OPERABILITY VALIDATION OF FUEL RODS WITH CLADDINGS MADE OF EK164-ID STEEL IN THE BN-600 REACTOR

S.B. Belov [1], B.A. Vasilyev [1], M.P. Farakshin [1], P.A. Talanov [1], A.Z. Kazantsev [1], T.A. Klimashina [1], A.A. Radionycheva

[1] JSC "Afrikantov OKBM", Nizhny Novgorod

E-mail of the main author: belovsb@okbm.nnov.ru

Abstract. To ensure the increased fuel burn-up in the BN-600 and BN-800 reactors, EK164-ID steel is going to be used as a fuel rod cladding material because it has enhanced radiation resistance (swelling and creeping) in comparison with the used ChS68-ID steel. To introduce this steel, an irradiation examination of experimental FSAs is needed to be performed. Owing to the irradiation examination, experimental data will be obtained to validate FSA operability and a database on properties of the steel will be updated.

By now, reactor examination of 14 experimental FSAs with EK164-ID fuel rod cladding has been successfully performed in the BN-600 reactor. The maximum achieved irradiation parameters are as follows: the fuel burn-up is ~ 14 % h.a., the damaging dose is ~ 100 dpa. The examination is planned to be continued to reach higher irradiation parameters- the fuel burn-up up to 14.8% h.a., the damaging dose up to ~ 112 dpa.

Activities aimed at improving the quality of cladding tubes both in the stage of fuel rod cladding manufacture and in the metallurgic stage of tubing stock manufacture are performed simultaneously with manufacture and irradiation of the experimental FSAs.

Results of these experimental activities will be used to validate operability of fuel rods made of this steel in the initial stage of the BN-1200 reactor operation.

Key words: fuel element, cladding, EK164-ID steel, radiation resistance.

1. Introduction

The ChS68 steel (06Cr16Ni15Mo2Mn2TiVB) in cold-worked condition is used as a material for fuel element claddings in the BN-600 reactor for a long time. Due to improvement of this material, the average fuel burnup of 74 MWd/kg was achieved for the fuel life of 592 equivalent full power days (efpd) of the main fuel assembly (FA) array, with maximum fuel burnup (UO_2) of 11.8% h.a. and maximum damage dose of 87 dpa. This material was used in the initial load of the BN-800 reactor. Nevertheless, because of MOX fuel application and higher neutron flux density, the provided operational characteristics of the BN-800 reactor core are lower: the average burnup of fuel is 62 MWd/kg for fuel life of 465 efpd, maximum (peak) fuel burnup is 9.4 % h.a., and maximum damage dose is 85 dpa.

An advanced material for fuel element claddings of sodium-cooled fast reactors is steel EK164 (07Cr16Ni19Mo2Mn2NbTiB). It is austenitic steel with increased nickel content, modified with boron and phosphor, complex-doped with three carbide-stabilizing elements (titanium, vanadium and niobium).

This paper presents prospects to increase fuel burnup by applying the EK164 steel for fuel element claddings in BN-600 and BN-800 reactors, and to enhance operational characteristics of BN-1200 core by applying this steel at the initial operation stage. Besides, the paper gives information on made and planned tests of fuel elements with EK164 claddings.

2. Prospects to increase fuel burnup by applying the EK164B steel for fuel element claddings

The EK164 steel was started to use in BN-type reactors in the late 1990s. Even the first tests of this steel in the BN-600 reactors showed its considerable superiority as compared with the ChS68 steel, which is used as a standard material of fuel element claddings of BN-600 and BN-800 reactors. The test results showed that irradiation-induced swelling of this steel (also in cold-worked condition) is ~ 2 times lower than that of the ChS68 steel under a damage dose of 77 dpa (at the value for standard fuel assemblies). In addition, after irradiation, this steel exhibits high mechanical properties and acceptable values of residual ductility.

By the present, the EK164 steel has been proved enough to apply it as a standard material of fuel element claddings.

At the present, activities are being performed to change over BN-600 and BN-800 cores from the steel ChS68 to the steel EK164 to be applied as FA fuel element claddings. Prospects of BN-600 and BN-800 core upgrade with application of the steel EK164 as FA fuel element claddings are shown in Table I. Initially, FAs with EK164 claddings will operate in the core together with “old” FAs with ChS68 claddings under the same operation parameters. Then, the transition refueling patterns with increased fuel life will be arranged.

TABLE I: BASIC PARAMETERS OF BN-600 AND BN-800 UPGRADED CORES

<table>
<tr><th>Reactor (fuel)</th><th>Parameters</th><th>2016</th><th>2017</th><th>2018</th><th>2019</th><th>2020</th><th>2021</th><th>2022</th><th>2023</th><th>2024</th></tr>
<tr><td rowspan="5">BN-600 (UO_2)</td><td>Fuel life, efpd</td><td colspan="6">592</td><td colspan="3">728-752</td></tr>
<tr><td>Fuel burnup (average), MWd/kg</td><td colspan="6">74</td><td colspan="3">93</td></tr>
<tr><td>Fuel burnup (peak), % h.a.</td><td colspan="6">11.8</td><td colspan="3">~15.0</td></tr>
<tr><td>Maximum damage dose, dpa</td><td colspan="6">87</td><td colspan="3">112</td></tr>
<tr><td>Fuel element cladding</td><td>ChS68</td><td colspan="2">ChS68, EK164</td><td colspan="6">EK164</td></tr>
<tr><td rowspan="5">BN-800 (MOX)</td><td>Fuel life, efpd</td><td colspan="7">465</td><td colspan="2">~580</td></tr>
<tr><td>Fuel burnup (average), MWd/kg</td><td colspan="3">62</td><td colspan="4">66</td><td colspan="2">83</td></tr>
<tr><td>Fuel burnup (peak), % h.a.</td><td colspan="3">9.4</td><td colspan="4">9.5</td><td colspan="2">12.0</td></tr>
<tr><td>Maximum damage dose, dpa</td><td colspan="3">85</td><td colspan="4">90</td><td colspan="2">112</td></tr>
<tr><td>Fuel element cladding</td><td colspan="2">ChS68</td><td colspan="2">ChS68, EK164</td><td colspan="5">EK164</td></tr>
</table>

For the BN-1200 reactor at the initial operation stage it is provided to apply only the EK164 steel as a fuel element cladding material. The maximum damage dose at BN-1200 FAs is ~ 116 dpa, fuel burnup is ~ 12 % h.a. To apply the EK164 steel additional irradiation tests must be performed for the above mentioned parameters.

3. The results of performed tests of experimental fuel assemblies with EK164 claddings of fuel elements

By the present, 14 FAs have been successfully tested in the BN-600 reactor: two combined FAs (in their composition ~ 50% of fuel elements were with EK164 claddings and the same quantity of FAs were with ChS68 claddings) and 12 FAs, which were completely loaded with fuel elements with EK164 claddings. The results of examination performed by the cladding leak-tightness monitoring system show leak-tightness of all fuel elements in spent FAs. FAs were tested in three batches:

- the first batch consisted of two combined FAs;
- the second batch consisted of six FAs;
- the third batch consisted of six FAs.

EK164 pin claddings for the second batch of FAs were manufactured using an upgraded tube production process [1, 3].

In the third batch of FAs the upgraded EK164 steel was used. It was upgraded at metallurgy and tube production process stages [3].
As a result of performed tests the irradiation parameters shown in Table II [2] were obtained. Table II gives data on FAs with maximum parameters of irradiation.

TABLE II: FUEL ASSEMBLIES WITH MAXIMUM PARAMETERS OF IRRADIATION

Batch of FAs	Type of FA	Number of operating cycles*, (residence time, efpd)	Peak burnup, % h.a.	Maximum damage dose, dpa
First batch, Combined FAs	FA of low-enrichment zone	4 (569)	9.1	77
	FA of high-enrichment zone	4 (569)	10.7	74
Second batch	FA of low-enrichment zone	5 (688)	12.1	95
	FA of high-enrichment zone	5 (726)	13.2	96
Third batch	FA low-enrichment zone	5 (~720)	~11.9	~ 99
	FA of medium-enrichment zone	5 (~720)	~12.4	~ 95
	FA of high-enrichment zone	6(~881)	~ 14.3	~ 101
*Operating cycle – operating interval between refuelings				

Five of eight irradiated FAs of the first and second batches with damage doses to 96 dpa were subjected to post-irradiation examination at Beloyarsk NPP. The results of swelling measurements of fuel element cladding material obtained from profilometry data confirm high swelling resistance of the EK164 steel as compared with the ChS68 steel.

Fuel elements from FAs of the first and second batches were selected for material-science studies in JSC “Institute of Nuclear Materials” (Zarechnyi). Analysis of post-irradiation material-science examination of EK164 claddings of fuel elements, having achieved maximum damaging doses of 96 dpa, allows to make the following conclusions [3]:

- fuel elements with EK164 claddings have considerable residual life by the criterion of the allowable maximum 15% swelling;

- mechanical properties determined in tests of tube samples are at the level providing residual life of safe operation;

- maximum depth of corrosion damages is ~ 14% of wall thickness and it is not a factor limiting elongation of fuel element life.

The total obtained results show that fuel element claddings have residual life of safe operation up to achievement of a damage dose of not less than 105 dpa [2, 3]. More precise forecasting of ultimate life of fuel elements with EK164 claddings requires post-irradiation examination of fuel elements having achieved doses close to the specified one. In the near future it is planned to perform post-irradiation examination of fuel elements of the third batch of irradiated FAs.

4. Planned tests

Future tests are planned in the BN-600 reactor to continue work to determine ultimate life of fuel elements with EK164 claddings, to obtain experimental data to justify elongation of FA life and increase of fuel burnup in BN-600 and BN-800 reactors, and to obtain data to justify operability of BN-1200 FA fuel elements at the initial operation stages. Table III shows planned maximum irradiation parameters of four FAs with EK164 claddings.

TABLE III: PLANED IRRADIATION PARAMETERS OF FOUR FUEL ASEMBLIES

Parameter	Value			
	FA of low-enrichment zone	FA of medium-enrichment zone	FA of high-enrichment zone-1*	FA of high-enrichment zone-2**
Prescribed life, efpd	752	752	752	888
Peak fuel burnup, % h.a.	13.0	13.8	14.3	14.8
Maximum damage dose, dpa	112	106	100	107

* FA, installed in high-enrichment zone cell with the most level of neutron flux density for irradiation during 5 operating cycles.

** FA, installed at the periphery of the high-enrichment zone for irradiation during 6 operating cycles.

Permission for irradiation of these four FAs under parameters given in Table 3, will be obtained based on results of post-irradiation examination of fuel elements from the third irradiated batch of FAs.

Now, these four FAs are installed in the BN-600 reactor for irradiation during four operating cycles (592 efpd). When the results of post-irradiation examination of fuel elements of third-batch FAs will be obtained, the justification will be developed for irradiation elongation of these FAs targeting parameters given in Table III. It is planned to obtain post-irradiation examination results of these four FA in 2020-2021.

These results will be a basis for changing over of BN-600 and BN-800 cores to operation with an elongated fuel life of FAs, as it is shown in Table 1. The obtained results will be also used to justify operability of fuel elements of experimental FAs of BN-1200 type which will be made by an individual program.

5. Conclusion

Achievement of high burnup of oxide fuel (UO_2, MOX) is limited considerably by radiation resistance of fuel element cladding material. The EK164 steel is a proved advanced material with increased radiation resistance, which is confirmed by irradiation examination experience.

Planned irradiation examinations of FAs with EK164 claddings will allow obtaining experimental data to justify elongation of fuel life and increase of fuel burnup in BN-600, BN-800 reactors, and application of obtained data to justify operability of BN-1200 FA fuel elements of the initial operation stage.

6. References

[1] Nikitina A.A., Ageev V.S., Leonteva-Smirnova M.V., Mitrofanova N.M., Naumenko I.A., Tselishchev A.V., Chernov V.M. Work development for structural materials of cores of fast reactors //Atomic energy.- 2015.- V.119.- No.5.- November.- P.292-300

[2] Bakanov M.V., Maltsev V.V., Oshkanov N.N., Chuev V.V. Main results of operation of structural materials in cores of the BN-600 reactors // Inter-branch scientific-technical conference "The 45th anniversary of test complex IVV-2M", Zarechnyi, Russia, May 26-27, 2011.

[3] Mitrofanova N.M., Tselishchev A.V., Budanov Yu.P., Leonteva-Smirnova M.V. Presentation of paper "Austenitic nickel-chromium steels for fuel element claddings of fast reactors – status and prospects" // Inter-branch scientific-technical conference "The 45th anniversary of test complex IVV-2M", Zarechnyi, Russia, May 26-27, 2011.