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Methods Used in Russia for Analysis of NPP Operating Experience. Application of the Results of Analysis for Decision-Making in the Field of Nuclear Safety Regulation

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1. Introduction

At present there are 31 power units in Russia under operation, 9 of them – with VVER-1000 reactors, 6 – with VVER-440 reactors, 11 – with RMBK-1000 reactors, 4 – EGP reactors, 1 – with BN-600 reactor.

Department for nuclear power plants safety regulation of the Federal Environmental, Industrial and Nuclear Supervision Service (Rostechnadzor) and Scientific and Engineering Centre for Nuclear and Radiation Safety (SEC NRS) process, analyze and use information on the NPPs operating experience to enhance their safety.

The main information sources on the NPP operating experience are the following:

- reports on violations in the NPP operation;
- data base on violations in the NPP operation that has been kept in SEC NRS since 1988;
- annual reports on NPP safety that are prepared by the nuclear power plants according to the requirements of the regulatory authority;
- results of the NPP inspections.

The results of analysis of the data base information on violations in the NPP operation and results of analysis of the annual reports on the NPP safety are used by Rostechnadzor and SEC NRS for the following purposes:

- to reveal violations in operation and conditions that are precursors of essential degradation of the systems and components of the power unit, and can cause severe accidents;
- to monitor, to reveal and to forecast the trends in the state of the NPP operational safety;
- to identify areas that require special, higher attention for ensuring safe operation of the NPP;
- to assess efficiency of measures taken for enhancement of the NPP operational safety;
- to elaborate recommendations for enhancement of the NPP operational safety and for NPP safety regulation.

2. Methods used for analysis of information on the NPP operating experience

To analyze information on the NPP operational experience deterministic method is used for assessment of violations in NPP operation and NPP performance and probabilistic method is used for assessment of violations in NPP operation.

3. **Deterministic method for assessment of violations in the NPP operation and NPP performance** is based on analysis of violations in the NPP operation and NPP performance from the view point of what safety criteria, which are contained in the regulatory documents on safety, are violated in operation; what is the degree of violations.

With respect to analysis of violations in the NPP operation this method covers the following:

- assessment, if the limits and/or conditions of safe operation are violated;
- assessment, if a violation in operation is a precursor of severe accident;
- revelation of equipment failures and human errors that "overlapped" with the initiating event, i.e. they occurred during propagation of the violation and were not included in the design scenario for this violation;
- revelation of the root causes of violations in operation, equipment failures, human errors;
- revelation of the common cause failures, repeated failures of the equipment of the safety systems, systems for normal operation, human errors;
- revelation of deficiencies in operational and technical documentation;
- revelation of deficiencies in organization of operation and training of the personnel.

Concerning analysis of the long-term characteristics of the NPP operation within a certain time period, this method covers evaluation of the following:

- efficiency of radiation protection of the population, environment and personnel;
- management of spent nuclear fuel;
- storage and treatment of radioactive waste;
- the state of fire and physical protection at the NPP.

For analysis of trends in the above NPP performance characteristics and for their control such a tool of the deterministic analysis, as safety indicators (SI), is used.

In the process of processing of the data base information on violations in the NPP operation and annual reports on the NPP safety, Rostechnadzor and SEC NRS define the following SI and use them in their activity (the main SI are enlisted here):

2.1.1. Capacity indicators

- Capacity factor (CF);
- Availability factor;
- Time use factor.

2.1.2. Indicators of the state and reliability of the physical protective barriers

- Indicator of the fuel element reliability (fuel element integrity);
- Indicator of the reactor core cooling circuit integrity;
- Results of non-destructive control of the equipment and pipelines metal in the primary circuit and systems important for safety;
- Leak from containment (integrity of containment).

2.1.3. Indicators of the state of the protective systems

- Numeric values of non-availability indicators of the safety systems (SS);
- Number of failures in the SS (on average per unit per year);
- Number of SS actuations, including:
- Number of violations in operation (incidents) with dependent and independent failures in the SS, overlapped with initiating failure in each incident;
- Number of dependant and independent failures in the SS, overlapped with initiating event in each incident.

2.1.4. Operating performance indicators

- Indicator of power fluctuation intensity;
- Total number of incidents (on average per unit per year);
- Number of accidents with actuation of emergency protection system (EP) (on average per unit per year);
- Number of incidents with violation of safe operation limits and conditions;
- Number of common cause failures;
- Number of repeated failures;
- Number of failures in the systems of normal operation (SNO) (on average per unit per year);
- Number of deficiencies in organization of the NPP operation (on average per unit per year);
- List of deviation from established water chemistry values in the main process circuit of the power unit;
- Indicators of exhaustion of the design service life of the basic equipment;
- Quality indicator of maintenance and repair; number of violations in the NPP operation due to lack of checks, maintenance of systems important for safety;
- Lists of actions to enhance safety;
- The list of emergency trainings and data on their performance.

2.1.5. Actions of the personnel

- Number of human errors (on average per unit per year);
- Number of cases of low safety culture (on average per unit per year).

2.1.6. Effectiveness of radiation protection of population, environment and personnel

- Radioactive releases above permissible limits;
- Number of workers exposed to radiation doses above permitted limits;
- Collective exposure dose.

2.1.7. Handling of spent nuclear fuel

- Extent of the spent fuel pool filling-up.

2.1.8. Storage and treatment of radioactive waste

- Filling-up of tanks for storage of liquid radioactive waste;
- Filling-up of storage facilities for solid radioactive waste.

2.1.9. The state of fire and physical protection of the NPP

- Data on fires and inflammations;
- List of planned measures to improve fire safety, including time schedule and executors;
- Information on the state of physical protection.

Figures 1-4 show the trends of fluctuation of the following safety indicators in 1995-2006:

- number of violations in NPP operation;
- number of actuation of emergency protection (EP);
- number of failures in the safety systems (SS) and systems of normal operation (SNO);
- number of human errors.

The figures demonstrate that since 1998 there is a trend in decreasing the above indicators.

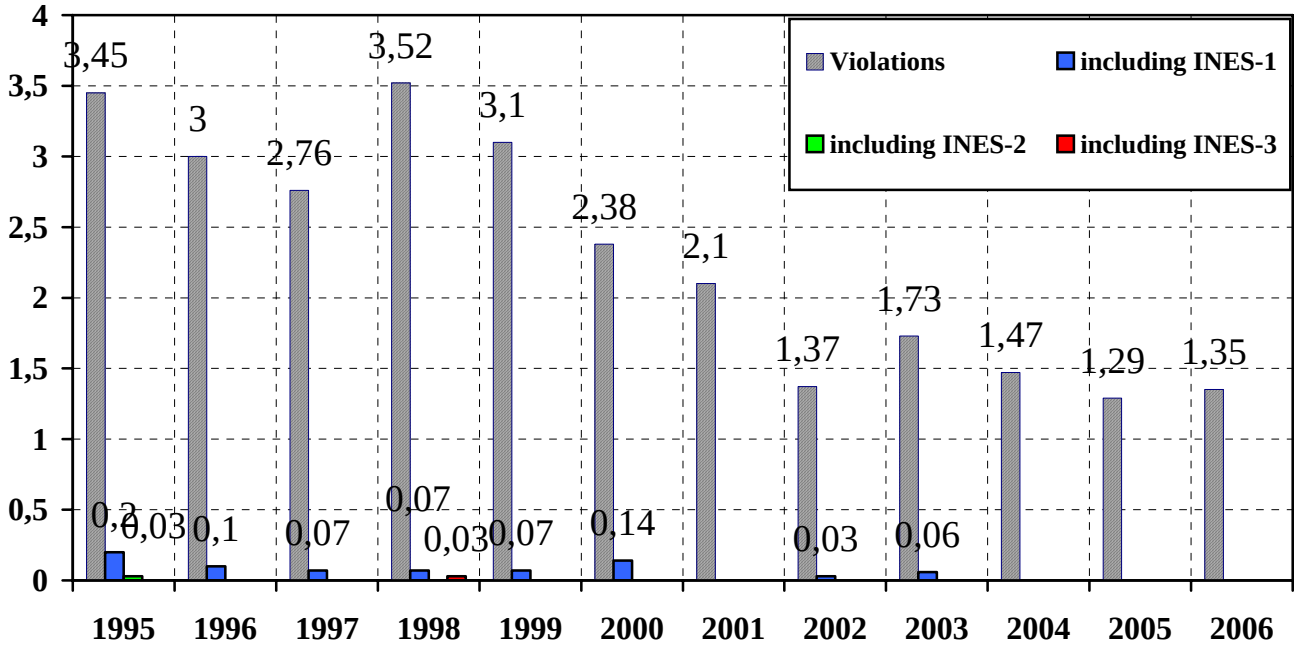

Fig. 1. The number of violations in NPP operation in Russia in 1995- 2006 (on average per unit). Violations evaluated as level 1, 2, 3 by «INES» scale are colored.

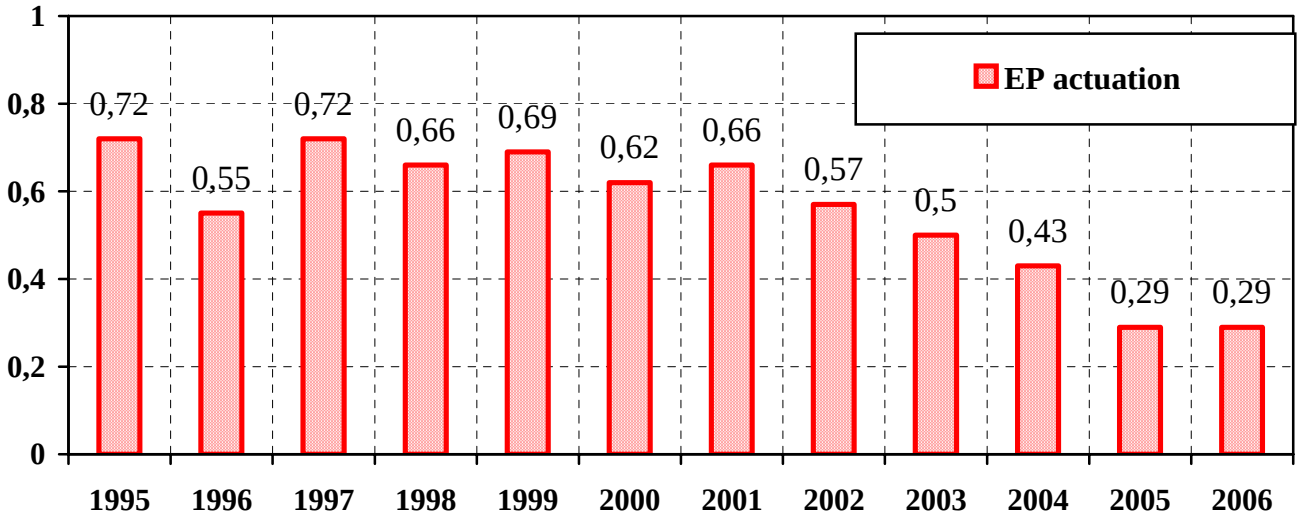

Fig. 2. The number of actuations of the emergency protection at Russian NPP in 1995-2006 (on average per unit).

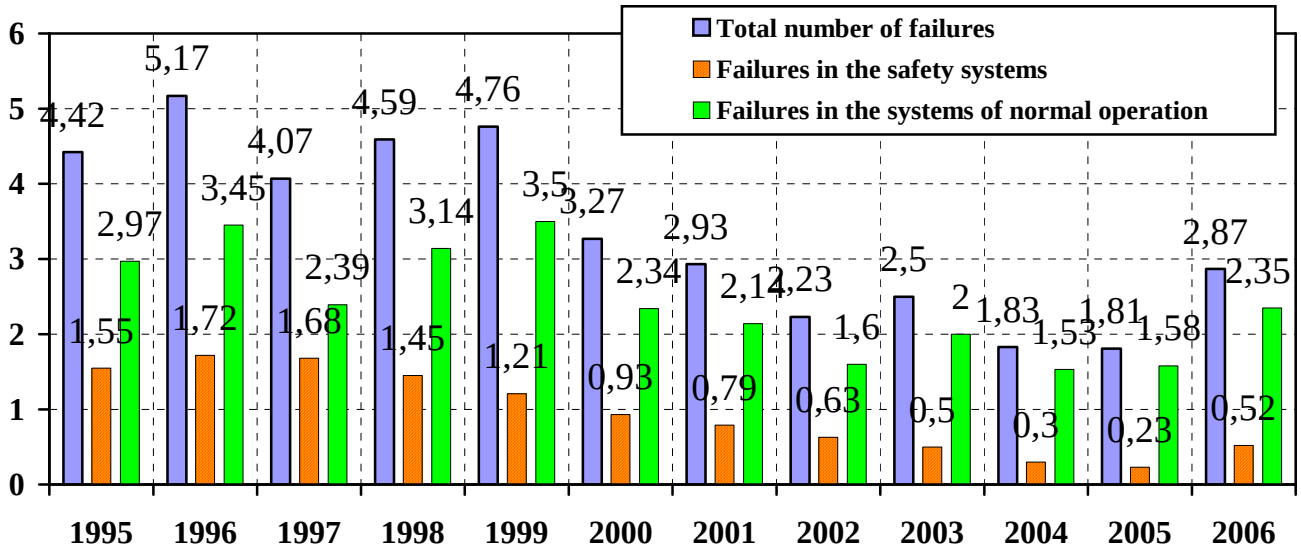

Fig. 3. The number of failures in the safety systems and systems of normal operation at Russian NPPs in 1995-2006 (on average per unit).

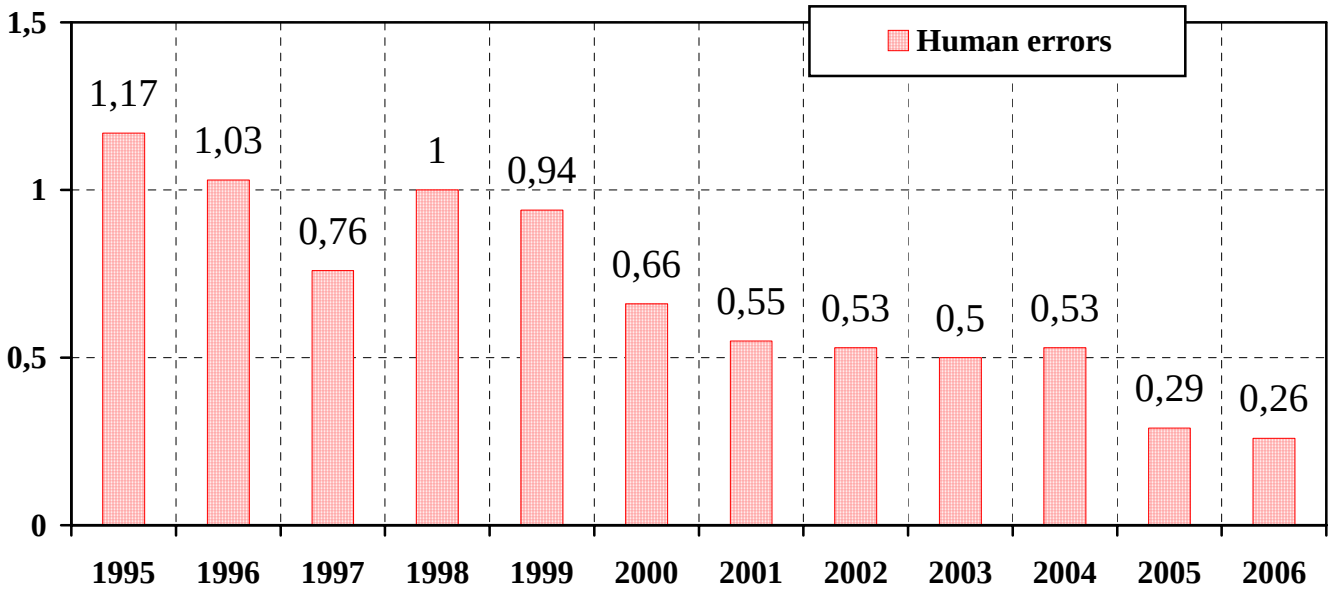

Fig. 4. The number of human errors at NPP in Russia in 1995-2006 (on average per unit).

2.2. Probabilistic method for assessment of violations in NPP operation

Probabilistic assessment of violations in NPP operation is the analysis of violations with the use of the probabilistic safety assessment method (PSA). The assessment consists in defining the probability that the violation in the NPP operation being under analysis will develop into the accident with core melt. The assessment enables to define importance for safety of the being analyzed violations in operation; to reveal violations that are the precursors of the severe accidents.

At present in the system of Rostechnadzor assessment of violations in the NPP operation with the use of PSA methods has not yet been widely spread. The first works on assessment of violations in operation of power units 1, 2 in 2004-2006 were performed at Leningrad NPP. SEC NRS began the work on probabilistic assessment of violations in NPP operation with VVER reactors. At present a requirement is being introduced into the regulatory documents on NPP safety that the operating organization shall perform the probabilistic safety assessment of violations in NPP operation.

3. Use of results of analysis of information on NPP operating experience in regulatory activities

The results of analysis of violations in NPP operation, annual reports on NPP safety, trends in NPP safety indicators, as well as results of NPP inspections are used by Rostechnadzor and SEC NRS in the licensing process, in review of documents justifying NPP safety:

- for extension of licenses;
- for extension of the service life (beyond the design service life)
- for upgrading;
- for making changes in the technical specification.

Results of this analysis are also used in making programs for inspection of the NPP units.

Basing on results of analysis and results of inspections at the NPP, the following actions could be taken:

- suspension, termination of the licenses;
- introduction of the special operational mode;
- issuance of prescriptions, introduction of license conditions.

Below there are some examples of response of the regulatory authority to the facts of revelation of safety deficiencies, «week point», revealed during operation:

- introduction of a special mode of operation of the power units RBMK-1000 of the first generation in 1990: limitation of their power (not more that 70% of the nominal power) due to safety deficiencies revealed in the process of operation. This limitation was kept within more than 10 years – up to elimination of safety deficiencies;
- prescription on performance of the work program for enhancement of the control rods reliability of the reactor control and protection system and introduction of the operational procedure of additional periodical testing of the CPS CR at NPP power units with VVER-1000 (1993-1997) after some cases of stucking of the CPS CR;
- decision not to give a permission for the start-up of the unit 3 of Kalinin NPP after scheduled maintenance before introduction of the control rods stripping («reciprocation») procedure after unavailability of 22 control rods was revealed at the power unit 5 «Kozloduy» (Bulgaria), March 2006 (the example of the use of international experience of the NPP operation in regulatory activity).
- prohibition to increase the operational limits and safe operation limits by the activity of bleed water of steam-generators and activity of steam/gas mixture at the turbine ejector

outlet, units 3, 4 Novovoronezh NPP, as a response to the effort made in 2003 to get a permission for the increase;

- introduction of the license conditions for operation of unit 2 Kalinin NPP: to perform measures on decrease of leak from the containment with the aim to achieve design value of leak in testing of containment: 0,3 % per 24 hours with the average overpressure 0,7 at. (2004).