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MODIFICATIONS OF FUEL COOLING CIRCUIT FOR MARIA REACTOR TO BE REQUIRED FOR CONDUCTING THE FULL CONVERTION OF THE CORE

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ABSTRACT

Anticipated MARIA reactor core conversion will be based on replacing the high enriched MR type fuel elements manufactured by Russia with low enriched MC type fuel elements fabricated by CERCA-Areva. The two MC type elements are being tested in the reactor at present. Hydraulic measurements and analysis of MC fuel element design exhibited that in comparison with MR fuel elements they have:

- hydraulic resistance coefficient greater in around 30%;
- heat transfer surface smaller in around 25%.

Admissible thermal power of the MR fuel element is 1.8 MW with coolant flow rate 25 m^3/h. Thermal-hydraulic calculation completed unveiled that to maintain the same value of thermal power for the MC fuel element requires to increase coolant flow rate up to 30 m^3/h.
The characteristics of the main pumps being using now in the fuel channel cooling circuit don't ensure to achieve such parameters for the core of typical configuration (around 25 fuel channels).
To accomplish full core conversion it is needed main pumps replacement for other ones with higher parameters.
The work contains data on measurements runs and calculation enabling to assess the required parameters for the new pumps.

Introduction

According to the overall trends in reactor MARIA an attempt for application of the low enriched (LEU, Low Enriched Uranium) nuclear fuel is being launched. The reactor was primarily designed for operation on high enriched fuel (HEU, High Enriched Uranium) with content of 80% 235 U. In the period 1999-2003 there has been performed a conversion on fuel enriched to 36%. In both cases the Russian MR type fuel was used.

Due to substantial reduction of enrichment under assumption to preserving to maximum degree the physical and thermal-hydraulic parameters of reactor primarily it was foreseen to use U-Mo fuel of highly densed uranium in the fuel (> 5g/cm^3) to be developed in Russian Federation. In 2005 the feasibility study for applying the silicide fuel (U_3Si_2) of 4.8 g/cm^3 density was commenced. Potential supplier of such fuel is the company Areva (CERCA). The proposed fuel has been tested to very high levels of burnup and for the time being is widely used in many research reactors in the world.

The fuel assemblies for MARIA reactor differ from the fuel elements U_3Si_2 (fuel plates) that have been used so far and due to that the implementation of the new fuel in MARIA reactor needs to developing a procedure for attestation of new fuel assemblies in MARIA reactor. The main component of the procedure for attestation of new fuel for MARIA reactor is irradiation of two trial fuel assemblies (LTA, Lead Test Assemblies) under reactor normal operational conditions.

The new fuel elements will be denoted further by letters MC to distinguish them from the MR fuel that has been used so far. The flow schema for the MARIA FA is shown on the Fig.1.

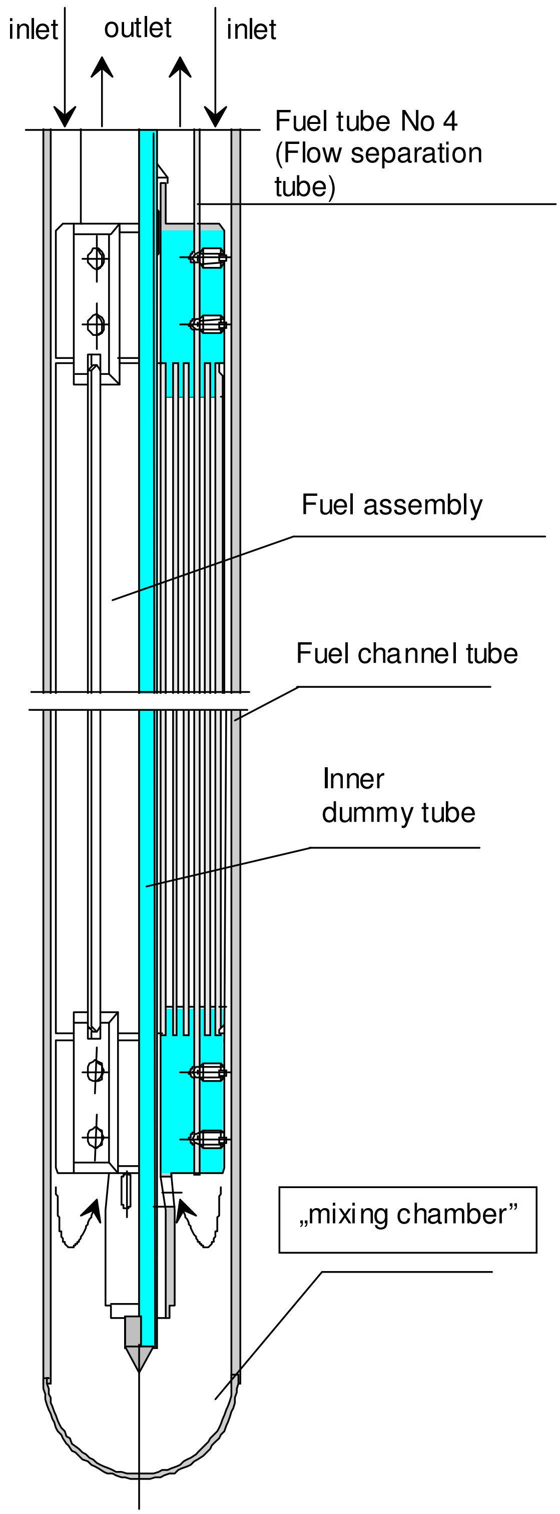


Fig. 1. Flow schema through the MARIA FA

Comparison of MR6 and MC5 horizontal cross-sections is shown on Fig. 2 and Fig. 3, respectively.

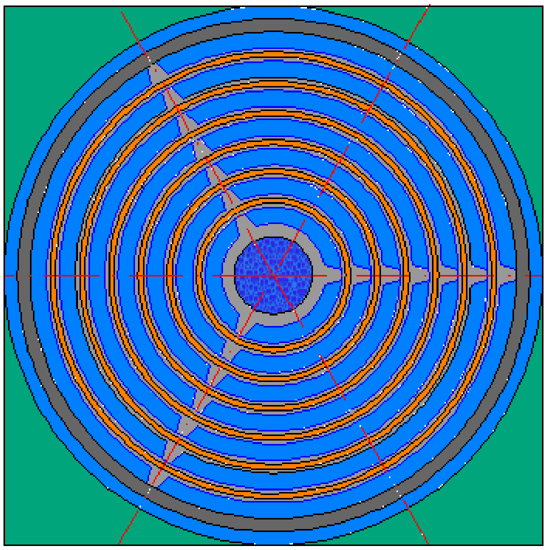


Fig2. MR6 horizontal cross-section

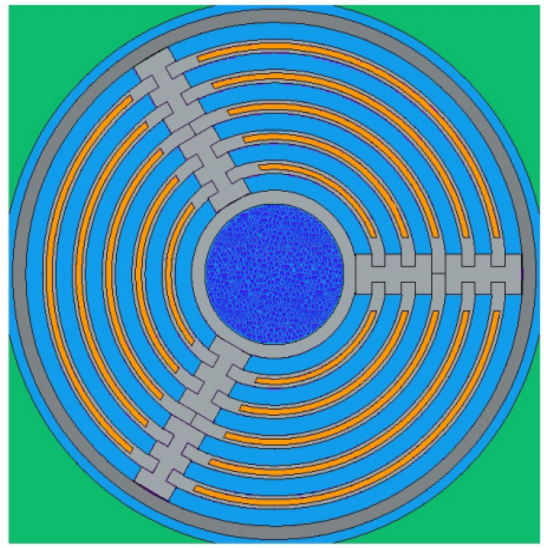


Fig.3. MC5 horizontal cross-section

Physical Characteristics of the Fuel

- Number of fuel tubes = 5 (6)
- ^{235}U content = 485 g (430 g);
- U_3Si_2 (wt 7.5% Si, 92.5% U) with density 12.2 g/cm^3;
- Uranium density in fuel meat = 4.79 g/cm^3 (2.79 g/cm^3)

Hydraulic Features Comparison

Parameter	MR		MC	
Water gaps	Inner	Outer	Inner	Outer
Hydraulic diameter [mm]	5	5	**4.49 ÷ 4.71**	**4.77 ÷ 4.82**
Water gaps surface [mm^2]	1005	1496	**724**	**1361**
Flow rate through the FA [m^3/h]	25		**30**	
Average water velocity [m/s]	↑ 6.8	↓ 4.7	**↑ 9.2**	**↓ 5.1**
Heat exchange area [m^2]	1.72		1.29	

Hydraulic characteristics Comparison

To making comparison of hydraulics characteristics for the MR6 type fuel element with MC5 a series of experiments was carried out on the out-of-reactor water test stand specially built for this aim. The tests were performed in a following way:

- Dummy fuel element of MC5 having an identical geometry as the real fuel element to be fabricated by CERCA which didn't contain uranium;
- Fresh fuel element of the MR6 type;
- Fresh MC5 LTA's.

Comparison of MR6 and MC5 hydraulic characteristics is shown on Fig. 4.

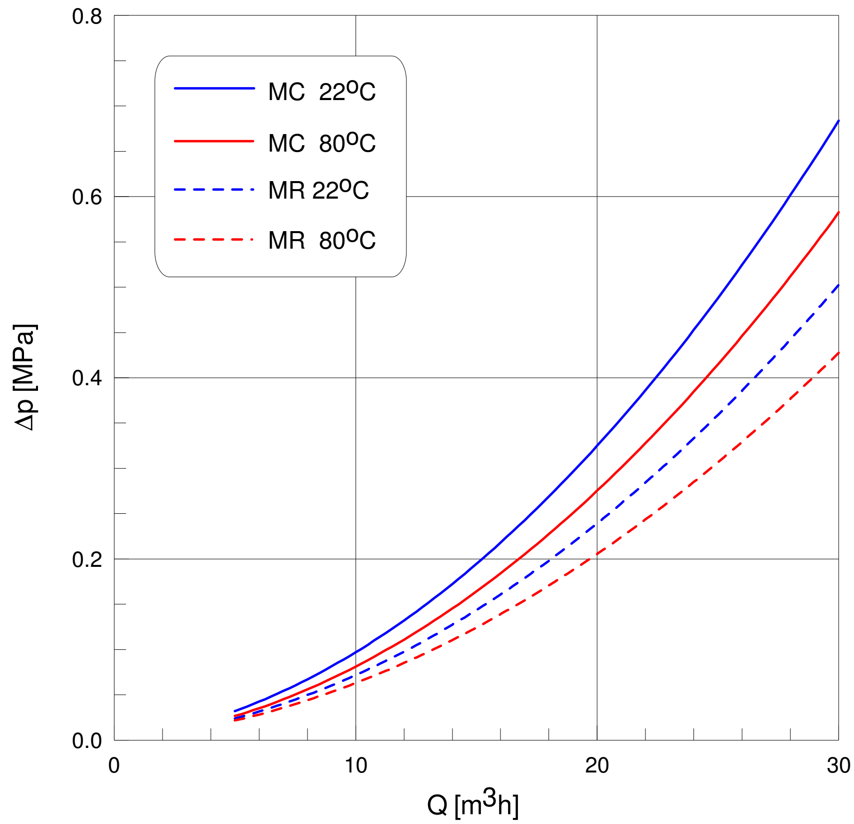


Fig.4. Comparison of MR6 and MC5 hydraulic characteristics

- Pressure drop for 22°C:
  - ✓ MR (25 m^3/h) – 0.36 MPa
  - ✓ MC (30 m^3/h) – 0.68 MPa
- Pressure drop for 80°C:
  - ✓ MR (25 m^3/h) – 0.31 MPa
  - ✓ MC (30 m^3/h) – 0.58 MPa

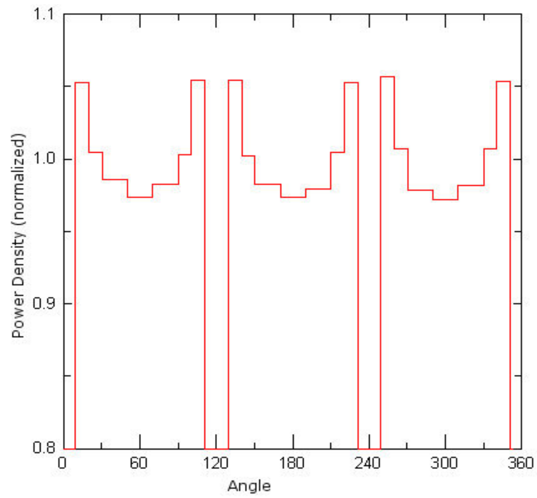
Neutronic Analysis

Specific features of MC insertion and irradiation

- Higher ^{235}U content (485 g – MC and 430 g - MR)
- Power peaking to the MC fuel in the initial phase of irradiation at the core centre
- Azimuthal fuel distribution discontinuity due to stiffeners
- Lower enrichment → change of kinetics parameters

Computer codes applied (IAE, ANL)

- WIMS-ANL – cell calculations and libraries
- REBUS, VARI-3D – diffusion codes (reactivity, power distribution, kinetics parameters calculations)
- MCNP – as above
- 4-th May 2009 – reference core



Impact of stiffeners and fuel distribution inhomogeneity, MCNP calculations
Azimuthal power density distribution on the 6-th tube → peaking factor $k_S = 1.06$ (maximum to average)

Fig.5. Azimuthal power density distribution for MC5

Results: Steady-state Thermal-Hydraulics Analysis

- ONBR > 1.2 criterion is more conservative than the saturation temperature
- Operation condition selected for MC fuel: $G_{k,nom} = 30$ m^3/h

For „warning" parameters i.e. MC element power = 1.98 MW (110%) and flow rate = 27 m^3/h (90%):

- $T_{k,max}$ = 152°C (153°C)
- q_{max} = 2.61 MW/m^2 (2.04 MW/m^2)

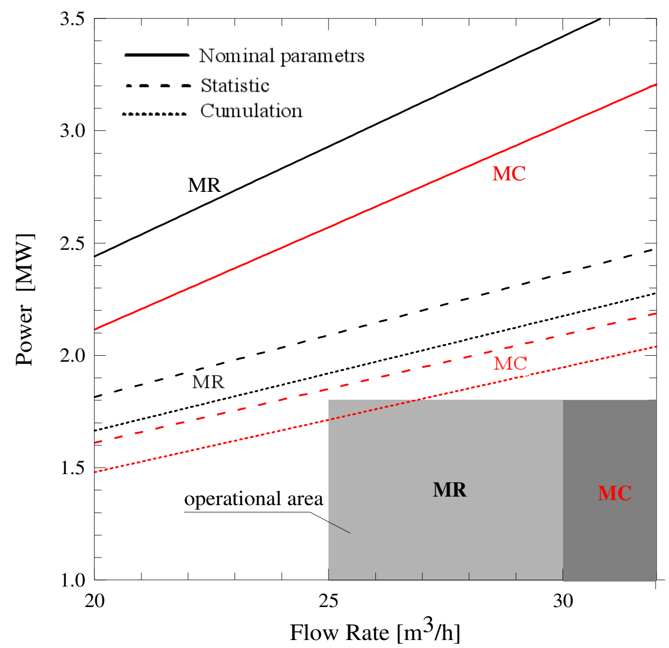


Fig. 6. Power vs. Flow Rate plot
(inlet water temperature 45°C and pressure 1.6 MPa)

Some conclusions of Thermal-Hydraulics analyses

- Steady-state Thermal-Hydraulics analysis confirms, that replacing of the nominal flow through the MR channel (25 m^3/h) by 30 m^3/h for MC fuel restores almost exactly all the thermal parameters (maximum clad temperature and ONBR) but the bulk water temperature (lowered);
- Uncertainty coefficients for both fuels are practically unchanged (valid for LTAs only);
- FP inventory for LTAs shows slightly higher values by max. 30% - no substantial changes in radiological consequences;

- Transient analysis results – all the thermal parameters behavior restored but bulk water temperature. No changes to reactivity and power courses;
- The nominal flow rate through the LTAs to be increased to 30 m^3/h and corresponding warning level of 27 m3/h and the scram – 24 m3/h
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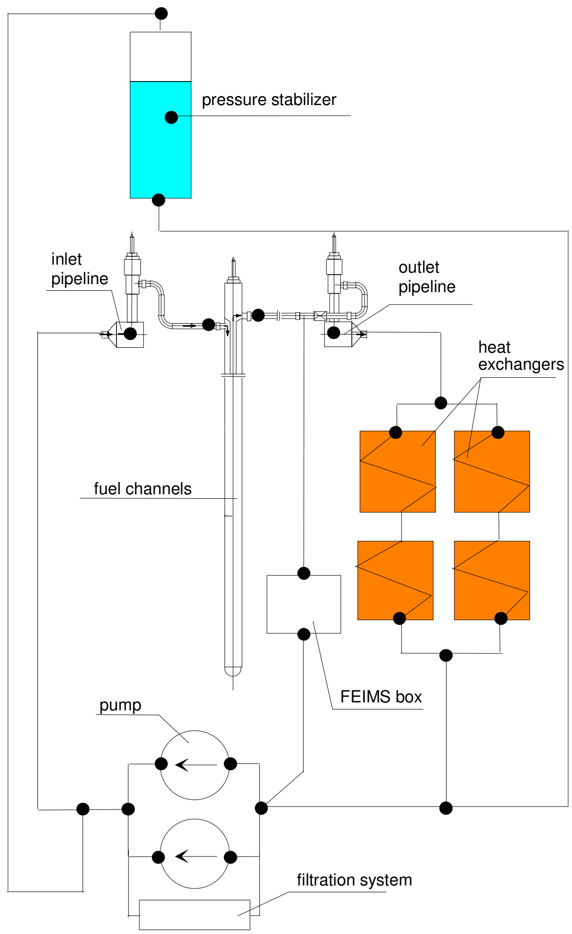
Simplified schema of fuel channels cooling circuit



Simplifications:
• 4 parallel pumps (2–hot reserve)
• 3 parallel heat exchangers (1-hot reserve)
• variable number of fuel channels (20÷27)

Fig. 7 Simplified schema of fuel channels cooling circuit

Pumps characteristics

Above mentioned requirements for proper cooling of MC5 FA shows us, that for full core conversion based on low-enriched MC5 fuel assemblies requires replacement of main pumps in pressurized fuel channels cooling circuit

The comparison of existing and proposed hydraulic characteristic of pumps system is shown on Fig. 8.

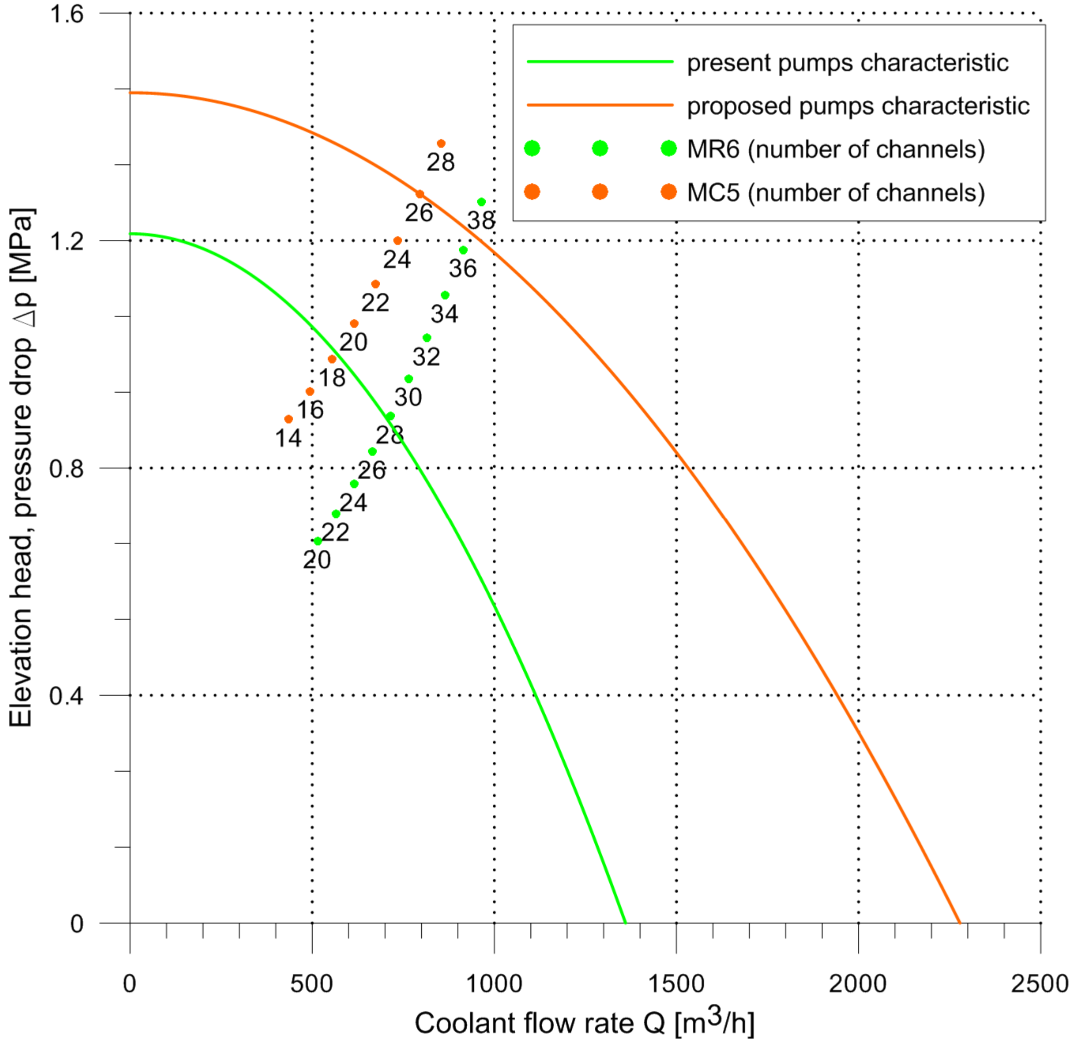


Fig.8. Comparison of hydraulic characteristics of presently used and proposed pumps

2 parallel pumps

✓ Present
  - 27 MR channels
  - 18 MC channels

✓ Proposed
  - MR – no limit
  - 26 MC channels

Conclusions

•Problem described above is not directly caused by the fuel enrichment change, but by change of fuel assembly design;

•Solution of the problem is rather simple, but needs significant modification of cooling system and involves additional costs.

References

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