PREPARATION RESULTS FOR LIFETIME TEST OF CONVERSION LEU FUEL IN PLUTONIUM PRODUCTION REACTORS

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ABSTRACT

The program of converting Russian production reactors for the purpose to stop their plutonium fabrication is currently in progress.
The program also provides for operation of these reactors under the conversion mode with using of low-enriched fuel (LEU).
LEU fuel elements were developed and activities related to their preparation for reactor tests were carried out.

INTRODUCTION

In accordance with Government-to-Government Agreement of the United States and the Russian Federation the program of conversion of Russian production reactors is underway. The object of such conversion is to stop weapons plutonium production. As this takes place, reactors should give continuity of heat and power service for the needs of a region where they are located.
A report about the feasibility study of these reactors operation under the conversion mode with LEU fuel was presented at the 21st Meeting RERTR'98. Based on the results of this analysis, it was resolved to make the gradual shift of reactors to LEU fuel after the beginning of their operation under the conversion mode. The development of low-enriched fuel is joined in the Russian-US Conversion Program of ADE type Production Reactors.
The in-pile lifetime tests are one of the most important aspects, determined the period of fuel development.
The results of preparation of in-pile lifetime tests of LEU fuel, destined for the conversion of production plutonium reactors are presented in this report.

RESULTS

It is supposed that the lifetime tests will be carried out in two standard channels of a production reactor core during its standard operation. Neutron-physical and heat-hydraulic calculations were performed for lifetime tests substantiation.

The following issues have been considered in calculations: the influence of LEU channels location on the nuclear pile reactivity margin, energy release in adjacent fuel channels, energy release in the experimental channels and their thermal-hydraulic characteristics. Fuel element design parameters have been specified, in particular, U-235 content of the fuel element. A comparison of LEU (1) and HEU (2) loading versions were performed during the calculations (see Table 1).

Table 1. The Results of Thermal Hydraulic Calculations

№	Parameter	Measur. Units	Modes	
			1	2
1	Average power of the adjacent plateau channels	kW	850	850
2	Power of an experimental channel	kW	810	810
3	Maximum power of a fuel element	kW	21.6	21.6
4	Coolant flow rate	m^3/hour	7.15	6.35
5	Coolant temperature - inlet - outlet	^oC	 90 188	 90 200
6	Maximum temperature of a fuel element	^oC	280	291
7	Maximum temperature of a fuel cladding - side surface - fuel element juncture - fuel element curving	^oC	 199/207 224 203	 211/215 238 216
8	Surface boiling margin - side surface - fuel element curving	^oC	 30 26	 16 12
9	Volume boiling temperature margin (at the outlet group header)	^oC	29	17
10	Coolant velocity (maximum at the channel height)	m/sec	8.7	7.8
11	Pressure drop - at the core - at support "pillow" - at the region of upper aluminum rods - at the inlet and outlet regions	MPa	 1.22 0.23 0.04 0.17	 1.33 0.17 0.03 0.13
12	Channel pressure - Inlet experimental - Inlet calculational - Outlet experimental	MPa	 3.87 3.87 2.21	 3.87 3.87 2.21
13	Coolant velocity at the region of support "pillow"	m/sec	6.1	5.5

The calculated neutron-physical and thermal hydraulic parameters verify the possibility for tests in the standard technological pile channels in conformity with the given parameters and safety requirements.
Based on the neutron-physical and thermal hydraulic calculations the requirements for the LEU fuel element were developed. The technical requirements include the determination of the basic fuel element design parameters and its operation conditions.
A fuel element design has been developed in accordance with the technical requirements (Fig. 1).
A fuel element consists of dispersed-type meat with uranium dioxide fuel of 19.7±3% enrichment (U-235) distributed in an aluminum matrix. Mass of U-235 in the fuel element is equal 18.0 g. The material of fuel element cladding is B1T aluminum alloy.
General service conditions for the fuel element are:

- Maximum power of a fuel element, kW – 25;
- Coolant pressure (excess):
  - inlet pressure, no more than, MP – 4.2;
  - outlet pressure, MP – 2.1-2.3;
- Maximum allowed technical channel velocity, m/s – 8.8;
- Fluence of damage-cause neutrons E>0.2 MeV at the end of campaign in the maximum load zone, N/cm^2 – 1.3×10^{21}.

Limiting operating conditions for the fuel element are:

- Fuel temperature, ^{0}C – 450;
- Side cladding temperature, ^{0}C – 250;
- Frontal cladding temperature, ^{0}C – 300.

Two versions of fabricating process have been used to produce experimental fuel elements. The first version is a technology which being used for manufacturing the DAV-90 type fuel elements for production reactors. This technology includes the process of rod extrusion from UO_2-Al composition and further fabrication of fuel element meats from this rod (Table 2).
Replacing HEU with LEU results in the increase of the volume fraction of UO_2 in the fuel element meat, and thus lowers its plastic characteristics. However, this technology may be applied for fuel elements manufacturing upon optimization of the technological parameters. As since it is supposed to arrange the industrial production of LEU fuel elements with high throughput, the second manufacturing version has been developed. It excludes the hot extrusion process (Table 3).
The new technology has a series of advantages. The wastes containing the uranium is being considerably reduced (15%). These wastes usually should be reprocessed and returned to the head of the technological process. Mechanical and chemical treatments of meat are not required. This technology makes possible to do away with expensive heavy press equipment. The new technology provides the higher quality of a meat and, in particular guarantees higher U-235 loading in a fuel element.
The in-pile lifetime tests of DAV-20K type fuel elements are proposed to be carried out in ADE-4 or ADE-5 types production reactors under the existing operation conditions. The test fuel elements should be operated in two separate channels, located among the standard channels.

Table 2. Manufacturing of Cores and Fuel Elements Extrusion Technology (Option-1)

INITIAL MATERIALS: Uranium dioxide with enrichment of 90 %
Aluminum powder PA-4 on GOST 6058-73

№	Operations	Process Characteristic	Equipment
1	Weighing of components	Weighing of uranium dioxide and aluminum powders according to technical standard	Balance up to 5 kgs
2	Mixing of initial components	Mixing of uranium dioxide and aluminum powder with the additive of bonding substance	Blade or cone mixer
3	Cold pressing	Forming of billets	Press by effort of 250 tons
4	Sintering and degassing of billets	Removal of bonding substance and sintering in vacuum	Drying case, vacuum furnace
5	Hot calibration of billets	Densification of billets at temperature up to non-porous state	Hydraulic press with effort of 500 t
6	Hot extrusion of rod	Manufacture of semi-finished meat	Hydraulic press with effort of 500 t
7	Machining of rod	Cutting of rod on meats	The turning machine tool
8	Chemical processing of meats	Etching in an alkaline solution, washing in cold and hot waters, processing in a solution of an acid	Baths for chemical processing
9	Meat's degassing	Degassing of meats at temperature in vacuum	The vacuum furnace
10	Assembly of fuel element and its calibration	The meat is inserted into cladding cup, calibrated with a required degree of deformation	Hydraulic press with effort of 25 t
11	Degassing of assembly	Vacuum degassing at temperature	Vacuum drying case
12	Rolling of an open end face of element	Rolling of an open end face of element by a roller	The turning machine tool
13	Gas squeezing of element	Heating and squeezing in autoclave	The vertical electric furnace, autoclave with pressure 200 at.
14	Hermetic sealing of element	Welding of rolled end face of element	Electron beam installation
15	Chemical processing and anodizing of element	Processing in a solution of HNO_3, washing and anodizing	Etching bath and equipment for anodizing
16	The control of element	Supervise the geometrical sizes, adjoining of cladding to the meat, quality of a surface and tightness	Measuring tool, installation of the ultrasonic control, control of a welded seam

Table 3. Manufacturing of Cores and Fuel Elements Extrusion-free Technology
(Option-2)

INITIAL MATERIALS: Uranium dioxide with enrichment of 19.7 %
Aluminum powder PA-4 on GOST 6058-73.

№	Operations	Process Characteristic	Equipment
1	Weighing of components	The weighing of uranium dioxide and aluminum powders according to technical standard	Balance up to 5 kgs
2	Mixing of initial components	Mixing of uranium dioxide and aluminum powder with the additive of bonding substance	The blade or cone mixer
3	Cold pressing	Forming of semi-finished meat	Press with effort of 50 tons
4	Sintering and degassing of semi-finished meat	Removal of bonding substance and sintering in vacuum	Drying case, vacuum furnace
5	Calibration of semi-finished meat	Densification of billets up to non-porous state in finished sizes	Hydraulic press with effort of 250 t
6	Sintering and degassing of meat	Removal of greasing and sintering in vacuum	Drying case, vacuum furnace
7	Assembly of fuel element and its calibration	The meat is inserted into cladding cup, calibrated with a required degree of deformation	Hydraulic press with effort of 25 t
8	Degassing of assembly	Vacuum degassing at temperature	Vacuum drying case
9	Rolling of an open end face of element	Rolling of an open end face of element by a roller	The turning machine tool
10	Gas squeezing of element	Heating and squeezing in autoclave	The vertical electric furnace, autoclave with pressure 200 at.
11	Hermetic sealing of element	Welding of rolled end face of element	Electron beam installation
12	Chemical processing and anodizing of element	Processing in a solution of HNO_3, washing and anodizing	Etching bath and equipment for anodizing
13	The control of element	Supervise the geometrical sizes, adjoining of cladding to the meat, quality of a surface and tightness	Measuring tool, installation of the ultrasonic control, control of a welded seam

In accordance with a concept developed for the conversion core of ADE-type reactors fuel elements are loaded in the conversion channels simultaneously with two types of absorbers containing boron and gadolinium.

The demanded quantity of experimental fuel elements for the lifetime tests was manufactured at Electrostal Machine-Building Plant. Absorbing elements have been also developed and manufactured.

CONCLUSIONS

A complex of works has been performed for preparing lifetime tests of LEU fuel elements for the conversion core of ADE-type production reactors.

1. Fuel element design and manufacturing technology have been developed.
2. The program of LEU lifetime tests has been prepared for two technological channels of ADE type operative reactor core.
3. A complete set of experimental fuel elements and absorbing elements for loading into two technological channels has been fabricated.