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Brief history of MARIA conversion from HEU to LEU

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ABSTRACT

MARIA reactor core initially operated with 80% enriched HEU fuel and converted to 36% HEU in 1999. Since 2005 in National Centre for Nuclear Research works on the fuel conversion from highly enriched uranium with 36% of 235U to low enriched one (LEU) with 235U content below 20% have been led. This is the most recent fuel conversion held in NCNR. This task sets before us a number of serious challenges. Main one was upgrading of reactor pump system, among others there are PIE tests of LTA's, measuring safety related coefficients, constant fuel channels monitoring using Fuel Integrity Monitoring System (FEIMS), vibration tests of new fuel and last but not least development of neutronic and thermal-hydraulic calculations inspired by the full core conversion. All this work is performed under supervision of some US experts within the framework of an US-government-funded international project to limit terrorist attack risk.

1. Introduction

MARIA reactor was primarily designed for operation on high enriched fuel 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. Then IEA has decided to utilize LEU silicide fuel with lower enrichment (19.75%) for conversion of the MARIA reactor, qualified under the RERTR Program and used successfully in many western research reactors. In 2005 the feasibility study for applying the silicide fuel (U_3Si_2) of 4.8 g/cm^3 density was commenced. Supplier of such fuel is the company Areva (CERCA). CERCA delivered to IAE one dummy fuel assembly (DFA) in May 2008 for hydraulic testing and two LTAs in July 2008. The proposed fuel has been tested to very high levels of burnup. Besides irradiation test, hydraulic tests was conducted. Measurements and analysis of MC fuel element design exhibited, that in comparison with MR fuel elements they have worse hydraulic and heat transfer coefficients, so main pumps system replacement was inevitable. 2009 is the beginning of LTA's irradiation, followed by inserting CERCA fuel and start of conversion in September 2012. Primary pumps replacement took place between June and September 2013. In September 2014 core conversion has ended and MARIA reactor is now operating only on LEU fuel elements.

2. Reactor pump system upgrade

To make 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. 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% andheat 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 previously used did not ensure to achieve such parameters for the core of typical configuration (around 25 fuel channels). To accomplish full core conversion main pumps replacement for other ones with higher parameters was needed.

Table 1. Parameters of new pumping units.

Parameter	Main pumps	ESWS pumps
Installed	4	3
Working	2	2
Flow rate, m^3/h	400	70
Pumping head, H2O m	128	12
Power demand, kW	179	3.1
Motor power, kW	200	4

3. LTA's irradiation testing and fuel characteristics

Since the new silicide fuel significantly differs from the Russian manufactured MR type fuel of 36% enrichment currently used in MARIA reactor it was necessary to perform a number of analyses of neutronics and thermal hydraulics, safety limits and transients required to prove its ability to operate safely in the reactor and to obtain from Regulatory Body an approval for insertion of LTAs in the core for the irradiation testing. Two low-enriched LTA's manufactured by CERCA-Areva were tested in the MARIA reactor core from August 2009 till January 2011. First LTA reached 5899 MWh (63%) burnup and the second one 4025 MWh (43%). After unloading the elements, post-irradiation sipping tests were conducted. Recently they were repeated after three years of cooling down. Results are shown below.

Table 2. LTA's sipping test results. Sudden increase in MC002 FP release is still being investigated.

Fuel element	Date of measurement	FP activity measurement		
		Cs-137	Eu-154	Eu-155
MC001	16.05.2011	575	750	-
	05.07.2014	300	-	-
	02.10.2014	2150	-	-
MC002	16.05.2011	215	-	-
	05.07.2014	21050	-	-
	02.10.2014	41550	-	-

Table 3. Fuel elements in MARIA reactor. All conversions were carried out successively, by gradually replacing old items with new fuel elements.

Type	Operation period	Material	Enrichment %	^{235}U Mass	U Density g/cm^3	Cladding mm
MR	1974 ÷ 1999	UAl_x	80	350	1.2	0.8
MR	1999 ÷ 2005	UO_2	36	540	2.3	0.6
MR	od 2005	UO_2	36	430	2.8	0.75
MC	from 2012 (tests 2009 ÷ 2011)	U_3Si_2	19.75	485	4.8	0.6
MR	from 2014 (tests from 2012)	UO_2	19.7	485	3.8	0.6

4. FEIMS

Fuel channels are constantly monitored by Fuel Element Integrity Monitoring System (FEIMS). Measurement result taken by FEIMS are normalized to the unitary fuel channel power of 1 MW and to the identical water inflow time to the detector of 60 seconds.

At the following illustration an important point is 09-14-2013, that day reactor started up after pause caused by replacement of cooling circuit pumps. It can be observed, that counts in all fuel channels increased visibly, but not exceed the limiting value 1.4·105 cpm. This has been recognized as a general increase of background activity after the pump replacement, when traces of metal filings may cause additional erosion of fuel clad and residual uranium began to circulate in reactor cooling circuit. The process developed within few cycles and next ceased. At present the burnup process decreases the signal of FEIMS system.

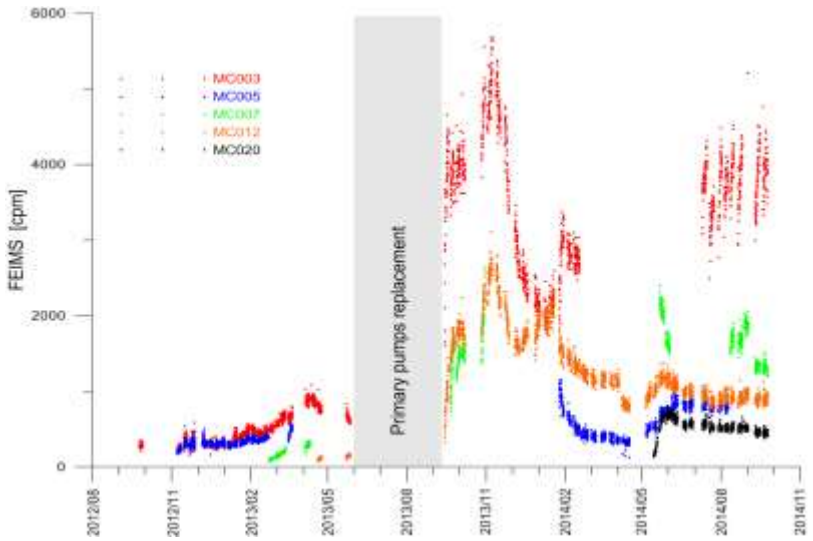

Fig.1. FEIMS signals for selected MC fuel elements.

5. Conclusions

Full core conversion from HEU to LEU fuel forced the MARIA reactor staff to undertake some drastic measures in order to complete it. It was a great success. In addition to mechanical improvements (i.e. pump replacement) thermal hydraulic and neutronic calculations field also had strenghtened. Core conversion had positively influenced cooperation between NCNR and Argonne National Laboratory.

6. References

[1] Collective work edited by K.Pytel, „Operational Safety Analysis Report of Maria Reactor", Świerk, March 2009.

[2] Annex 2013/2 to „ Operational Safety Analysis Report of Maria Reactor".