SOFTWARE AND METHODICAL TOOLS FOR NUCLEAR PLANTS PROBABILISTIC SAFETY ANALYSIS AND SAFETY MONITORING IN RUSSIA

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In recent decades probabilistic methods for safety analysis were well advanced. Probabilistic safety analysis is one of the efficient methods for nuclear plants safety study. It provides systematic evaluation of plant safety level and basis for developing of technical measures and operational procedures to increase safety.

Probabilistic methods to study nuclear plants safety require developing and introduction of appropriate methods and software infrastructure, which allows obtaining information about the nuclear plant safety level at all life cycle stages.

JSC "Afrikantov OKBM" has developed methods and software allowing to perform probabilistic study of nuclear plants safety and also to implement safety and reliability monitoring during nuclear plant operation.

I. NUCLEAR PLANTS PROBABILISTIC SAFETY ANALYSIS SOFTWARE SYSTEM

To perform probabilistic safety analysis of nuclear plants in JSC "Afrikantov OKBM" CRISS software system is using. The CRISS software system has been developed and improved by "Afrikantov OKBM" during past 25 years and it is the first domestic software put into practice of probabilistic safety assessment for nuclear plants in Russia.

Different generations of the CRISS software system have been broadly used by "Afrikantov OKBM" since the late 1980s to support the design and to perform the PSAs of nuclear plants of different types (Table 1).

TABLE I. Phases of Russian CRISS software system development

Time interval	System	Practical use
Late 1980s – early 1990s	TREES CRISS	BN600, BN800, small and medium reactors
Late 1990s	CRISS 2.0	
2001 – 2002	CRISS 3.0 CRISS 3.1	PSA of GT-MHR project PSA of floating power unit
2004 – 2009	CRISS 4.0	PSAs of BN600, small and medium reactors
Since 2009	CRISS 5.1	PSAs of BN600, BN800, BN1200 PSA of KLT-40S floating power unit RITM-200 nuclear incebreaker's propulsion plant

In 2011 fifth generation of CRISS software system CRISS 5.1 was licensed by Russian regulatory body Rostechnadzor for performing of nuclear facilities probabilistic safety analysis.

CRISS 5.1 software operating experience, an increase in the complexity of nuclear plants probabilistic models as well as expanding the range of probabilistic safety analysis tasks identified the need for further development of the software, first of all, in terms of improved performance of computational algorithms and expanding of the models used.

In 2012 - 2015 CRISS 5.2 and 5.3 software versions have been developed. These versions included implementation of an improved minimal cutsets generator allowing to increase in the 2 - 3 times the calculation speed of integrated probabilistic nuclear plants models analysis. In 2015 "Afrikantov OKBM " developed PSA software system CRISS 6.0. The main feature of CRISS 6.0 software system is the introduction of the automated human reliability analysis subsystem.

CRISS 6.0 software system is designed for modeling and analysis of safety systems and a nuclear plant as a whole during the probabilistic safety analysis at all stages of the nuclear plant life cycle. The CRISS software system was developed on the base of "client-server" architecture.

Using the "client-server" architecture for PSA software system enables collaboration of PSA developers with a single logical-probabilistic model, and provides the following benefits:

- exclusion of expenses of time, the potential for errors associated with the integration of models of safety systems, and accident sequences developed by different users;
- increase the speed of the software response due to the transfer of all data procedures to the server;
- ensuring data integrity with server-side procedures;
- the ability to create backup copies of all development projects to avoid data loss and data recovery when a hardware failure occurs;
- user rights to make changes to logical-probabilistic model are differentiated.

CRISS 6.0 software uses a two-level "client-server"architecture. Software server part includes relational database, database management and administration procedures, and client software includes a database interface and user tools: fault trees and event trees graphical editors, tools to perform probabilistic models analysis and to generate reports. As the database management system the Oracle Database 11g Express Edition is used.

CRISS 6.0 software system allows to:

- accumulate in database information about safety systems, initiating events, human errors, components reliability data including common cause failure (CCF) models parameters, initiating events frequencies, operability tests scheduling for safety systems components;
- manage the relational databases;
- create and edit fault trees using AND, OR, M/N, negation gates;
- edit models logic using house events;
- create and edit event trees using transfers;
- perform fault trees and event trees qualitative and quantitative analysis with automated CCF modeling using the following CCF models: α- and β- factors, Multiple Greek Letters, binomial failure rate;
- perform accident sequences analysis using function events success treatment;
- perform calculation of the second and third order approximations of the top event probability;
- perform importance analysis, sensitivity analysis and uncertainty analysis;
- perform failure mode and effects analysis (FMEA);
- implement HRA procedures using THERP and HRA methodic;
- edit minimal cutsets
- import databases and logic models (fault trees and event trees) from other PRA software (RiskSpectrum Professional and SAPHIRE);
- print and save fault trees and event trees graphic images, qualitative and quantitative analysis results, importance analysis, sensitivity analysis and uncertainty analysis results in Microsoft Word format
- develop new report templates and to edit existing templates;
- differentiate users access rights;

Graphic images of logic models developed by using CRISS software system are presented at Fig. 1.

II. NUCLEAR PLANTS RELIABILITY AND SAFETY MONITORING SYSTEM

The validity of probabilistic safety analysis results is largely determined by using specific database containing information on nuclear plant equipment reliability indices including the parameters of the CCF models, the frequencies of initiating events, operability tests scheduling for safety systems components. Receiving the above mentioned data is only possible in the process of nuclear plants operation monitoring.

During operation of nuclear plants ensuring of reliability and safety includes the development of sustainable operating experience feedback. Information on operating experience shall be examined for any precursors to, or trends in, adverse conditions for safety, so that any necessary corrective actions can be taken before serious conditions arise (Ref. 1), Requirements to operating experience feedback are defined in regulatory requirements and IAEA recommendations. According to these requirements “Afrikantov OKBM” developed and deployed the analytical reliability and safety monitoring system to monitor reliability and safety of nuclear plants.

The analytical reliability and safety monitoring system for the BN-600 unit was developed and implemented by OKBM and Beloyarsk NPP based on the information retrieval system “Istochnik-BN“ (Ref.2).

The information retrieval system “Istochnik-BN“ was developed on the base of database management system Oracle; it has the “client-server“ architecture and supports large number of users. The information retrieval system uses the universal data format to collect information concerning equipment operation experience. The program ensures information storage in the form of a certain structure, data systematization and processing; it has the developed data search and exchange system.

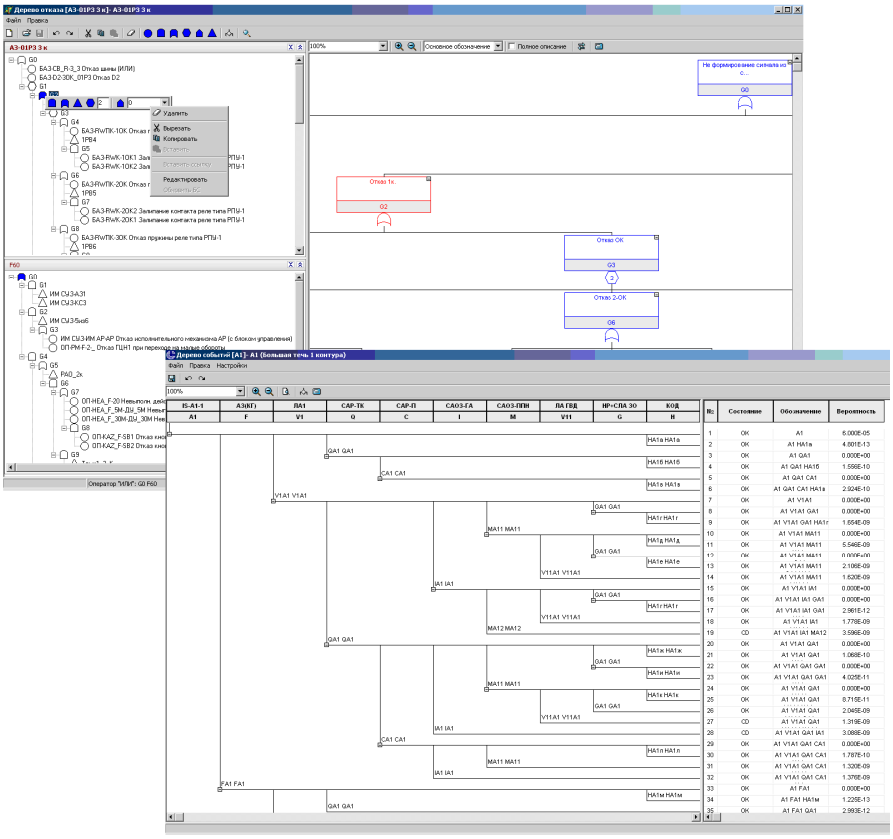

Fig. 1. Fault trees and event trees graphic editors

The main goals of analytical reliability and safety monitoring system introduction include enhancement of plant operation based on modern information technologies, nuclear plant safety and reliability improving, decisions on plant lifetime extension and formation of database for new nuclear power plants design.

"Istochnik-BN" system allows to:

- automatically calculate reliability indices and safety indicators for nuclear plants by operation years (capacity factor, operation factor, availability factor, portion of unplanned outages, portion of planned outages and number of unplanned scrams per 7000 h of operation);
- automatically plot distribution charts of nuclear plant malfunctions (power reduction and unplanned outages), release amount, ejection of radioactive products to environment from the nuclear plant, personnel exposure doses at the nuclear plant by operation years;
- accumulate data for the operation model of certain equipment or group of equipment providing a possibility of comparing operation modes against the design operation model to monitor the residual lifetime of equipment;
- automatically calculate reliability indices for critical equipment by type of equipment based on operation experience (total operating time, failures number and failure rate, average mission time to failure, probability of failure on demand);
- automatically plot distribution charts for number of failures for single-type equipment by operation years, as well as relations for the failure rate and availability of single-type equipment on operating time;
- automatically plot charts for number of failures for single-type equipment by operation years, as well as dependences of the failure rate and availability of single-type equipment on operating time;
- promptly search for information by the certain set of criteria;
- automatically make reports on operational experience of critical equipment within the BN-600 unit.

The information retrieval system "Istochnik-BN" is integrated with the maintenance and repair planning system of the Beloyarsk NPP concerning provision of information interaction between systems. "Istochnik-BN" system along with OKBM is also installed at the Beloyarsk NPP; data are electronically exchanged between these two enterprises.

Interface of information retrieval system Istochnik is shown in Fig. 2.

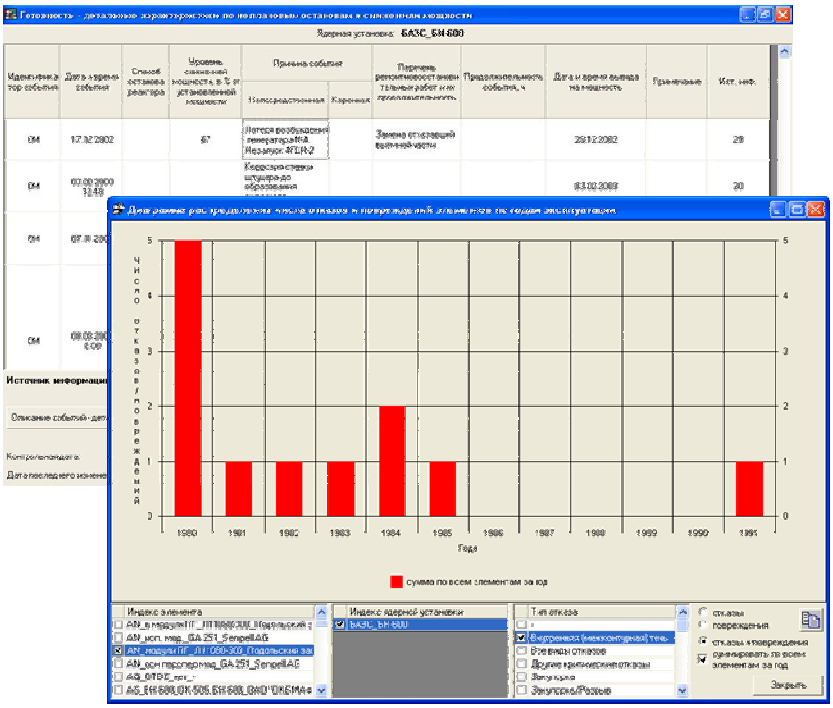

Fig. 2. Interface of information retrieval system “Istochnik-BN“

Since the beginning of the power unit operation in 1980 up to now the database on BN-600 equipment reliability, availability and malfunctions including information on unplanned loop shutdowns and scrams was created by the information retrieval system “Istochnik-BN“. Data accumulated are updated at regular intervals, and they are used to prepare annual reports on field supervision of BN-600 operation.

The analytical reliability and safety monitoring system for icebreakers’ nuclear propulsion plants was realized by “Afrikantov OKBM” also on the base of the information retrieval system Istochnik (Ref.3). Information retrieval system Istochnik is using by icebreakers’ nuclear propulsion plants operator. In information retrieval system Istochnik database on plant and equipment reliability, availability and malfunctions was created. Database comprises information from the beginning of nuclear propulsion plants operation. Accumulated data are updated at regular intervals, and they are used to prepare monthly and annual reports for regulator.

III. RISK MONITOR SYSTEM

An important area of probabilistic methods use during the operation of nuclear plant is the introduction of risk monitoring.

To perform the task of nuclear plant safety level evaluation during operation using probabilistic methods “Afrikantov OKBM” together with the Beloyarsk nuclear power plant has been developed and introduced into industrial operation at Unit 3 risk monitor system RIM.

The risk monitor system RIM was developed on the base of client-server architecture using the common administered database where user rights to make changes are differentiated. As the database management system the Oracle Database 11g Express Edition is used. Risk monitor system RIM utilizes actual PSA model developed in software system CRISS 5.1 and revised according to the Living PRA model requirements (Ref.4).

Risk monitor system RIM allows to:

- estimate plant risk for various configurations of plant systems and different initiating events;
- calculate the allowed outage time for certain configurations of plant systems produced by removing equipment from operation for repair or maintenance;
- assess the cumulative risk for nuclear plant over an assigned time period;
- check that safety margins are fulfilled for different configurations of plant systems;

- prepare equipment maintenance and repair schedules based on information about the current risk level;
- grade power unit equipment according to importance for plant safety;
- make prediction estimates of the nuclear plant risk for cases when equipment fails and normal operation is violated;
- work out reporting documentation that contains information on the nuclear plant risk level during operation.

RIM client software provides the ability to monitor risk in two modes:

- in real time mode taking into account the current system configuration and status of power unit during its operation;
- in planning mode for the safety level assessment during planning of the maintenance and repair of systems important to safety.

Interface of risk monitor system RIM in various modes is shown in Fig. 3.

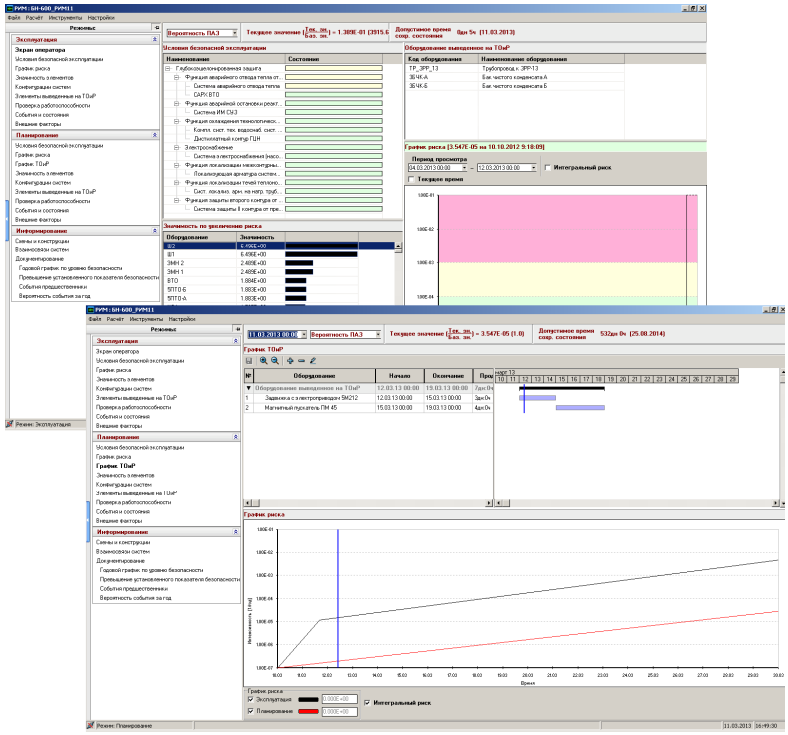

Fig. 3. Interface of risk monitor system RIM

Introduction of risk monitor system RIM at Beloyarsk NPP Unit 3 was launched in 2011. Based on trial operation results and users wishes software has been finalized. Interrelation between the risk monitoring system RIM and the maintenance and repair planning system, as well as with the analytical reliability monitoring system "Istochnik-BN" available at the Beloyarsk NPP unit 3 was ensured. The RIM system is connected with the specified systems using a special program namely an application server. Exchange of information between programs is made on a special TCP protocol with regulated data formats. A connection with the maintenance and repair planning system supplies the risk monitor system with actual information on the current equipment condition and planned maintenance and repair. The information retrieval system "Istochnik-BN" gathers information on reliability of components important for safety and on the frequencies of initiating events making it possible to update the relevant database of the risk monitor system.

In 2015 RIM risk monitor system has been introduced into industrial operation at the Beloyarsk nuclear power plant BN-600 unit.

IV. CONCLUSIONS

1. Probabilistic methods are effective and time - tested tools for nuclear plants safety assessment and monitoring.
2. "Afrikantov OKBM" developed and licensed methods and software to solve the tasks of:

- full- scale probabilistic safety analysis of different levels;

- risk monitoring during nuclear plant operation;
- analytical reliability and safety monitoring for nuclear plants and components.

3. Methods and software mentioned above are being used successfully for nuclear plants safety analysis and assessment at all lifecycle stages.

REFERENCES

1. INTERNATIONAL ATOMIC ENERGY AGENCY, *Fundamental Safety Principles, Safety Fundamentals*, IAEA SAFETY STANDARDS SERIES No. SF-1, IAEA, Vienna, Austria (2007)
2. L.V. ABRAMOV, A.M. BAKHMETYEV, I.A. BYLOV, YU.L. KAMANIN, E.A. ZVYAGIN, YU.A. MAKHAEV, E.L. ROZENBAUM, V.A. SHAMANSKY, "Introduction of reliability, safety and risk monitoring technology in BN-600 power unit" , Proceedings of an International Conference Fast Reactors and Related Fuel Cycles: Safe Technologies and Sustainable Scenarios FR13, Paris, 4- 7 March 2013, International Atomic Energy Agency (2013).
3. ALEXANDER M. BAKHMETYEV, IGOR A. BYLOV, ALEXANDER V. MOREV AND ALEXEY V. BAKLANOV "Developing of Safety Analysis and Monitoring Methods Applying to Small Modular Reactors", Small Modular Reactors Symposium ASME 2014, Washington, DC, USA, April 15–17 , American Society of Mechanical Engineers, (2014).
4. RISK MONITORS *The State of the Art in their Development and Use at Nuclear Power Plants*, NEA/CSNI/R(2004)20, OECD, Paris, France (2004).