of the steam generators (SG) tubes integrity maintenance of the nuclear power plants is one of the most actual problems of world nuclear engineering.

This problem has arised on the western manufacture NPP more 20 years ago, and then and on the Russian NPP.

The urgency of the problem of the steam generators tubes integrity maintenance of the operational and new NPP is defined by that damages:

- Lead to decrease of NPP economic parameters because there are:

- necessity of replacement of SG with greater number muffled tubes. So, the cost of replacement more than 200 SG on the NPP of western manufacture has reached 12 billion USD and today continues to grow; in Russia replacement only 4 SG is made;

- essential underproduction of the electric power because off-schedule shutdowns and long time of the EC control, repair and muffling;

- Increase of material inputs and increase of dozes of an irradiation of the NPP personnel because of tubes repair and control;

- Makes threat of NPP radiating safety of the atomic power station (because of small and average leaks of the first contour in the second);
- Makes threat of NPP nuclear safety (in case of break more than one tubes).

- Is a challenge problem; so, it is solving already more than 20 years and till now up to the end is not solved. Proceed tubes muffling and SG replacements. For example, in February of 2005 after EC of two SG on the " St. Lucie " NPP (USA) it has been muffled 798 and 838 tubes. Replacement of these SG is planned. On the various operational NPP cases of tubes break are observed.

By consideration of a problem of the SG tubes integrity maintenance following basic questions have been solved:

1. The reasons of not design damages of tubes are certain.
2. Criterion function (a task which faces to system) is certain nuclear power plants modern means and technologies is certain..
3. Existing on the NPP technologies and methods of tubes integrity maintenance, first of all stipulated by SG maintenance instructions, is analysed; the estimation of efficiency these technologies and methods is lead. On the basis of the received results the system of SG tubes integrity maintenance is developed.
4. Separate elements of the system are modified up to a condition necessary for performance by system of the criterion function.

The technology of the SG tubes integrity maintenance gy) is developed in 1996 for a case of maintenance of SG reliable operation of Balakovskaja NPP (block №2). In connection with positive experience of application of this technology on BalNPP and in view increase of a urgency of a problem of tubes integrity maintenance on other NPP, there was a task to generalize the experience received on BalNPP and to apply it to all units with VVER-440 and VVER-1000 on which there were damaged SG tubes.

Such work has been executed in 2003. Result of this work there was guidance РД ЭО-0552-2004 «Methodical recommendations on system methodology application for VVER-440 and VVERS-1000 SG tubes integrity maintenance» (further – MR).

Methodical recommendations MR have commissioned on all the NPP with VVER in 2004.

Actually MR applied only on those NPP units on which were available SG with the damaged tubes. Such units was 6 in Russia. On one block MR did not apply for the organizational reasons.

The heaviest consequences from SG tubes unreliable are connected with necessity of an off-schedule shutdown of the unit for liquidation of intercircuit leaks. Thus, one of the main tasks of MR application is maintenance of SG tubes reliability by criterion of resistance to formation of intercircuit leaks (a leak from the first circuit in the second) during operation. Or in other words, It is necessary to exclude off-schedule shutdown units because of intercircuit leaks.

The mentioned above problem is solved with a high degree of efficiency on the basis of application of MR. In all cases operation of units after MR application passed successfully, without off-schedule shutdown for the reasons of inadmissible leakings from the first in the second contour.

On figure 1 change of quantity off-schedule shutdown of units before and after MR application is shown. From figure 1 it is visible, that on all units where MR applied off-schedule shutdown was not observed (curves 1,3,4 and 5). Exception makes one unit on which MR did not apply because of the organizational reasons (curve 2). On this unit for the considered period has occured two off-schedule shutdown (curve 2).

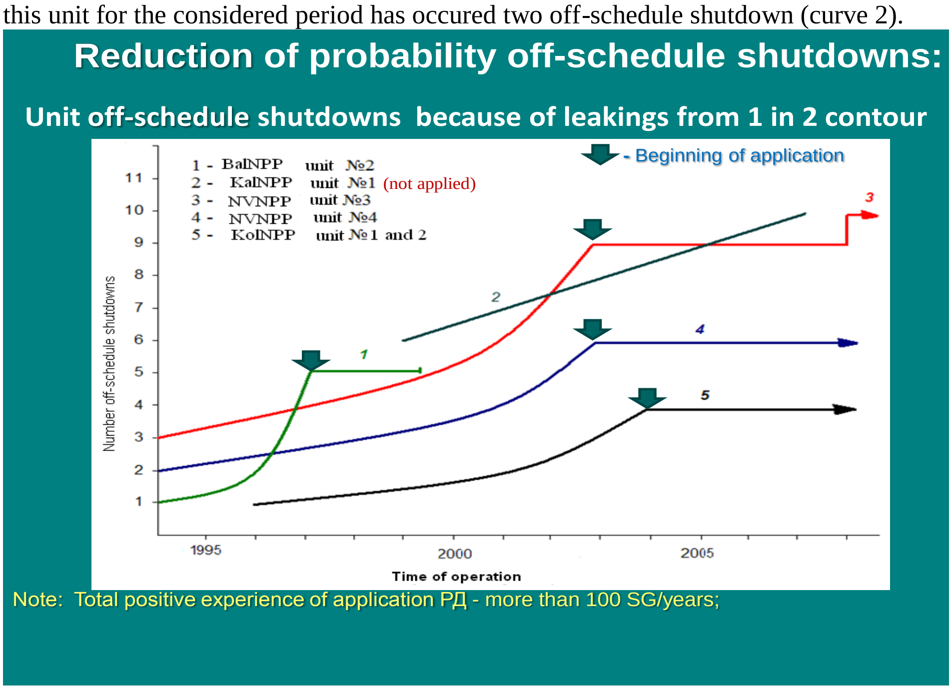

Figure 1

One off-schedule shutdown has occured also on NVNPP, unit 3, in 2008 (curve 3 on figure 1). That is connected with discontinuance of performance of MR recommendations for the organizational reasons in scheduled shutdown in 2007. This case testifies that is necessary for applying with high carefulness all MR recommendations, otherwise not design degradation of SG tubes process renews.

Other technical results received during development and application of system technology of SG tubes integrity maintenance

1 Termination of not design process stress corrosion cracking of SG tubes

In figure 2 dynamics of increase of number of leaky tubes on a steam generator with the most damaged tubes is presented. It is visible, that before MR application the number of leaky tubes was increased with acceleration. After MR application speed of increase of number of leaky tubes has fallen practically up to zero.

2 The Guaranteed exception of an opportunity of sudden break of tubes with formation of the big leak

Exception of an opportunity of sudden break of tubes with formation of the big leak during operation is of great importance for NPP safety as in this case there can be radiating consequences and conditions for initiation of failure with nuclear consequences (in case of break of two and more tubes) are created.

MR application in full volume it is guaranteed excludes an opportunity of tubes break during operation. The probability of tubes break becomes equal to zero after performance of MR recommendations. Some results of an estimation of reliability of SG tubes in interrelation with carried out actions are shown in figure 3. It is visible, that the set of actions of last variant in figure 3 provides impossibility SG tubes break even in the most rigid mode - in case of pressure drop in second contour of SG up to zero (for example, as a result of break of a steam line).

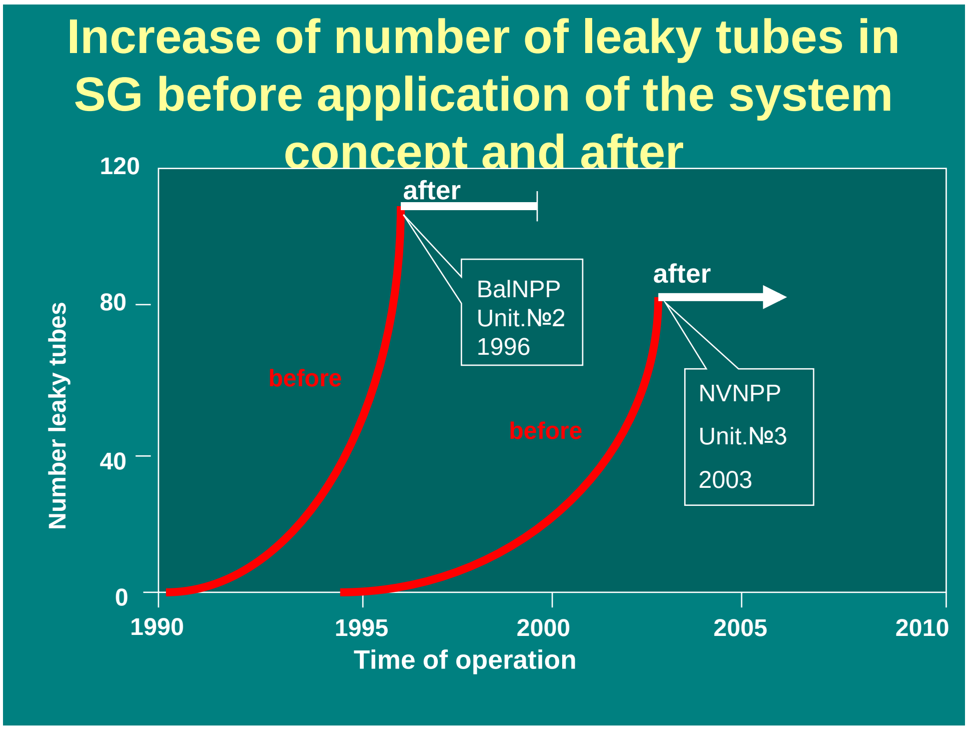

Figure 2

3 Increase of the detectability of the eddy current (EC) in-service inspection

After performance of MR recommendations the detectability of eddy current in-service inspection (EC) raises twice (Curves in figure 4).

4 Increase of detectability of a pneumatichydraulic density inspection of SG tubes

Detectability of a pneumatichydraulic density inspection of SG tubes after performance of MR recommendations raises from 50 % up to 100 %. (points in figure 4).

5 Decrease in expenses for operation of steam generators with damaged tubes

As a result MR performance are reached as well other results having both technical and economical value for the NPP, namely:

1) Development of the electric power is increased because the termination off-schedule shutdown of units and also because reduction of terms of scheduled preventive repair in which EC control of SG tubes was on «a critical way».

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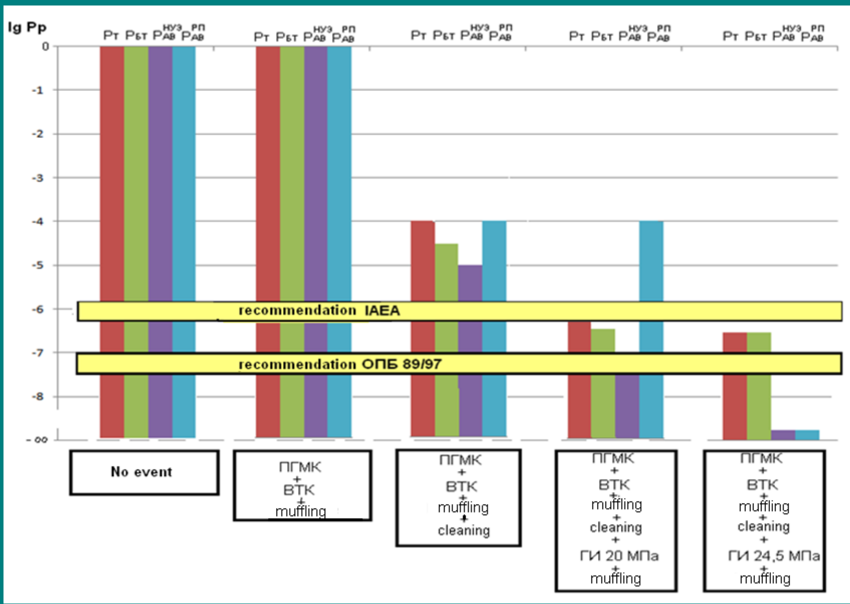

Influence on probability of destruction of steam generator tubes because of various technical actions

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Researched actions

ПГМК – Pneumatic-hydraulic test of SG tubes integrity;
ВТК – Eddy-current test
ГИ – Hydrotest

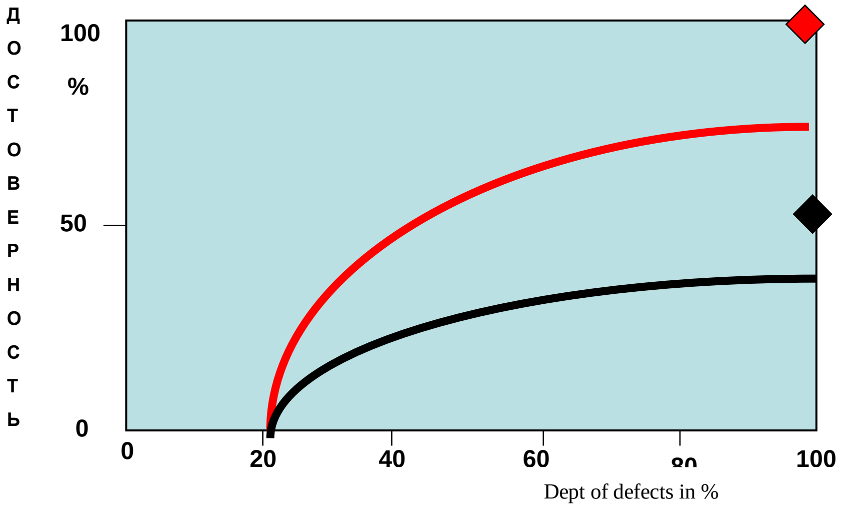
Researched events

P(Т) – Probability occurrence of a leak < 5 liters/h;
P(БТ) – Probability occurrence of a leak > 5 liters/h;
P(АВ) (НУЭ) – Probability sudden occurrence of the big leak because of break of a tube in Normal conditions operation mode ;
P(АВ) (РП) – Probability sudden occurrence of the big leak in emergency operation with break of a steam line.

Figure 3

2) Expenses for SG maintenance service are reduced because volumes of EC control and muffling of leaky tubes are reduced.
3) Disappears necessity of replacement of steam generators as there is an opportunity of them reliable operation not only during design term of operation in 30 years, but also at its substantial growth.

Figure 4.
Detectability of EC and pneumatichydraulic density inspection of SG tubes



EC before HT and CC; EC after HT and CC; PH before HT and CC; PH after HT and CC

So, application of the strength safety system concept on the NPP with VVER for SG tubes integrity maintenance has given technical and economic benefit, namely:

- Reliability and Safety of SG tubes have raised;
- Have stopped off-schedule shutdown of power units because of tubes leaks;
- Sudden occurrence of the greater leaks essentially exceeding 5 litres at hour, becomes impossible;
- A level of leakings in SG after MR application or It is not observed, or is at the bottom admissible level;
- The condition of tubes is stabilized, in case of occurrence insignificant leakings their size during operation practically does not vary, even at the cycles connected with unit shutdown;
- Disappears necessity for great volumes of EC inspection;
- SG lifetime by criterion «number muffled tubes» increases and volumes of muffling of leaky tubes are reduced;
- Underproduction of the electric power because of tubes leaks falls up to zero, thus cost of SG maintenance service decreases.

In the monography examples of the decision of other actual problems arising on NPP are given also.