РОСАТОМ

ГОСУДАРСТВЕННАЯ КОРПОРАЦИЯ ПО АТОМНОЙ ЭНЕРГИИ «РОСАТОМ»

APPROACHES TO SAFETY JUSTIFICATION OF SFR DESIGNS

V. Rachkov, Y. Ashurko

Submitted to the IAEA-GIF Workshop on Operational and Safety Aspects of Sodium Cooled Fast Reactors,

Vienna, Austria, 23-25 June 2010

GENERAL INFORMATION

All activities in the area of nuclear energy use in Russia are regulated by a great number of documents issued by a special regulatory authority exercising among other things the state supervision of nuclear and radiation safety (currently called the Federal Service for Environmental, Technological and Nuclear Supervision — Rostekhnadzor).

The principal goal of regulatory documents is assurance of safe nuclear energy use that excludes exceeding permissible limits in radiation impact on environment, population and personnel of nuclear sites.

The regulatory documents take into consideration both national experience and recommendations of relevant documents of the IAEA and other international organizations, and these documents are periodically updated on a base of new experience gained.

HIGH-PRIORITY REGULATORY DOCUMENTS (1/2)

The documents containing the requirements to nuclear power plants (NPPs) and reactor facilities (RFs) at all stages of their life (development, design, construction, operation, decommissioning) including NPPs with SFR are of particular interest for us.

Most of these documents contain regulations and requirements to specific RF systems and equipment, specific aspects of reactor technologies, approaches and stages of their implementation in contrast to a number of documents referring to the high-level documents and specifying the most general norms and rules that have to be complied with in managing radiation-hazard facilities.

Among the high-level documents the following basic documents on technical aspects of nuclear and radiation safety have to be highlighted:

- *«General Regulations on Ensuring Safety of Nuclear Power Plants. OPB-88/97» (revised in 1997);*
- *«Nuclear Safety Rules for Reactor Installations of Nuclear Power Plants. PBYa RU AS-89» (the latest amendments introduced in 2007).*

HIGH-PRIORITY REGULATORY DOCUMENTS (2/2)

РОСАТОМ

NPP siting is performed based on the requirements of a special document «Nuclear plant siting. Basic safety criteria and requirements» and takes into account all distinctive features of the site including potential impact of natural and technologically induced factors on NPP safety (seismic activity, specific relief features, typical natural phenomena, potentially hazardous production facilities etc.) as well as potential NPP impact on the population and environment.

The most general requirements to RF and NPP designs as well as to the basic systems that should be part of them are incorporated in the above-mentioned OPB-88/97 and PBYa RU AS-89. These documents also specify the requirements and conditions that must be complied with in providing and substantiating RF and NPP safety.

MAIN SAFETY CONCEPTS AND PRINCIPLES (1/3)

The following principles and concepts are taken as a basis of the approaches to providing and substantiating RF and NPP safety:

- *Defense in-depth concept;*
- *Single failure principle;*
- *Independence principle;*
- *Common cause failures accounting;*
- *Principle of deterministic and probabilistic approaches combination in the analysis of accident processes;*
- *Principle of technical and organizational measures combination for safety provision;*
- *Principle of non-interference of personnel in automatic safety system operation at the initial stage of accidental process (during first 10-30 minutes from the beginning of system operation);*
- *Principle of conservative approach to the analysis of abnormal operations events and design basis accidents (DBAs) in the course of NPP designing and selection of system and equipment characteristics etc.*

MAIN SAFETY CONCEPTS AND PRINCIPLES (2/3)

РОСАТОМ

In compliance with the OPB-88/97 requirements NPP safety should be provided by means of implementation of defense in-depth concept based on application of successive physical barriers (fuel matrix, fuel element cladding, reactor coolant circuit boundary, RF confining structures and biological shielding) on the path of release of ionizing radiation and radioactive substances into the environment, and a system of technical and organizational measures on protection of barriers and maintaining their efficiency, as well as on protection of personnel, population and environment.

MAIN SAFETY CONCEPTS AND PRINCIPLES (3/3)

ROCATOM

The system of technical and organizational measures specified by the defense in-depth concept should:

a) be provided among other things at the expense of:

- *Use and development of inherent self-protection properties;*
- *Application of safety systems designed on basis of the principles of spatial and functional independence, diversity and redundancy; single failure;*
- *Use of reliable best-practice technical solutions and substantiated techniques, calculation analyses and experimental investigations;*
- *Meeting the regulatory documents requirements on RF and NPP safety, compliance with the requirements of RF and NPP designs;*
- *Stability of technological processes;*
- *Implementation of quality assurance programs at all stages of NPP creation and operation;*
- *Formation and introduction of safety culture at all stages of NPP creation and operation;*

b) and consist of five levels of defense in-depth:

1) *NPP siting conditions and prevention of abnormal operation);*
2) *Prevention of DBAs by systems of normal operation;*
3) *Prevention of beyond design basis accidents (BDBAs) by safety systems;*
4) *BDBA management;*
5) *Emergency planning.*

MAIN SAFETY SYSTEMS

In particular, in accordance with the defense in-depth concept, NPP should have safety systems designed for performing the following principal safety functions:

- *Reactor shutdown and maintaining it in a subcritical state (at least two independent systems);*
- *Decay heat removal from the reactor;*
- *Retention of radioactive substances within the established boundaries.*

MAIN SAFETY REQUIREMENTS (1/3)

RF and NPP designs should provide for the required technical means and organizational measures aimed for prevention of exceeding safe operation limits and conditions, including prevention of DBAs and minimization of their consequences and ensuring safety in case of anyone of initiating events considered in the design taking into account simultaneous occurrence of imposed additional failures:

- *A failure independent on an initiating event of anyone of the active safety system components or passive ones having mechanical moving elements or one personnel error independent on the initiating event;*
- *The failures of elements having an impact on accident progression that result in deviations from safe operational limits and are undetectable during NPP operation should also be taken into consideration.*

MAIN SAFETY REQUIREMENTS (2/3)

The measures should be specified against BDBAs, if they are not excluded based on inherent self-protection properties of the reactor and principles of its arrangement, and the technical means, if necessary, for BDBAs management to mitigate their consequences.

NPP meets the safety requirements if its radiation impact on the personnel, population and environment under normal operation, operational incidents, including design basis accidents does not result in exceeding radiation doses established for personnel and population, permissible values of releases and discharges, content of radioactive substances in the environment, as well as it is minimized in case of BDBAs.

MAIN SAFETY REQUIREMENTS (3/3)

The following safety requirements and recommendations should be mentioned as the most important ones:

- *For avoiding the necessity to evacuate the population efforts should be made in design to ensure that probability of limiting emergency radioactivity release beyond established boundaries will not exceed 10^{-7} per reactor year;*
- *When designing the RF, it is necessary to aim at the value of probability of the core disrupture accident that does not exceed 10^{-5} per reactor year.*
- *Characteristics of nuclear fuel, design of the reactor and other equipment of the primary circuit (including coolant purification system) considering operation of other systems shall not permit formation of secondary critical masses under severe BDBAs and those involving fuel meltdown.*

NPP SAFETY ANALYSIS REPORT (1/2)

The basic document on substantiation of RF nuclear safety and NPP safety on the whole is the NPP Safety Analysis Report (NPP SAR) which is an indispensable part of NPP design.

NPP SAR should include:

- *List of initiating events of DBAs;*
- *List of BDBAs;*
- *Classification of DBAs and BDBAs by the frequency of their occurrence and severity of consequences;*
- *Analysis of DBAs and BDBAs and their consequences (as to BDBAs the analysis of core disrupture accident is required).*

BDBA analysis is carried out based on realistic rather than conservative estimates.

NPP SAFETY ANALYSIS REPORT (2/2)

NPP SAR must also contain analysis of possible failures of systems and elements important to safety with selection of failures dangerous for RF and NPP, and assessment of their consequences on the basis of probabilistic safety assessment.

- *For example, about 30 failures of systems and elements important to safety, which are potentially dangerous for RF and NPP, are analyzed in the BN-800 design.*
- *When designing RF and NPP systems and elements, priority should be given to systems and elements, which design is based on the passive principle of operation and inherent safety features.*
- *The possibility of diagnostics (examination) of state of safety systems and normal operating elements important to safety, which fall into safety classes 1 and 2, and the possibility of their representative tests should be provided.*

NPP SAR must contain data on reliability parameters of normal operation systems important to safety and their elements falling into safety classes 1 and 2 as well as the safety systems and elements. Reliability analysis must be conducted with taking into account common cause failures and personnel errors.

Design materials related to NPP safety analysis and substantiation shall include results of probabilistic safety analysis.

RF and NPP safety should be analyzed using the verified codes.

DBA AND BDBA LISTS FOR BN-800

For example, within the BN-800 design consideration is made of 4 initiating events of DBAs and 9 BDBAs.

The initiating events of DBAs for the BN-800 include:

- *Blockage of a core fuel subassembly cross-section;*
- *Loss of tightness of the primary circuit gas communications;*
- *Leakage from the primary circuit auxiliary sodium piping;*
- *Erroneous withdrawal of fuel subassembly with high decay heat rate into a transfer cell.*

The following BDBAs are analyzed in the BN-800 design:

- *Loss of grid electric power supply without scram;*
- *Total loss of grid and emergency power supplies;*
- *Total loss of grid and emergency power supplies with simultaneous failure of all shutdown systems (ULOF accident);*
- *Guillotine-type rupture of the primary circuit auxiliary sodium piping;*
- *Guillotine-type rupture of the main sodium piping of the secondary circuit;*
- *Loss of tightness of the main and guard reactor vessels and fire in the reactor vault;*
- *Fire in the central hall of a reactor building with a damage of control and electric power supply systems;*
- *Formation of the hydrogen-air mixture in the SG box;*
- *Aircraft crash on the reactor building.*

NPP SYSTEM AND EQUIPMENT CLASSIFICATION (1/2)

OPB-88/97 requires fulfillment of NPP systems and elements classification according to:

- *designation;*
- *relation to safety;*
- *type of safety functions to be performed.*

According to designation NPP systems and elements are divided into:

- *systems and elements of normal operation;*
- *safety systems and elements.*

From the standpoint of relation to safety all NPP elements and systems are divided into:

- *systems and elements important to safety;*
- *other systems and elements not related to safety.*
- *By the type of their functions safety systems and elements are divided into:*
- *protection systems;*
- *localizing systems;*
- *support systems;*
- *control systems.*

NPP SYSTEM AND EQUIPMENT CLASSIFICATION (2/2)

ROCATOM

4 safety classes are identified depending on influence of NPP elements on safety:

Safety Class 1 includes fuel elements and NPP elements whose failures appear initiating events of BDBAs resulting in fuel elements damage with exceeding limits established for DBAs in case of normal operation of safety systems.

Safety Class 2 contains the following NPP elements:

- *elements whose failures are initiating events resulting in fuel elements damage within limits established for DBAs in case of normal functioning of safety systems taking into account the number of failures in them specified for DBAs;*
- *safety systems elements whose single failures result in non-performance of functions by relevant systems.*

Safety Class 3 includes NPP elements as follows:

- *systems important to safety, not included into Safety Classes 1 and 2;*
- *those containing radioactive substances whose release into the environment (including NPP premises) due to their failure exceeds the values specified in accordance with radiation safety standards;*
- *those performing control functions of personnel and population radiation protection.*

Safety class 4 contains elements of NPP normal operation, which do not influence safety and are not included in Safety Classes 1, 2 and 3.

LIST OF MAIN ITEMS IN OPB-88/97 AND PBYa RU AS-89

Safety requirements for the following main elements and systems of NPP and its operation phases are set forth in OPB-88/97 and PBYa RU AS-89:

- *core design and its characteristics;*
- *primary coolant circuit;*
- *systems and equipment related to the process control (unit control console, emergency control console, normal operation control systems, and control safety systems);*
- *other types of safety systems (protection systems, localizing systems, support systems);*
- *refueling systems and nuclear fuel and radioactive waste storage systems;*
- *NPP operation phases (commissioning, normal power operation, emergency modes, decommissioning).*

SPECIFIC REQUIREMENTS TO SFR (1/2)

The following limits of fuel element failure for SFRs are fixed in PBYa RU AS-89:

Operational limit of fuel element failure:

- *Defects with gas leakage – not more than 0.05% of the total amount of core fuel elements;*
- *Defects with direct contact of nuclear fuel with coolant – not more than 0.005% of the total amount of fuel elements in the core.*

Limit of safe operation:

- *Defects with gas leakage – not more than 0.1% of the total amount of core fuel elements;*
- *Defects with direct contact of nuclear fuel with coolant – not more than 0.01% of the total amount of fuel elements in the core.*

Maximum design limit of fuel element failure (for MOX-fuel and fuel pin cladding made of austenitic steel ChS-68KhD):

- *Fuel element cladding temperature – not more than 900°C;*
- *Fuel temperature – not more than 2300°C;*
- *Swelling of fuel cladding – not more than 15%.*

SPECIFIC REQUIREMENTS TO SFR (2/2)

SFRs must also meet the following requirements: temperature and reactor power reactivity coefficients as well as total reactivity coefficient of coolant and fuel temperature must be negative within the whole range of reactor parameters changes under the normal operation, abnormal operational events, including DBAs.

The existing regulatory documents do not contain specific requirements for a value of sodium void reactivity effect (SVRE) except for the general requirement included in PBYa RU AS-89 about the necessity to substantiate a permissible interval of SVRE values for BDBAs in the RF and NPP design.

If a reactor facility under operation does not meet any specific requirement of a new regulatory document, which comes into force, corresponding deviations with compensatory actions shall be drawn up. Then a work plan on bringing the RF safety in compliance with the mentioned requirements of the regulatory document shall be drawn up and implemented.

CONCLUSION

Russian regulatory documents regulating the issues related to safety of reactor facilities and NPPs, including sodium cooled fast reactors, are developed with regard for the gained operation experience and IAEA recommendations, and they meet the up-to-date level of safety requirements.

ΡΟCΑΤΟΜ

Thank you
for your attention !