OPEN JOINT STOCK COMPANY
«Research and Development Institute of Power Engineering
named after N.A. Dollezhal awarded with Order of Lenin »

OPERATIONAL RESULTS OF NPPS WITH RBMK REACTORS FOR THE PERIOD OF 2010-2012, TECHNICAL CHALLENGES OF FINAL STAGE OF RBMK REACTORS OPERATION

Yu.G. Dragunov, Director – General Designer of JSC RDIPE,
Corresponding member of RAS;
A.A. Petrov – Chief Constructor of JSC RDIPE;
E.V. Burlakov – Director of R&D IAS NRC “Kurchatov Institute”,

МНТК-2012

Key indicators of NPPs with RBMK reactors in 2011

- **Power production** – 77 664.5 mln.kWh (45% of total power produced by NPPs);
- **Capacity factor** – 80.32%;
- **Availability factor** – 81.03%;
- **Number of events** – 11;
- **Number of reactor trips** with actuation of reactor protection system – 7.

Note: During the said period of time activities related to finalization of special systems upgrade at Unit 1 of Smolensk NPP, and large-scale examination of Leningrad NPP unit #1 reactor were performed.

Main activities performed at power units of RBMK NPPs within the period of 2010-2012

1. Modernization and life time extension
2. Implementation of controlling systems complex
3. Implementation of uranium- erbium fuel with 2.8% enrichment
4. Implementation of cluster regulating elements
5. Fuel improvement
6. Safety enhancement and neutronic characteristics improvement
7. Activities aimed at increase of extreme external events resistance
8. Resolution of the problem of weld joint cracking through IGSCC mechanism (details were reported at MNTK-2010)

1. Activities on modernization and life time extension

Smolensk NPP, unit № 1:

- ✓ Full-scale modernization realized
- ✓ Preparation for life time extension performed
- ✓ Report on In-Depth Safety Assessment developed
- ✓ Repair of 800-mm diameter pipe weld joints has been performed. Weld joints with high-nickel backing welds and austenite sealing welds have been repaired.

Leningrad NPP, unit № 4:

- ✓ License for life time extension obtained

By now full-scale modernization is fulfilled at 9 power units with RBMK reactors, 6 of which underwent authorization procedure necessary for life time extension.

2. Implementation of controlling systems complex

Composition of controlling systems complex :

- integrated monitoring, control and protection system (IMCPS) ;
- safety control systems for process systems;
- computer-based systems with data input units;
- main control panel and emergency (reserved) control panel;
- UPS;
- information computer system «Scala-micro».

2010 – Leningrad NPP, unit № 4

2011 – Smolensk NPP, unit № 1

НИКИЭТ им.Н.А.Доллежаля

3. Implementation of uranium- erbium fuel

NPP - unit	Core loading with 2,6% fuel/2,8% fuel started on	2,8% fuel percentage	Increase of average power production since the time when 2,6% enriched fuel has been loaded
Leningrad NPP-1	04.1997/11.2005	94%	28%
Leningrad NPP-2	04.1997/01.2001	85%	31%
Leningrad NPP-3	10.1998/03.2004	93%	30%
Leningrad NPP-4	04.1997/10.2005	92%	34%
Kursk NPP-1	07.1999/01.2007	88%	34%
Kursk NPP-2	06.2000/04.2007	86%	44%
Kursk NPP-3	06.2000/01.2005	97%	33%
Kursk NPP-4	06.1999/01.2005	97%	38%
Smolensk NPP-1	11.1999/02.2005	99%	36%
Smolensk NPP-2	11.1999/09.2005	99%	33%
Smolensk NPP-3	06.1999/02.2005	98%	28%

4. Implementation of cluster regulating elements

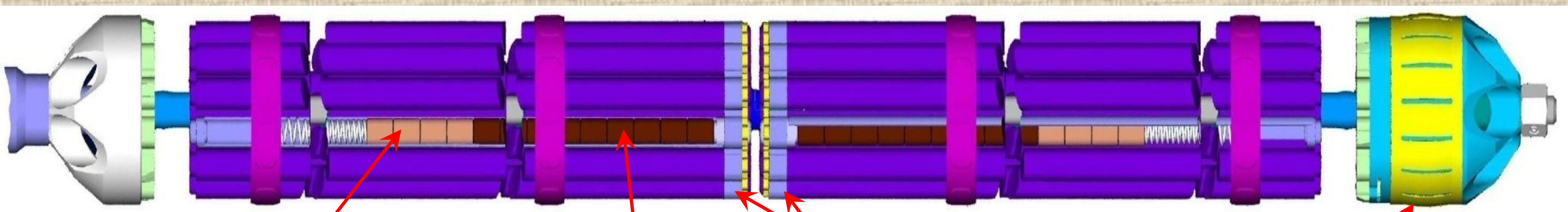
NPP - unit	Level of implementation of cluster regulating elements
Leningrad NPP-1	Less than 20 elements are to be installed
Leningrad NPP-2	Full scope implemented
Leningrad NPP-3	Full scope implemented
Leningrad NPP-4	54 elements are to be installed
Kursk NPP-1	63 elements are to be installed
Kursk NPP-2	Full scope implemented
Kursk NPP-3	Less than 20 elements are to be installed
Kursk NPP-4	Full scope implemented
Smolensk NPP-1	Full scope implemented
Smolensk NPP-2	Less than 20 elements are to be installed
Smolensk NPP-3	Full scope implemented

Set of cluster regulating elements for manual and automatic reactor regulation of different units consist of
135 to 166 actuating mechanisms

5. Fuel improvement

Design specifications of FA-PFC:

- **operating life – 3 940 MW day/FA**
  (for FA with 2.8% enrichment - 3 380 **MW day/FA**);
- **reliability – (1-2)·10^{-5} failures of fuel elements per year for 1 power unit;**
- **specified lifetime – 10 years.**

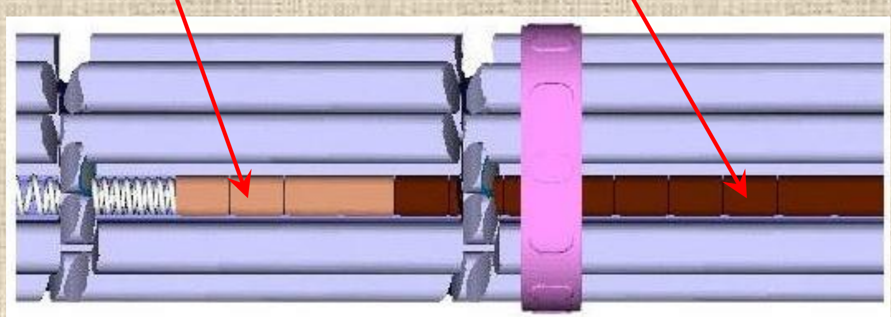


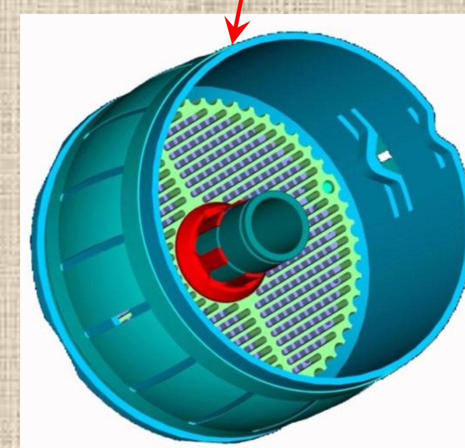
Fuel pellets of 2.5% enrichment with erbium content 0.3% (length 935 mm)

Fuel pellets of 3.2% enrichment with erbium content 0.7% (length 2590 mm)

Support grids ensuring central fastening of fuel elements

Tailpiece filter





6. Safety enhancement and neutronic characteristics improvement

Nuclear safety enhancement is ensured due to the following:

- **implementation of IMCPS with two fast-acting independent shutdown systems (AZ and BSM)**

  time needed to insert negative reactivity -1 β_{ef} is :
  - in AZ mode –1.3 sec,
  - in BSM mode – 1.2 sec,
  - in combined AZ+BSM mode – 0.9 sec

- **implementation of cluster regulating elements, which reduce positive effect of reactivity under conditions of de-watering of cooling circuit of the control and protection system from 2 β_{ef} to <1 β_{ef};**

- **reduction of steam reactivity effect to (0.3-0.8) β_{ef} .**

7. Activities aimed at increase of extreme external events resistance

- Participation in conduct of stress-tests in NPPs and release of reports
- Development of technical requirements, technical specifications for measures on increase of power units robustness under conditions of beyond design basis accidents
- Analysis of beyond design basis accidents with long-term blackout and loss of sources for cooling water makeup

НИКИЭТ им.Н.А.Доллежаля

TECHNICAL CHALLENGES OF FINAL STAGE OF RBMK REACTORS OPERATION

Key factors restricting operational life time of reactor

1. Fissuring of graphite blocks, curvature of fuel channels (FC) and control and protection system channels
2. Centerline shrinkage of graphite stack columns and reducing of engagement of telescopic joint «process channel path – graphite column»
3. Diametric and longitudinal creep of FC tube and change of properties of zirconium alloy of FC tube

1. Fissuring of graphite blocks, curvature of process channels and control and protection system channels

Trend of fissured graphite blocks amount growth (in accordance with inspection findings from Leningrad NPP unit 1)

Parameter / Year	2008	2010	2011
TV-examination of graphite after removal of process channels, cells	64	71	22
Detected cells with cracks in blocks, pcs.	32 (50%)	45 (63%)	19 (90%)
Total amount of fissured blocks, pcs.	75of 896 (8%)	164 of 994 (16%)	93 of 280 (33%)

1. Fissuring of graphite blocks, curvature of process channels and control and protection system channels

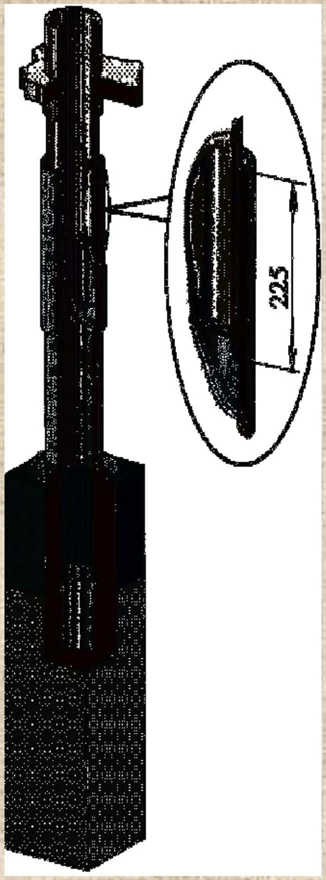
Supplementary program of experimental and theoretical studies of Leningrad NPP Unit 1

- reactor installation conditions assessment;
- performance analysis of in-core devices under conditions of form deformation of graphite stacking;
- justification of core components structural stability in course of operation under conditions of form deformation of graphite stacking;
- analysis of possibility of conditions change of emergency situations connected with deformations of core components

Conclusion: value of 100 mm is taken as justified value of allowable deflection of process channels and control and protection system trains for the years 2011-2012 considering deformation growth rate.

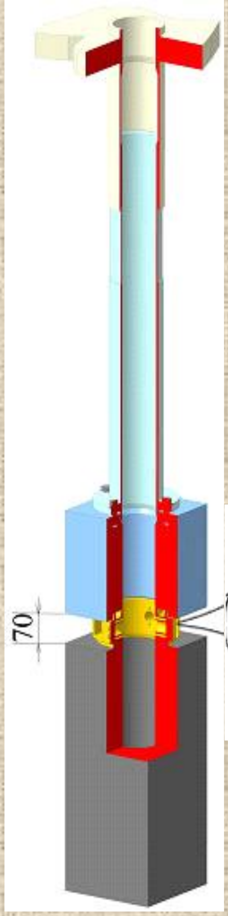
2. Centerline shrinkage of graphite stack columns and reducing of engagement of telescopic joint «process channel path – graphite column»

Recovery of TCT by means of segment inserts mounting



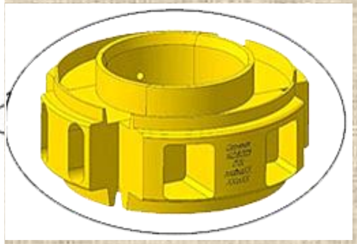
Design condition of TCT

225mm – engagement value of TCT in cold conditions, that ensures 30 years of reactor facility operation

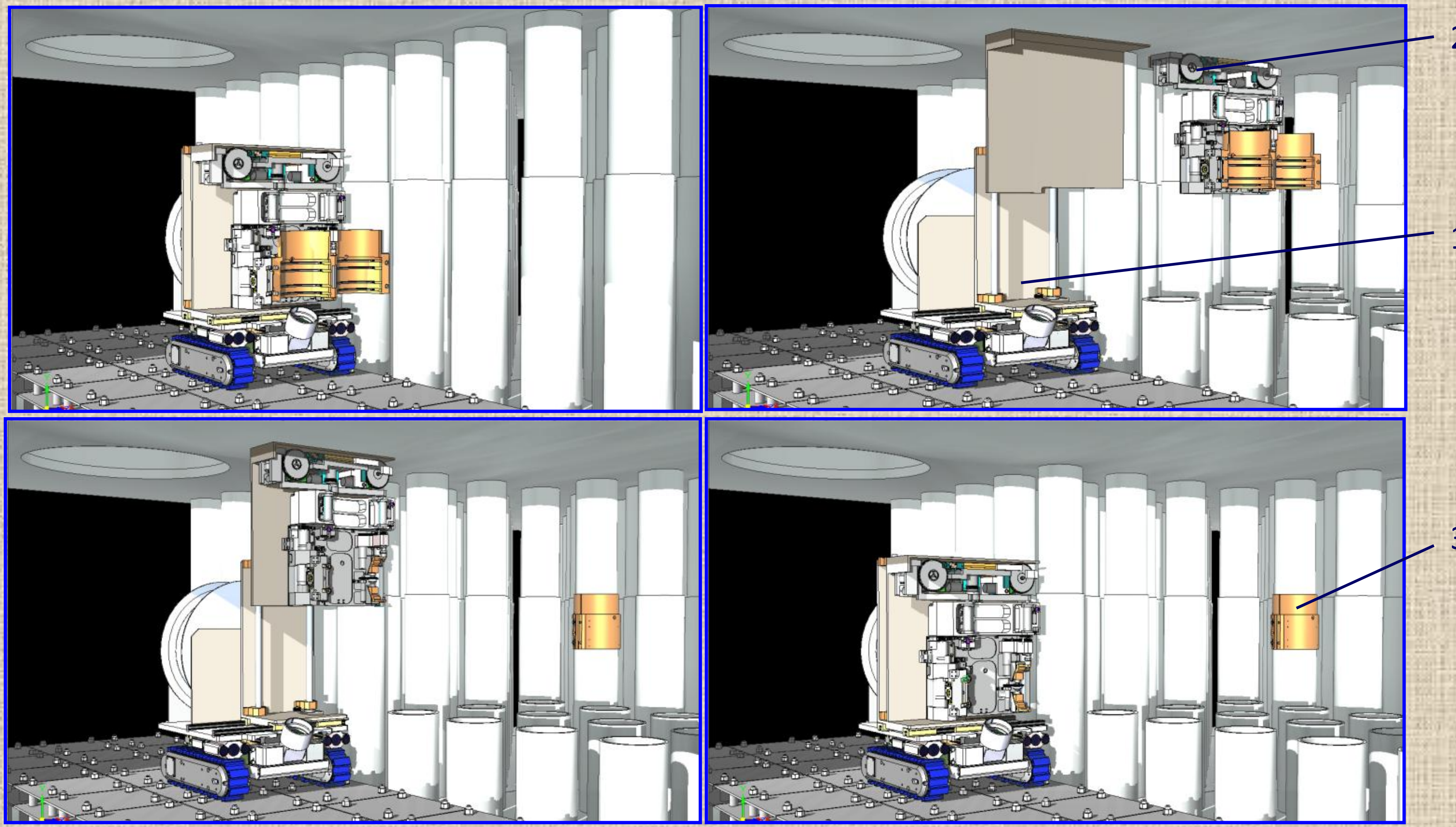


TCT recovery

Segment insert (expansion device)

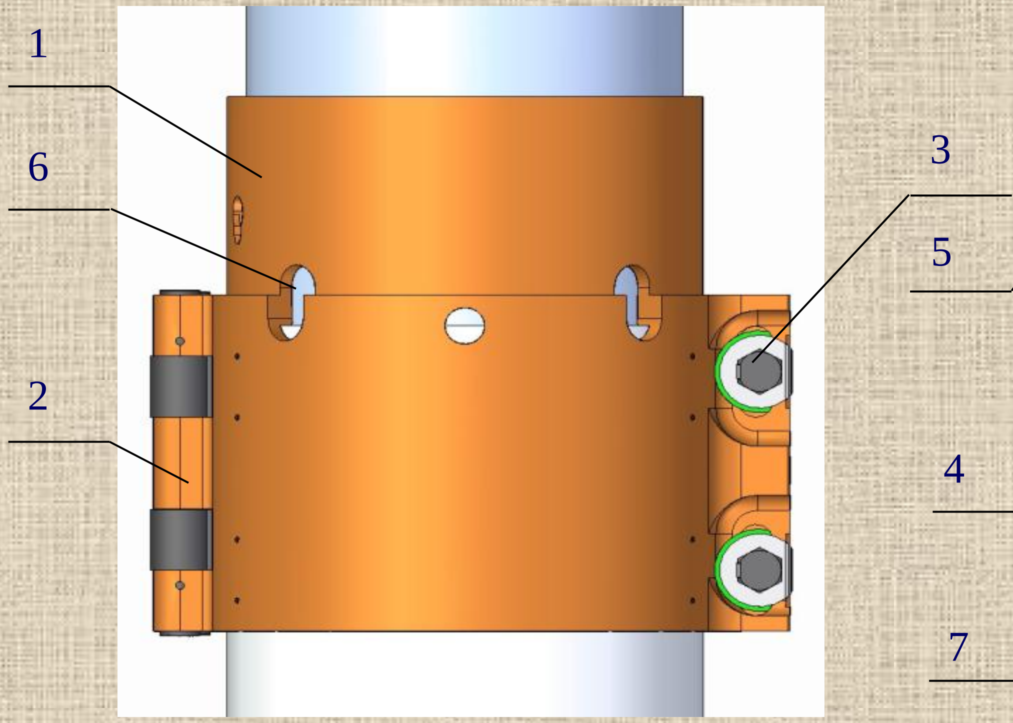


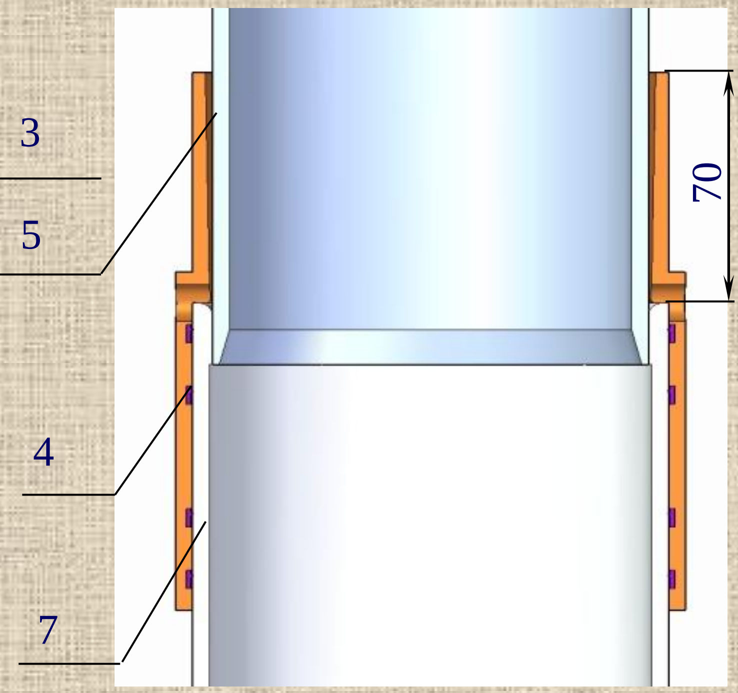
Alternative recovery of TCT using robotic system



1 – robot for delivery; 2 – robot for mounting; 3 – extension clamp

Extension clamp





1 – Extension clamp
2 – pivot hinge
3 – screwed connection
4 – fixing member
5 – tube duct
6 – windows with gage marks
7 – flange pipe

tightening torque of screwed connection – $10_{-0,5}$ N·m

3. Diametric and longitudinal creep of PC tube and change of properties of zirconium alloy of PC tube

Cause of change	Risk	Remedy or compensation
Diametric creep of PC, enlargement of PC internal diameter	Attrition of margins till the level of FA heat exchange crisis; vibration amplification	Definition of internal diameter tolerance that could ensure vibration resistance and allow sufficient heat removal. When limit internal diameter size is exceeded PC should be replaced.
Longitudinal creep, extension of PC	Depletion of lower expansion joint travel,, possible bog down and buckling of PC	Replacement of expansion joint with a new one or restoring of its travel by means of its contraction.
Change of properties of zirconium alloy of PC tube (hardening and embrittlement, corrosion, hydrogen pickup)	Increased probability of PC integrity failure	Control over tendency in zirconium alloy properties based on the results of post-reactor studies. Estimating of limit characteristics. Timely replacement of PC.

Main functional areas of ageing management of RBMK reactor components

1. Improvement of control and monitoring of core components conditions
2. Simulation (modeling) and predicting of graphite stack deformation processes
3. Analysis of emergency situations development under conditions of graphite stack deformation processes
4. Investigation of form-change processes effect onto neutronic characteristics of the core

Main functional areas of ageing management of RBMK reactor components

5. **Justification of core elements and enclosing structures stability**
6. **Theoretical and experimental studies of operability of control and protection system rods and FA control rods, heat exchange processes efficiency**
7. **Justification of limits and conditions of safe operation**
8. **Development of compensatory measures** (upgrade of reactor structures and components, maintenance procedure development, optimization of operation conditions, modification of procedures)

НИКИЭТ им.Н.А.Доллежаля

Compensatory measures to ensure safe operation of reactor facility under conditions of deformation of graphite stack.

1. **Purpose – deceleration of bending deflection rate**

Ways of realization:

- ***Hardening of reflector*** (installation of upgraded KOOs)
- ***Local recovery repair (maintenance)*** (formation of another crack in graphite block opposite to existing one, straightening of columns with help of drag bars)
- ***Installation of drag bars in separate PC***
- ***Optimization of operation modes. Profiling of power density field.***

ИКИЭТ им.Н.А.Доллежаля

2. **Purpose – to ensure operability of core internals**

Ways of realization:

- ***Modernization of control rod drives***
  (reduction of links length of absorber rods, RCCA sleeve strength reduction)
- ***Modernization of FA***
  (increase of spacer grids number)

НИКИЭТ
им.Н.А.Доллежаля

THANK YOU FOR ATTENTION!