Federal Environmental,
Industrial and Nuclear Supervision Service

FEDERAL STANDARDS AND RULES IN THE FIELD OF USE OF ATOMIC ENERGY

Approved by
Decree of Federal
Environmental, Industrial
and Nuclear Supervision
Service
of _________200__ № ___

Basic Requirements to Fuel Elements and Fuel Assemblies with Uranium-Plutonium (MOX) Fuel for Nuclear Power Plants

NP-080-07

Effective since
____________ 200__

Moscow 2007

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Basic Requirements to Fuel Elements and Fuel Assemblies with Uranium-Plutonium (MOX) Fuel for Nuclear Power Plants

Federal Environmental, Industrial and Nuclear Supervision Service
Moscow, 2007

These federal standards and rules in the field of use of atomic energy "Main Requirements for Fuel Rods and Fuel Assemblies with Uranium-Plutonium (MOX) Fuel for Nuclear Power Plants" establish main safety requirements to be met in the course in design and fabrication of fuel rods and fuel assemblies with pelleted uranium-plutonium oxide (MOX) fuel for nuclear power plants with VVER and BN reactors.

This document is one of the documents within the system of the federal standards and rules in the field of use of atomic energy which establishes requirements to different types of nuclear fuel, fuel rods and fuel assemblies.

This is the first release of this document.

The document has been developed on the basis of the Federal Law "On the Use of Atomic Energy", legal and regulatory 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.*

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Proposals of Rosatom, GI VNIPIET, MCC, PA Mayak, TVEL, MSZ, NCCP, Gidropress, OKBM etc. were considered and taken account of during the document development.

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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

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 design 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 (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 chain nuclear fission 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 chain nuclear fission reaction and (or) for nuclide accumulation.
Uranium-plutonium (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.

1. Purpose and scope

1.1. This document establishes requirements to be met in the course of the design and fabrication of fuel rods and fuel assemblies with pelleted uranium-plutonium oxide (MOX) fuel (hereinafter MOX-fuel FR and FA) for NPPs with VVER-1000 and BN-600 reactors.

1.2 The document has been developed on the basis of the Federal Law “On the Use of Atomic Energy”, legal and regulatory 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.

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 design and fabrication of FR and FA with MOX-fuel.

2.2. The MOX-fuel FR and FA 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.

2.3. The design of the core and its components, including MOX-fuel FR and FA, shall be so that during the normal operation and operational events including design basis accidents the corresponding FR damage limits are not exceeded.

2.4. The MOX-fuel FR and FA design 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 FR and FA, characteristics of the RI, compatibility of MOX-fuel FR and FA with components of the reactor core RI, other NPP systems designed for fuel handling, requirements of federal standards and rules for systems of storage and transportation of unirradiated and spent nuclear fuel shall be taken into account.

3.2. Solutions adopted in the MOX-fuel FR and FA 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. When designing the MOX-fuel FR and FA, the NPP RI operating conditions shall be taken into account, including those during the RI normal operation and operational events, as well as design basis accidents, considering:

- RI design operational modes, their number and design behavior;
- force (mechanical) heat and radiation impacts on the reactor core components;
- physical and chemical interaction of the core materials and coolant;
- limiting deviations of design and process characteristics and process parameters;
- shock and vibration impacts, cycling heat loads, radiation and temperature creep as well as material aging;
- impacts of fission products and admixtures to the coolant and MOX-fuel which affect strength and corrosion resistance of FR;;
- other factors which degrade mechanical characteristics of the core structural

materials and fuel rod cladding.

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

3.4.1. During normal operation and operational events, including design basis accidents, unplanned movements and (or) deformations of MOX-fuel FR and FA and other components of FA and the core that lead to an increase in reactivity and degrading of heat removal which lead to FR damage in excess of design limits.

3.4.2. The MOX-fuel FA design shall be so that FR and other FA components' geometry changes which are possible during normal operation and operational events including design basis accidents, do not lead to blockage of the through section of FA leading to FR damage in excess of design limits and do not prevent normal functioning of CPS rods.

3.4.3. 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.

3.4.4. The fuel burn-up shall not exceed maximum values set forth in the design.

3.4.5. The MOX-fuel FR and FA design shall withstand thermal, mechanical and radiation loads under all design modes.

MOX-fuel FR claddings, tail pieces and their junction points shall have the preset strength in case of irradiation, sufficient corrosion resistance, withstand stresses caused by internal and external pressure, vibrations, temperature, seismic impacts.

3.4.6. During the assigned service life the MOX-fuel FA design shall exclude a possibility of deformations leading to unacceptable degrading of heat removal from the MOX-fuel FR surface. Changes in the geometry of the MOX-fuel FR and FA components during operation shall not cause violations of conditions of their fixation in spacers.

3.4.7. An increase or decrease of the FR outer diameter during operation shall not exceed the value established in the design.

3.4.8. The permissible range of the FR cladding diameter changes shall be such as to ensure that fuel rods are placed in spacers with required friction force, undesigned FR movements are excluded and required thermal hydraulic characteristics of MOX-fuel FR and FA are provided.

3.4.9. Permissible elongation of FR cladding shall not exceed the limiting values established in the design.

3.4.10. The FR claddings shall be compatible with spacing components under the normal operation and operational events.

3.4.11. 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.

3.4.12. Corrosion of MOX-fuel FR cladding, oxidation of the outer and (or) inner surfaces of the cladding and its hydration shall not lead to unallowable degrading of the fuel rod mechanical characteristics, loss of performance of the fuel rod, unallowable increase in the MOX-fuel FR cladding temperature, its unallowable embrittlement and FR damage.

3.4.13. Crud deposition 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.

3.4.14. The MOX-fuel FR cladding fretting corrosion (abrasion) shall not lead to unpermissible reduction of strength and loss of integrity of the fuel rod.

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

3.4.16. Pressure of gas mixture under the FR cladding shall not exceed the value established in the design.

3.4.17. MOX-fuel characteristics, design and positioning of the MOX-fuel FR and FA in the core shall exclude local power densities which lead to the MOX-fuel FR damage in excess of the design limits.

3.4.18. In case of design basis accidents involving a fast reactivity increase the specific threshold energy of FR destruction (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.

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

3.4.20. Under design basis accidents interaction between components of MOX-fuel FR and FA shall not lead to their melting.

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

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

3.4.23. The MOX-fuel FA design shall provide:

- its examination, testing and control during manufacturing, as well as inspection during operation;
- repair at the producer's before it is loaded into the core;
- removal from the core, and also after the design basis accident.

3.4.24. The MOX-fuel FA with different isotopics, FR with burnable absorbers in the fuel and special burnable absorbers within MOX-fuel FA shall bear unique identification signs which shall be clearly seen with a naked eye and (or) with industrial monitoring devices during FA assembling.

3.4.25. The MOX-fuel FA shall bear unique identification signs which show their nuclide composition and enrichment of nuclear fuel in fuel rods which can be made out with a naked eye and (or) with the application of devices used for reloading.

3.4.2. 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 FR and FA 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 and FA fabrication, errors of techniques, codes and calculations shall be taken into account.

4. MOX-fuel FR and FA fabrication

4.1. The 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, in compliance with the quality assurance program.

4.2. Quality of the MOX-fuel FR and FA and structural materials, semi-finished products and component parts for fabrication thereof (hereinafter the materials, semi-finished products and component parts) 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 FA and FR during its fabrication. The MOX-fuel FR and FA, materials, semi-finished products and component parts shall meet technical conditions. Appendix 1 presents a list of main indicators, parameters and characteristics of the fuel material (plutonium dioxide powder, uranium dioxide powder), pellets, MOX-fuel FA and FR which shall be established in the technical conditions.

4.3. Quality of materials, semi-finished products and component parts shall be confirmed by certificates of conformance as per regulations for evaluation of conformance of the equipment, materials, semi-finished products and component parts supplied to nuclear facilities.

4.4. The producer of MOX-fuel FR and FA shall carry out an acceptance inspection of quality of materials, semi-finished products and component parts in accordance with technical conditions of their supply.

4.5. Parts and assembly units of MOX-fuel FR and FA shall bear the marking which allows their identification during fabrication.

4.6. The MOX-fuel FR and FA compliance with the established requirements shall be confirmed by the producer in accordance to the procedure defined in regulatory documents.

4.7. During the fabrication of the MOX-fuel FR and FA, materials, semi-finished products and component parts, the producer shall carry out the in-process 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.

4.8. Instruments and equipment used for control and tests shall be qualified and verified prior to their operation. The control results shall be documented in the reports. The reporting format shall be established by the producer.

4.9. 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.

4.10. The delivery package of MOX-fuel FA to NPP shall include accompanying documentation, namely, FA certificate, technical conditions, outline drawing and operator’s manual.

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 (recommended)

1. Plutonium dioxide powder:
   - Radionuclide content indicating the percentage of plutonium isotope content;
   - Mass fraction of the total number of plutonium and americium-241 isotopes;
   - Content of admixtures;
   - Total boron equivalent (for VVER);
   - Moisture content;
   - Powder bulk density;
   - Particle size;
   - Total specific surface;
   - Exposure dose rate caused by 1 kg at a distance of 1 m, as of fabrication date.

2. Uranium dioxide powder:
   - Radionuclide content indicating the percentage of uranium isotope content;
   - Content of admixtures;
   - Oxygen coefficient (U/O ratio);
   - Total uranium isotopes mixture content;
   - Total boron equivalent (for VVER);
   - Flowability;
   - Sinterability;
   - Moisture content;
   - Powder bulk density;
   - Particle size;
   - Chemical composition;
   - Total specific surface.

3. Pellets:
   - Uranium and plutonium isotopic composition;
   - Mass fraction of the total uranium and plutonium; conditional mass fraction of plutonium to the sum of uranium and plutonium;
   - Admixture content;
   - Total boron equivalent (for VVER);
   - Hydrogen content (for VVER);
   - Oxygen coefficient (U/O+Pu+Am ratio);
   - Average conditional size of grain;
   - Distribution of plutonium fissile isotopes;
   - Maximum size of plutonium-containing (PuO_2) particles;
   - Sinterability (thermal stability);
   - Density;
   - Inner and outer diameter and height
   - Availability of round cups and a central hole for gas release;
   - Availability of chamfers;
   - Requirements for surface (roughness, permissible sizes of cleavage and cracks etc.);

- Volume fraction of open pores;
- Nitric acid solubility degree.

5. Fuel rods:
   - Cladding material;
   - Cladding wall diameter and thickness;
   - Mass of uranium and mass of plutonium;
   - Mass of fuel column;
   - Fuel core fixing arrangement;
   - Welding types of the lower and upper welding joints;
   - Allowance for plutonium content;
   - Degree of the leaktightness;
   - Parameters of the outer spiral winding (for BN-600);
   - Helium pressure;
   - Fuel column length;
   - Compensatory space length;
   - Gap between the pellet and cladding;
   - Allowances for single pores and their sizes;
   - Maximum permissible length of the single gap between the fuel column pellets, ad total gap magnitude;
   - Fuel column-averaged value of plutonium isotopes;
   - Distribution of burnable absorber (gadolinium, erbium) concentration along the fuel column length (if the design provides for absorber availability);
   - 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 etc.);
   - Requirements to the surface (roughness, depth of scratches, stripes etc.);
   - Permissible non-fixed alpha-contamination of the surface with plutonium;
   - Equivalent dose rate of X-ray and gamma-radiation on FR surface;
   - Marking requirements.

6. Fuel assembly:
   - Isotopic composition of the fuel composition;
   - Fuel column height;
   - Fuel mass;
   - Number of FRs and fuel erbium-gadolinium rods;
   - Total mass of FA;
   - Geometrics, allowances for the form and location of surfaces, FA configuration, permissible deformations;
   - FA overall and port sizes;
   - Value of the permissible helium leak (leak-in) from the FR within FA;
   - Total value of the fixed and unfixed contamination of the outer FA surfaces;
   - Equivalent dose rate of X-ray and gamma-radiation on FA surface;
   - Marking requirements.