RERTR 2010 — 32nd INTERNATIONAL MEETING ON
REDUCED ENRICHMENT FOR RESEARCH AND TEST REACTORS

October 10-14, 2010
SANA Lisboa Hotel
Lisbon, Portugal

IRRADIATION TESTING OF LEAD TEST ASSEMBLIES FROM CERCA IN MARIA RESEARCH REACTOR

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ABSTRACT

The Maria reactor at the Institute of Atomic Energy POLATOM (IAE) in Poland is high-power research reactor that has used HEU fuel manufactured in Russia since it began operation. The IAE has decided to utilize LEU silicide fuel qualified under the RERTR Program and used successfully in many western research reactors for conversion of the MARIA reactor. IAE has contracted with CERCA in France to supply lead test assemblies (LTAs) having a different design, therefore it was necessary to qualify the CERCA fuel assembly for MARIA reactor by direct irradiation of LTAs in the reactor. IAE has completed its analysis and has obtained approvals from the IAE MARIA Safety Committee and from National Atomic Energy Agency of Poland for irradiation testing of the LTAs in MARIA. In August and October 2009 irradiation testing of the 2 LTAs have been started. In August 2010 the 1-st LTA have reached 42% average burnup and was removed from the core and the 2-nd LTA will be removed after occur at approximately 60%.

1. Introduction

The MARIA reactor at the Institute of Atomic Energy POLATOM (IAE) in Poland is high-power research reactor that has used HEU fuel manufactured in Russia since it began operation. The IAE has decided to utilize LEU silicide fuel qualified under the RERTR Program and used successfully in many western research reactors for conversion of the MARIA reactor [1].

IAE has contracted with CERCA in France to supply LTAs having a different design therefore it was necessary to qualify the CERCA fuel assembly for MARIA reactor by direct irradiation of LTAs in the reactor.

IAE has completed its analysis and has obtained approvals from the IAE MARIA Safety Committee and from the National Atomic Energy Agency of Poland for irradiation testing of the LTAs in MARIA.

Irradiation testing program was prepared with close cooperation between IAE and Argonne National Laboratory.

Description of MARIA RR

The high flux research reactor MARIA is a water and beryllium moderated reactor of a pool type with graphite reflector and pressurized channels containing concentric tube assemblies of fuel elements. The reactor has been designed with a high degree of flexibility. A vertical cross-section of the reactor pool is shown in Fig.1.

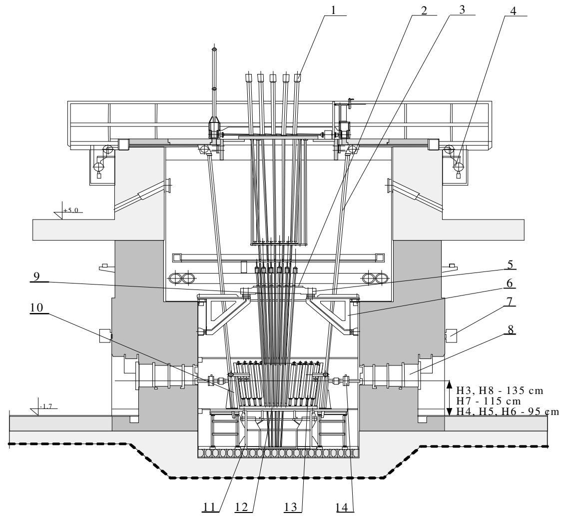

Fig.1. A vertical cross-section of the reactor pool.

The main characteristics and data of MARIA reactor are as follows:

- nominal power — 30 MW(th),
- thermal neutron density — 3×10^{14} n/cm^2·s,
- moderator — H_2O, beryllium,
- cooling system — channels type,
- output thermal neutron flux density at horizontal channel — $3 \div 5 \times 10^9$ n/cm^2·s,
- fuel assemblies:

- material:	UO2-Al alloy
- enrichment:	36%
- cladding:	aluminium
- shape:	concentric tubes
- active length:	1000 mm

The main areas of reactor application are as follows:

- production of radioisotope,
- experiments with utilization of neutron beams from horizontal channels,
- neutron radiography,
- neutron transmutation doping,
- training of students.

From July 2009 till January 2010 there was developed the Mo-99 irradiation and transport technology in MARIA reactor and then expedition of irradiated HEU targets to the processing at the Petten (Netherlands) facility.

The characteristics of LTAs (MC) fuel

The LTA's were made according to the detailing of CERCA Romans, containing fuel element characteristics, manufacturing procedures, etc. [2].

Fuel being us in MC elements is uranium silicide dispersion U_3Si_2 in aluminium matrix enriched to 19.75 % ^{235}U. The MC fuel element consist of 15 bent fuel plates joined in 5 fuel tubes. The plates composing the tube # 4 (FT4, separation tube) are lengthwise welded and rolled. The other tubes the assemblies of three bent fuel plates are longitudinally swaged on special connectors. ^{235}U content in the fuel element is 485.0 ± 5.0 g. The hydraulic losses of the MC fuel are substantially greater than the MR fuel [3].

2. Preparatory works for LTA insertion

Before inserting the MC fuel assemblies to the MARIA reactor core the IAE had to perform a number of theoretical analyses, measurements and calculations to obtain approvals from the Reactor Safety Committee and National Atomic Energy Agency to start the irradiation of CERCA fuel.

The irradiation program of the MC fuel in MARIA reactor covers two phases:

- insertion of 2 MC fuel assemblies into the core and operate them through 12 weeks;
- continuous irradiation them in the core until the final burnup of around 40% and 60% will be achieved which corresponds to the value of burnup 158 MWd and 245 MWd.

The insertion and irradiation of the MC fuel in MARIA reactor proceeded in conformity with requirements contained in the Annex No. 1/2009 to the operational Safety Analyses Report for MARIA reactor.
This Annex was submitted at first to IAE Nuclear Safety Committee for discussion and approval and then the MC fuel examination program was brought to the NAEA President to obtain the permit for MC fuel irradiation at the MARIA reactor core. Such permit was received in the first half of August 2009.
On the stage of insertion and irradiation of the test fuel there have been in power all up till now existing limits and thresholds for the MR fuel (Russian fuel) except for the coolant flow rates through the MC fuel assemblies under the forced convection. The coolant flow limit levels for the individual MC fuel assembly are as follows:

- warning signal $G_{K.SO} = 27\ m^3/h$
- emergency signal $G_{K.SA} = 24\ m^3/h$

whilst the rated flow rate through the fuel channel is:

- $G_{K.NOM} = 30 m^3/h$

It was decided to insert the two LTAs from CERCA at separate times into the MARIA core.

After each insertion of move the IAE followed established procedures for operating with a new core configuration. This included approach to criticality and operation at a series of increasing total reactor power until reaching rated power.

3. LTA irradiation

The first MC001 fuel element was inserted in the core at August 10, 2009. The second MC002 fuel element was inserted into the MARIA core at October 2009 after acceptance by Regulatory Authority of Report of the first phase testing irradiation of MC001. The power generated in the MC001 was systematically increased toward the allowed maximum of 1.8 MW. This initial irradiation phase was expected to occur during August through the end of November 2009.

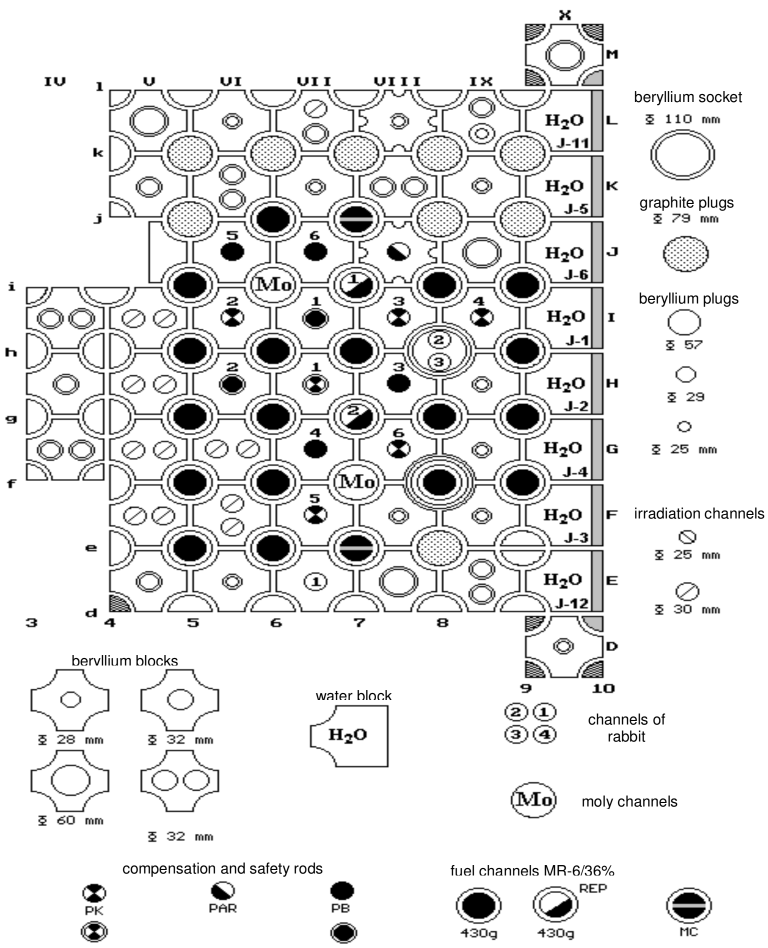

Fig.2. Configuration of reactor core.

Then reactor continue normal operational cycles with the LTAs in several locations, see Fig.2.

There were 5 steps of core position changes of MC fuel:

1. The first MC001 fuel assembly commenced to operate in MARIA reactor for 1 week in position i-5,
2. Then MC001 was moved to high flux position g-6 and operated for one week at the power of 1.6 and was kept as before in position g-6 for 4 weeks and operated on power 1.8 MW,
3. With MC001 still in position g-6 the MC002 was inserted in low flux position i-5,
4. With MC001 still in position g-6 the MC002 was moved in high flux position f-6,
5. With MC001 still in position g-6 and MC002 still in position f-6 the operation was continued for 4 weeks.

Finally the MC001 occupied mostly position i-7 and MC002 position e-7.

Each MC fuel assembly was monitored by the normal thermal-hydraulic instruments (i.e., coolant flow rate, temperature rise and outlet temperature). The fuel element power is computed from flow rate and temperature rise. The MC fuel element was also monitored by the Fuel Element Integrity Monitoring System (FEIMS) which is based on detecting of delayed neutrons from fuel fission. An increased signal level could indicate a loss of fuel clad integrity. Safety limit measured by the FEIMS is below $1.4 \cdot 10^5$ cpm/1 MW. The LTA giving increased signal level should be moved to fuel storage pool for examination. Signal level on FEIMS were performed every 15 minutes instead of the normal frequency of 8 hours. Fuel channel water contamination was checked once per day.

In August 2010 the MC002 after reached 42% (172 MWd) burn-up was discharged from the core. The MC001 will still occupy position i-7 to achieve the required burn-up.

Below there are shown some measuring results from the irradiation of the LTA MC fuel elements in the period August, 2009 – September, 2010.

In Fig.3 is shown a histogram of major operational parameters of the first test fuel element denoted as MC001 during period August, 2009 – September 2010 of irradiation it in the MARIA reactor core.

The irregular green continuous line corresponds to the power generated in the fuel channel (P_{chan}), the red irregular broken line corresponds to the total power ($P_{chan} + P_{r.pool}$) and red monotonously rising line is the fuel burnup. The scattered blue points correspond to the number of the FEIMS pulses per minute normalized to the power of 1 MW.

In Fig.4 is shown the change of major operational parameters – power emitted in the fuel channel, total power inclusive the position of thermal power emitted in the reactor pool, the fuel element burnup of the MC002 FA and the scattered blue points representing the number of pulses per minute measured by the FEIMS and normalized to the power of 1 MW.

In Fig.5 there are depicted the normalized to 1 MW power counts per minute generated by FEIMS versus the time of irradiation.

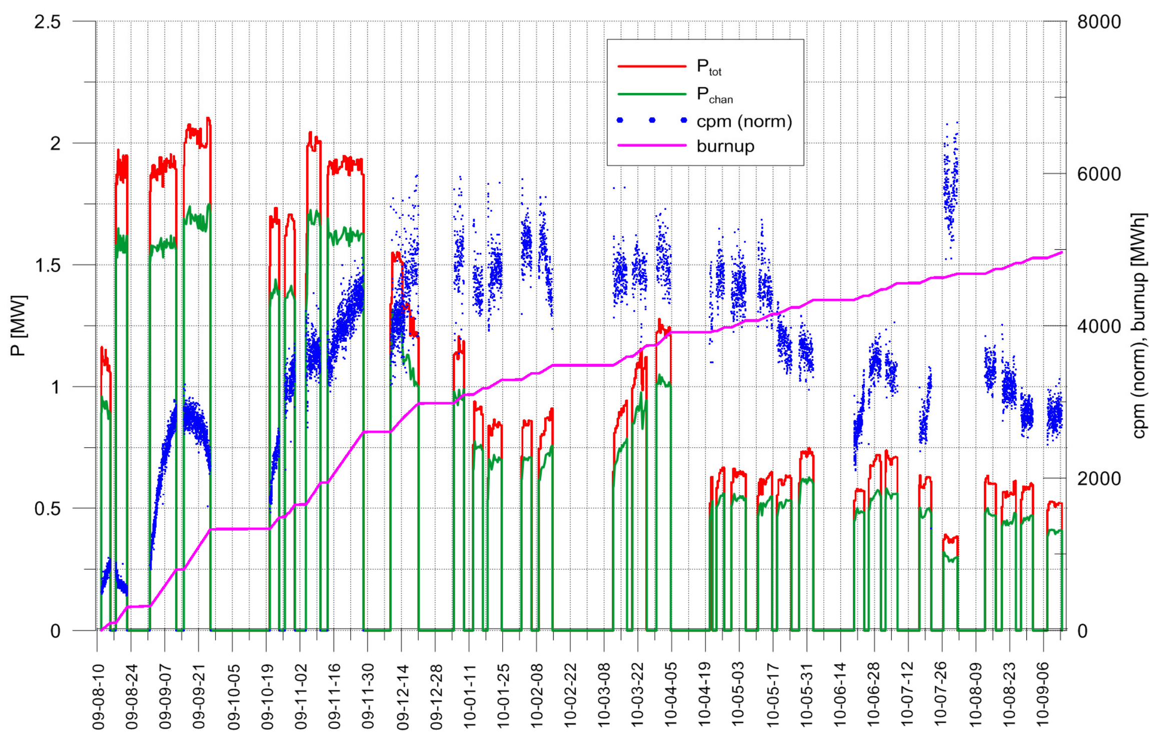

Fig. 3. Histogram of positioning in the core, power loading, burnup and FEIMS indication for the first test fuel element from CERCA (MC001).

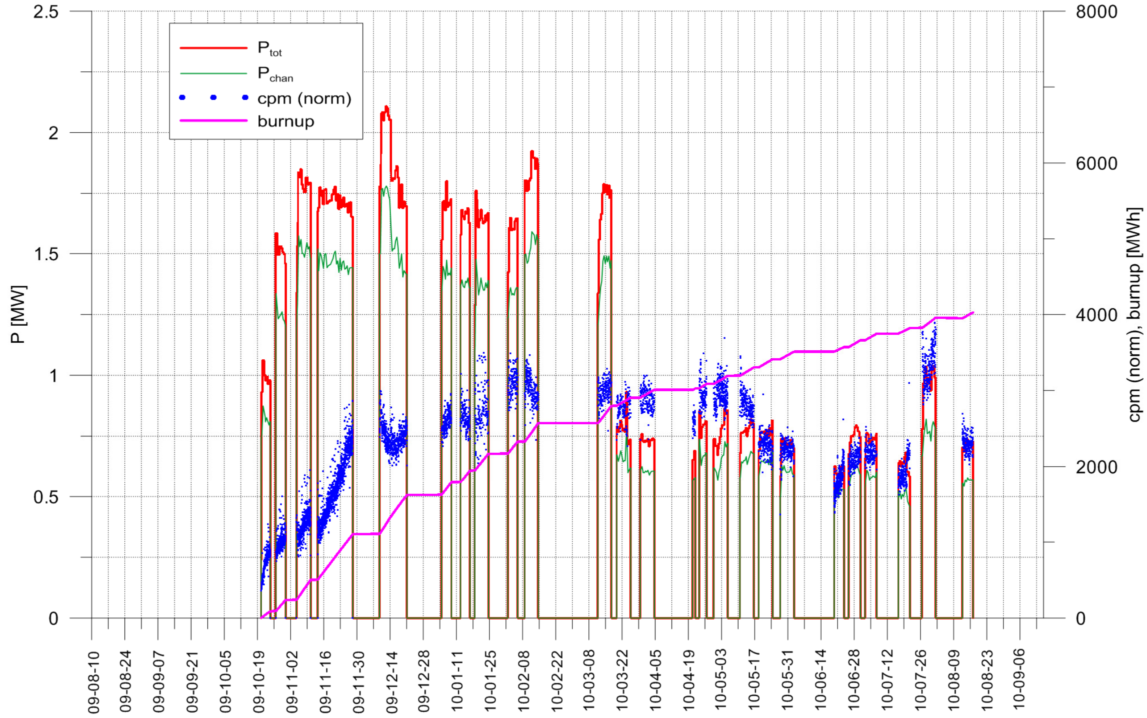

Fig.4. Histogram of positioning in the core, power loading, burnup and FEIMS indication for the second test fuel element from CERCA (MC002).

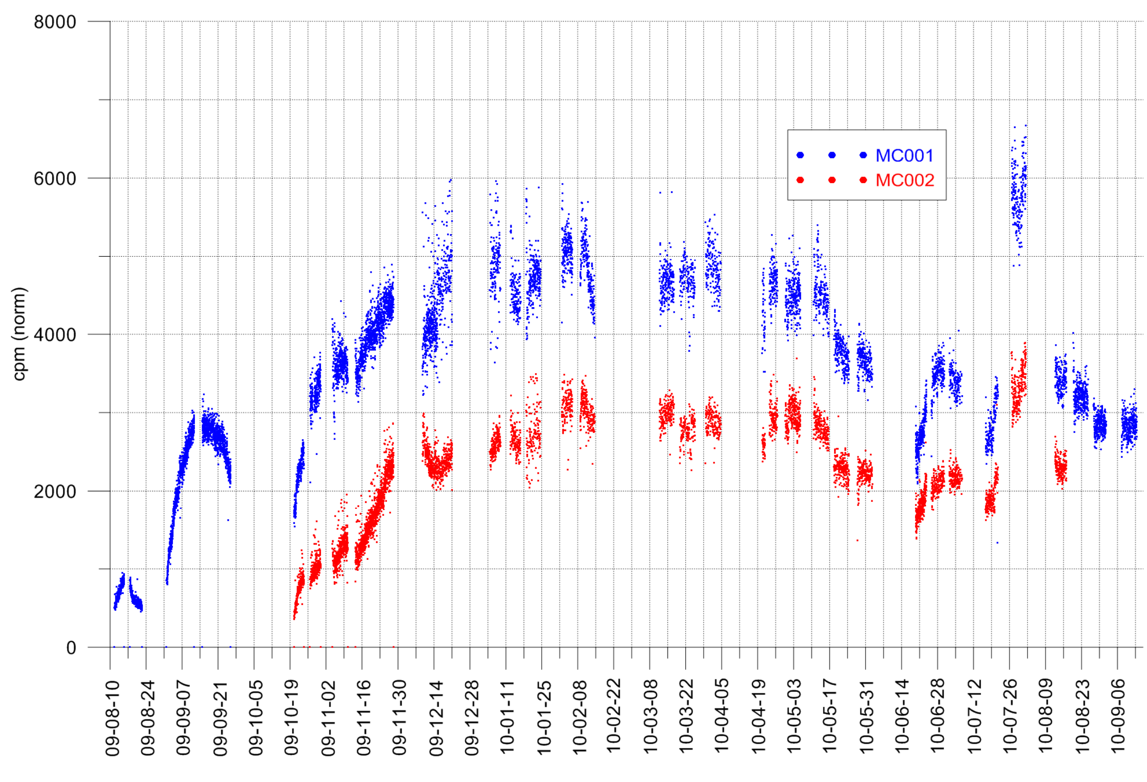

Fig.5. Experimental data of counts per minute vs. time of irradiation obtained from FEIMS for FA MC001 and MC002.

4. Conclusions

Till the end of September 2010 the results of irradiation testing are positive. During the irradiation there was no observed any leakages of the fission products through the fuel cladding.
According to the program of irradiation LTA-1 (MC002) was discharged from the core after reached 172 MWd (42 %) burn-up. The second LTA-2 (MC001) reached at about 50 % (200 MWd) and after achieving the required burn-up (60 %) will be discharged from the core into storage pool for post irradiation examination.
IAE POLATOM and AREVA will cooperate to dismantle the both LTA's assemblies for three parts each to control the inner surfaces of the fuel tubes, mainly the tube # 4.

MARIA RR conversion schedule:

1. End of LTAs irradiation – February 2011
2. Post irradiation examination March – April 2011
3. Exchange of main pumps
   - Design modification planning (DMP) – January 2011
   - DMP approvals from IAE Safety Committee and from NAEA of Poland February – March 2011
   - Delivery of new pumps and installation October – November 2011
4. Delivery of LEU fuel from CERCA – March 2012
5. Approvals from IAE Safety Committee and NAEA for MARIA RR conversion from HEU to LEU fuel – March 2012
6. Beginning of conversion – April 2012
7. End of conversion – May 2013

References

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[3] W. Mieleszczenko, K. Pytel, J. Lechniak, A. Mołdysz, K. Andrzejewski, T. Kulikowska, Z. Marcinkowska, P. Garner, N. Hanan, „CERCA Fuel Assembly Testing in MARIA Reactor – Safety Analysis Summary and Testing Program Scope", RERTR-2009, Beijing, Chinas, November 1-5, 2009.