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MAIN REQUIREMENTS FOR URANIUM-PLUTONIUM (MOX) FUEL FOR NUCLEAR POWER PLANTS

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NP-XX-XX

Federal Environmental, Industrial and Nuclear Supervision Service
Moscow, 2006

These federal standards and rules "Main Requirements for Uranium-Plutonium (MOX) Fuel for Nuclear Power Plants" are one of the documents within the system of the federal standards and rules which establish requirements to different nuclear fuel types (in terms of characteristics and isotopic composition of the fuel components, fuel form, characteristics of the materials of the FR claddings, other FR and FA elements) and other specifics defined in the course of the products manufacturing.

The document has been developed on the basis of the Federal Law "On the Use of Atomic Energy", other legal documents of the Russian Federation, federal standards and rules in the field of use of atomic energy, other regulatory documents, as well as recommendations of the international organizations.

These federal standards and rules in the field of use of atomic energy establish main safety requirements to be met in the course of the design and fabrication of the uranium-plutonium (MOX) fuel (fuel rods and FA with pelleted MOX-fuel) for NPPs with WWER-1000 and BN-600 reactors.

This is the first release of this document.

Table of contents

List of abbreviations 5

Main terms and definitions 6

1. Purpose and scope 7

2. General provisions 7

3. MOX-fuel FR and FA design 7

4. MOX-fuel, MOX-fuel FR and FA fabrication 10

Appendix 1 List of parameters and characteristics of the initial components and products to be established in the technical conditions for MOX-fuel, MOX-fuel FR and FA fabrication (mandatory) 12

List of abbreviations

CPS	- Control and Protection System
FA	- Fuel Assembly
FR	- Fuel Rod
BN	- Fast Breeder Reactor
NPP	- Nuclear Power Plant
RI	- Reactor Installation
VVER	- water-cooled water-moderated power reactor

Main terms and definitions

For the purposes of this document the following terms and definitions are used.

Core	shall mean the part of a reactor where the nuclear fuel, moderator, absorber, coolant, reactivity controls and structural components designed to effect the controlled nuclear fission reaction and transfer energy to the coolant are placed.
FR damage	shall mean the violation of at least one of the damage limits established for FRs.
FR destruction	shall mean the loss of integrity of the FR structure resulted in degradation of the FR geometry which provides for its cooling as designed.
FR leak	shall mean a fuel rod damage which causes a loss of integrity of the fuel rod cladding like a gas non-integrity and (or) direct contact of the nuclear fuel with the coolant.
Fuel assembly	shall mean the machine engineering product which contains nuclear materials and is designed for generation of thermal energy in a nuclear reactor through the controlled nuclear reaction.
Fuel rod	shall mean a separate assembly unit which contains nuclear materials and is designed for generation of thermal energy in a nuclear reactor through the controlled nuclear fission reaction and (or) for nuclide accumulation.
MOX-fuel	shall mean the nuclear fuel where nuclear materials in the form of uranium oxide and plutonium oxide is used for FR and FA fabrication.
Nuclear fuel	shall mean the materials which contain or capable of breeding fissile (fissionable) nuclear substances and are intended to be used for FRs and FAs fabrication.

1. Purpose and scope

1.1. These federal standards and rules "Main Requirements for Uranium-Plutonium (MOX) Fuel for Nuclear Power Plants" are one of the documents within the system of the federal standards and rules which establish requirements to different nuclear fuel types (in terms of characteristics and isotopic composition of the fuel components, fuel form, characteristics of the materials of the FR claddings, other FR and FA elements) and other specifics defined in the course of the products manufacturing.

1.2 The document has been developed on the basis of the Federal Law "On the Use of Atomic Energy", other legal documents of the Russian Federation, federal standards and rules in the field of use of atomic energy, other regulatory documents, as well as recommendations of the international organizations.

1.3 These federal standards and rules in the field of use of atomic energy establish main safety requirements to be met in the course of the design and fabrication of the uranium-plutonium (MOX) fuel (fuel rods and FA with pelleted MOX-fuel) for NPPs with WWER-1000 and BN-600 reactors.

2. General provisions

2.1. The requirements established by the federal standards and rules in the field of use of atomic energy shall be met at all stages of pelleted MOX-fuel (hereinafter referred to as the "MOX-fuel FRs and FAs" or "MOX-fuel") design and fabrication.

2.2. The MOX-fuel FRs and FAs planned to be used in RI designed for the uranium oxide fuel, as well as operating conditions for such MOX-fuel FRs and FAs, shall meet the requirements established in the RI design in accordance with the regulatory documents for the uranium oxide fuel.

2.3. The design of the MOX-fuel FRs and FAs and design and implementation of the core containing the MOX-fuel and its components shall be so that during the normal operation and operational events including design basis accidents the appropriate FR damage limits (number and degree of the damage) established in the RI design.

The excess of the established safe operation limits for the MOX-fuel FR damages shall be excluded during the assigned service life in RI.

2.4. The MOX-fuel FRs and FAs design, design and implementation of the core shall be operable, reliable and safe in the course of the operation during the assigned service life.

3. MOX-fuel FR and FA design

3.1. When designing MOX-fuel FRs and FAs, characteristics of the RI and its unirradiated and spent nuclear fuel management systems, including storage, shall be taken into account, and the compatibility of the MOX-fuel FRs and FAs with RI and other NPP systems designed for fuel management, storage and transportation shall be provided for.

3.2. The solutions applied in the MOX-fuel design shall meet the safety criteria, be confirmed by safety justification including calculations, experimental data and data obtained during the NPP operation with the given fuel type.

3.3 To justify the design solutions related to the MOX-fuel FRs and FAs the research works including theoretical and experimental studies of the RI design and core, where the MOX-fuel FRs and FAs will be used, shall be carried out.

3.4. When designing the MOX-fuel FRs and FAs, NPP RI operating conditions shall be taken into account, including those during the normal RI operation and operational events, as well as design basis accidents, considering:

the design number of modes and their design behavior;

impacts of radiation and other factors which degrade mechanical characteristics of the MOX-fuel FA and FR materials as well as FR cladding integrity;

thermal, mechanical and radiation deformation of the MX-fuel FRs and FAs cuased by the loads;

physical and chemical interactions of the MOX-fuel FR, FA and core materials;

maximum values of the thermal and engineering parameters of the core;

vibration and thermal cycling; fatigue, corrosion and ageing of the MOX-fuel FR and FA materials;

effects of the coolant admixtures and fissile products on corrosion of the MOX-fuel FR claddings, FA structural elements.

3.5 When designing MOX-fuel FRs and FAs, values of limits and constraints which provide for conditions to meet the below mentioned requirements for the MOX-fuel FRs and FAs, under which the MOX-fuel FR and FA damages are limited to the acceptable levels, shall be set forth and justified.

Quantitative magnitudes of these parameters, characteristics and conditions shall be set forth for a specific RI, core geometry, type of the fuel charge, MOX-fuel FR and FA type and taking into account the below requirements.

3.5.1. During normal operation of RI, operational events including design basis accidents at RI the MOX-fuel FA design shall exclude unplanned movements, deformations of the core components, changes in FR and other MOX-fuel FA components' geometry, reduction of through section of the MOX-fuel FA, degrading of heat removal leading to FR damage in excess of design limits which cause increase in reactivity, prevent normal functioning of CPS rods.

3.5.2. The fuel matrix and cladding of the MOX-fuel FR under normal operation and operational events including the design basis accidents shall fulfill functions of physical barriers.

3.5.3. The fuel burn-up shall not exceed maximum magnitudes set forth and justified in the appropriate design documentation.

3.5.4. The MOX-fuel FRs and FAs design shall be so that the MOX-fuel FRs and FAs are capable of withstanding loads under all design modes caused by thermal, mechanical and radiation effects. Also the MOX-fuel FR claddings, end fittings and their junction points shall have the established strength in case of irradiation, withstand stresses caused by the internal and external pressure, vibrations, temperature, seismic impacts and have sufficient corrosion resistance.

3.5.5 During the assigned service life the MOX-fuel FRs design shall exclude a possibility for deformations resulting in degrading of heat removal from the MOX-fuel FRs surface. Changes in the geometry of the MOX-fuel FR including FA structural components during the operation shall not cause violations of conditions of their fixation in spacers.

During the operation decrease and (or) increase in the outer FR diameter shall not exceed the value established in the design. The permissible range of the FR cladding diameter changes shall be such as to ensure that fuel rods are in spacers in a stable way and to exclude the beyond design basis MOX-fuel FRs movements and fretting wear (fretting corrosion) of the FR cladding. The FR claddings shall be compatible with spacing components under the normal operation and operational events. The FR cladding shall retain the circumferential stability under the normal operation. Fatigue damages caused by static and cyclic loads shall not exceed values established in the design.

3.5.6. The oxidation of the outer and (or) inner surfaces of a fuel rod with the MOX-fuel and their hydration shall not lead to loss of performance of the fuel rod, increase in the MOX-fuel FR cladding temperature, and impermissible degradation of the FR mechanical characteristics and damage.

3.5.7. In case of normal operation and operational events, including design basis accidents the oxidizing of the MOX-fuel FR cladding during RI operation shall not lead to their excessive embrittlement.

3.5.8. The MOX-fuel FR cladding fretting corrosion shall not lead to unpermissible reduction of strength and loss of integrity of the cladding.

3.5.9. Under the normal RI operation the MOX-fuel FR cladding temperature shall not exceed its maximum value established in the design.

3.5.10. MOX-fuel characteristics, positioning of the MOX-fuel FRs and other devices affecting reactivity in the core shall exclude local power densities which lead to the MOX-fuel FR damage in excess of the design limits.

3.5.11. The permissible range of the MOX-fuel FR cladding diameter changes shall be so that required thermal and hydraulic characteristics of the MOX-fuel FRs and FAs are provided for.

3.5.12. Deposits on the outer surface of the MOX-fuel FR cladding shall not lead to degradation of thermal and hydraulic characteristics of the MOX-fuel FAs and core.

3.5.13. In case of the operational events including the design basis accidents FR deformations and FR geometry changes due to swelling and rupture of the FR cladding and due to deformation of other MOX-fuel FR and FA components shall not lead to clogging of the MOX-fuel FA through section and hinder heat removal.

3.5.14. In case of accidents involving a fast reactivity increase the specific threshold energy of FR damage (the energy released in a nuclear fuel mass unit within a short period of time in case of fast reactivity insertion and sufficient to cause a FR destruction) shall not be exceeded and fuel melting shall be excluded.

3.5.15. The fuel temperature shall not exceed the maximum value of the temperature specific for the fuel melting in the event of the design basis accidents.

3.5.16. During the design basis accidents the interaction between different MOX-fuel FR, FA components shall not cause their melting.

3.5.17. The MOX-fuel FR design shall exclude the displacement of the fuel pellets during the FR transportation and fabrication and transportation of fuel assemblies, and provide for the required continuity of the fuel column during the operation in the core.

3.5.18. During the transport and process operations the design of the MOX-fuel FR as a part of the FA and transport package shall withstand the loads established in the design.

3.5.19. The MOX-fuel FA design shall provide its examination, testing and control during the manufacturing, as well as control during its operation.

3.5.20. The MOX-fuel FA shall provide its repair at the producer's before it is loaded into the core.

3.5.21. The MOX FA design shall provide its removal from the core, and also after the design basis accident.

3.5.22. The MOX-fuel FAs with different content of plutonium and uranium-235, FRs with burnable absorbers in the fuel and other fuel shall bear unique identification signs which shall be clearly seen with a naked eye and (or) with the application of industrial monitoring devices during FA assembling.

3.5.23. The MOX-fuel FR design shall bear unique identification signs which show the nuclear fuel constituents (plutonium content, content of uranium-235 in FRs) which shall be clearly seen with a naked eye and (or) with the application of devices used for reloading.

3.6. When designing, quantitative values of MOX-fuel FR and FA parameters and characteristics shall be set conservatively (with margin coefficients). The margin coefficients shall be determined based on data of experimental studies and operating experience as regards FRs and FAs used at NPPs with other fuel types and while selecting initial data and carrying out calculations to justify safety. At that, engineering allowances for FR fabrication, errors of techniques, codes and calculations shall be taken into account.

4. MOX-fuel, MOX-fuel FR and FA fabrication

4.1. The MOX-fuel, MOX-fuel FR and FA shall be fabricated in accordance with the process documentation (process procedures, process flow diagrams etc.), which regulates the content and conduct of all process and control operations.

The MOX-fuel, MOX-fuel FR and FA shall be fabricated in compliance with the quality assurance program.

4.2. The MOX-fuel, MOX-fuel FRs and FAs quality shall meet the criteria and requirements for the NPP safe operation. At that, these criteria and requirements shall be taken into account while determining the parameters and characteristics of the MOX-fuel, MOX-fuel FAs and FRs during its fabrication. The technical conditions for the pelleted MOX-fuel fabrication shall set forth requirements to parameters and characteristics (of the plutonium dioxide powder, uranium dioxide powder, bulk powder) , as well as parameters and characteristics of products (pellets, FRs and FAs). Appendix 1 presents a list of parameters and characteristics of the initial components and products, which shall be established in the technical conditions for MOX-fuel, MOX_fuel FRs and FAs fabrication.

4.3. Materials for manufacturing the MOX-fuel, MOX-fuel FR and FA shall be selected taking into account required physical and mechanical properties, processibility and workability in operating conditions during the assigned service life.

4.4. Quality and properties of the base material (semi-finished products and blanks) shall met requirements of technical conditions and shall be confirmed by certificates of conformance in accordance with the Rules for Shipment of Equipment, Components and Semi-finished Products to NPP.

4.5. Parts and assembly units shall bear the marking indicated on the drawing, which allow to identify them during the fabrication.

4.6. Before release for assembling the finished products (assembly units, parts) shall be cleaned, moth-balled and packed (including plugging of holes) in accordance with requirements of technical conditions for the products.

4.7. It is not allowed to use materials without certificates of conformance.

4.8. The producer of each batch of MOX-fuel FAs coming to NPP shall confirm that MOX-fuel, MOX-fuel FRs and FAs comply with the requirements established for it.

4.9. During the fabrication of the MOX-fuel, MOX-fuel FRs and FAs and components, the producer shall carry out the production technical control in the scope provided in the engineering and process documentation. The said control results shall meet requirements of this document and regulatory documentation developed taking into account the design documentation and technical conditions.

4.10. Devices and facilities used for the control and tests shall be certified and verified prior to their operation. The control results shall be documented in the reports. The reporting format shall be established by the producer.

4.11. The producer shall carry out an incoming quality inspection of the materials as per the technical conditions for the shipment of components for the MOX-fuel FRs and FAs fabrication.

4.12. The MOX-fuel FAs shipment to RI shall include accompanying documents including the FA specification, technical conditions, outline drawing, list of instructions, operating manual.

4.13. Transportation and storage of materials intended for fabrication of MOX-fuel shall be carried out in accordance with requirements of federal standards and rules and technical conditions for specific materials and technical conditions for products.

Appendix 1

List of parameters and characteristics of the initial components and products to be established in the technical conditions for MOX-fuel, MOX-fuel FR and FA fabrication (mandatory)

1. Plutonium dioxide powder:
   - Radionculide content indicating the percentage of plutonium isotope content;
   - Permissible content of admixtures;
   - Mass fraction of the total number of plutonium and americium-241isotopes;
   - Chemical composition;
   - Total boron equivalent of the admixtures;
   - Powder bulk density;
   - Moisture content;
   - Particle size;
   - Total specific surface;
   - Exposure dose rate caused by 1 kg at a distance of 1 m.

2. Uranium dioxide powder:
   - Radionculide content indicating the percentage of uranium isotope content;
   - U/O ratio;
   - Uranium content;
   - Chemical composition;
   - Permissible content of admixtures;
   - Total boron equivalent of the admixtures;
   - Powder bulk density;
   - Flowability;
   - Sinterability;
   - Thermal stability;
   - Moisture content;
   - Particle size.

3. Bulk powder:
   - Homogeneity;
   - Grain density;
   - Powder bulk density;
   - Plutonium content;
   - Binding agent.

4. Pellet:
   - Uranium and plutonium isotopic composition;
   - Admixture content;
   - Size of a grain in a uranium matrix;
   - Sinterability or thermal stability;
   - Material density;
   - Maximum size of plutonium-containing particles;

- Oxygen factor;
- Inner and outer diameter and height;
- Sinterability;
- Gap between pellets and cladding;
- Ellipticity,
- Material humidity;
- Availability of round cups and a central hole for gas release;
- Availability of chamfers;
- Permissible sizes of cleavage and cracks;
- Surface roughness;
- Total boron equivalent;
- Volume fraction of open pores.

5. Fuel rods:
   - Cladding material;
   - Fuel type (availability of the hole or round cups);
   - Cladding wall diameter and thickness;
   - Mass of uranium and mass of plutonium;
   - Fuel core fixing arrangement;
   - Welding types of the lower and upper welding joints;
   - Allowance for plutonium content;
   - Degree of the leaktightness (at the test temperature equal or close to the operating temperature);
   - Parameters of the outer spiral winding (for BN-600);
   - Allowances for single pores and their sizes;
   - Helium pressure;
   - Fuel column length;
   - Compensatory space length;
   - Gap between the pellet and cladding;
   - Maximum permissible length of the single gap between the fuel column pellets, ad total gap magnitude;
   - Maximum permissible size (area) of the fuel sherd which got inside the fuel column;
   - Fuel column-averaged value of the uranium-235 and plutonium-239 mass fraction in the FR;
   - Accuracy of the uranium-235 and plutonium-239 mass fraction distribution inside the FR (profiling);
   - Accuracy of burnable absorber (gadolinium, erbium) concentration distribution along the fuel column length if the design provides for absorber availability;
   - FR diameter;
   - Material characteristics (admixture composition and permissible values) of which the FR cladding is made;
   - FR geometrics (diameter, thickness, deviation from the linearity of the basic tube etc.);
   - Requirements to the welds (including number of pores and distance between them);
   - Requirements to the surface (roughness, depth of scratches, stripes etc.);
   - Alpha-contamination of the FR cladding;
   - Exposion dose rate of X-ray and gamma irradiation on the FR surface.

6. Fuel assembly:

- Isotopic composition of the fuel composition;
- Fuel column height;
- Fuel mass;
- Number of FRs and fuel erbium-gadolinium rods;
- Total mass and isotopic composition of the FA structural materials;
- Material characteristics (admixture composition and permissible values), of which the FA cladding is made;
- Geometrics, allowances for the form and dislocation of surfaces, FA configuration, permissible deformations;
- FA overall and port sizes;
- Value of the permissible helium leak (leak-in) from the FR being the FA part;
- Total value of the fixed and unfixed contamination of the outer FA surfaces;
- Marking quality.