

Maria research reactor conversion to LEU fuel

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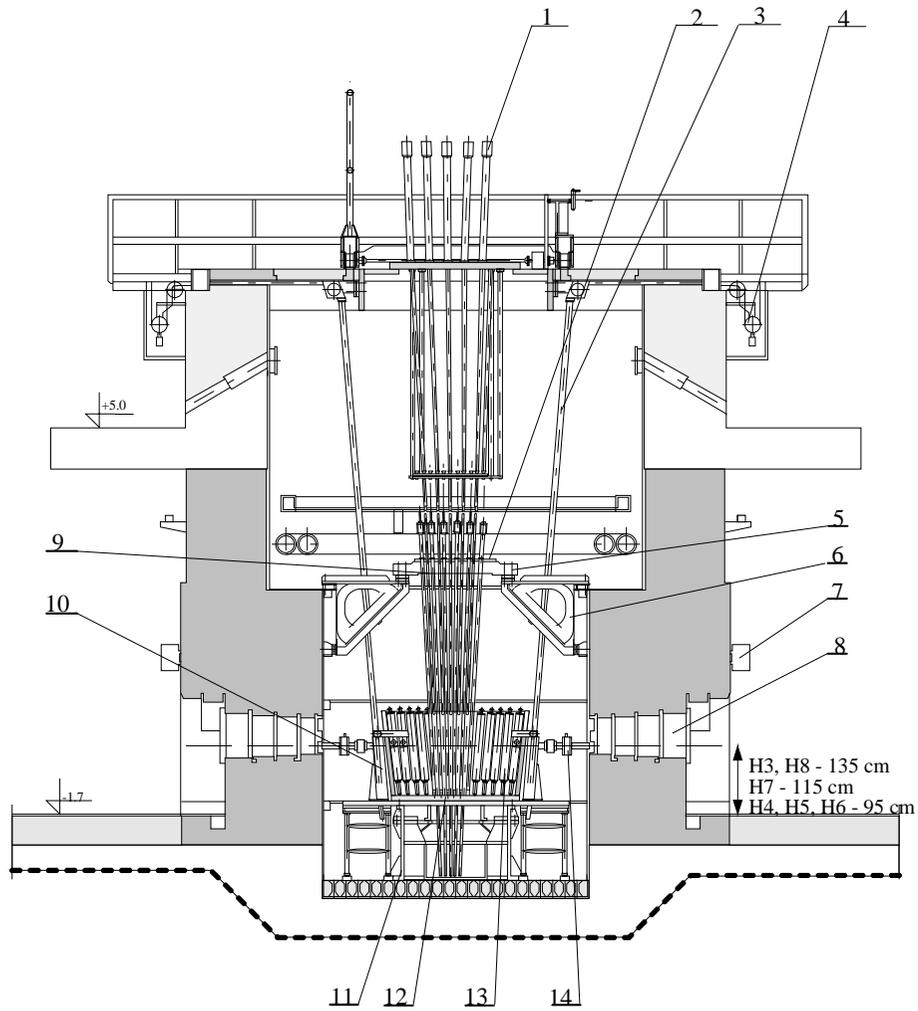
Introduction

- Conversion program of MARIA RR is closely associated with the „Global Threat Reduction Initiative”,
- The Maria reactor is a Russian-designed research reactor that operates with Russian highly enriched uranium (HEU) fuel,
- The reactor initially operated with 80% enriched HEU and converted to 36% HEU in 1999,
- The program objective is to convert the current core to low enrichment uranium (LEU) fuel,
- The proposed silicide fuel with a density of 4.8 g/cm^3 has been qualified to achieving very high burn ups,
- The assembly design proposed for use in the MARIA reactor will be unique,
- It needs to be qualified for the MARIA operating conditions by irradiating two lead test assemblies (LTA's) in the MARIA reactor.

MARIA RR description

- The Institute of Atomic Energy (IAE) is the operator of the multifunctional nuclear research reactor MARIA,
- The high flux research reactor MARIA is a water and beryllium moderated reactor,
- It is a pool type with graphite reflector and pressurized channels containing concentric tube assemblies of fuel elements,
- The main characteristics and data of MARIA reactor are as follows:
 - nominal power 30MW(th),
 - thermal neutron flux density 4×10^{14} n/cm²·s,
 - moderator H₂O, beryllium,

- cooling system channels type,
- fuel assemblies:
 - material: UO_2 -Al alloy
 - enrichment: 36%
 - cladding: aluminium
 - shape: concentric tubes
 - active length: 1000mm
- output thermal neutron flux density at horizontal channels: $3\div 5 \times 10^9 \text{ n/cm}^2 \cdot \text{s}$.



- | | |
|---------------------------------------|---|
| 1. control rod drive | 8. horizontal beam slide damper |
| 2. mounting slab | 9. fuel channel |
| 3. ionisation chamber channel | 10. ionization chamber shielding |
| 4. ionisation chamber drive | 11. basket basis |
| 5. slab supporting structure | 12. reflector housing |
| 6. slab bracket | 13. reflector blocks |
| 7. horizontal beam slide damped drive | 14. horizontal neutron beam compensator |

Reactor MARIA utilization

- production of radioisotopes,
- research in neutron physics,
- neutron radiography,
- testing of fuel and structural materials for nuclear power engineering,
- neutron activation analysis,
- neutron transmutation doping.

Radioisotope production

- The vertical in-core isotope channels and the modernized hydraulic transfer system are considered for high activity radioisotope production,
- For the domestic customer the following major target materials are irradiated: S, TeO₂, Lu₂O₃, Yb₂O₃, Cu, Se, SmCl₃, KCl,
- New approaches being developed for processing of radioisotopes of a current interest in nuclear medicine and industry are iridium seed-targets.

Research and development program

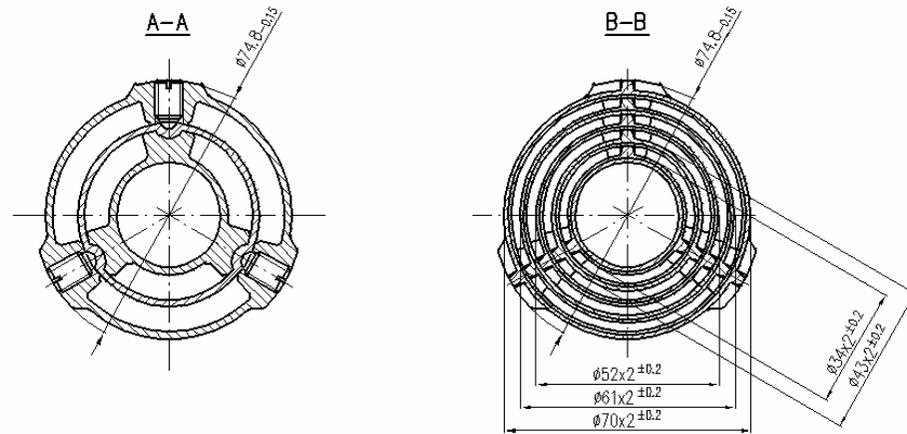
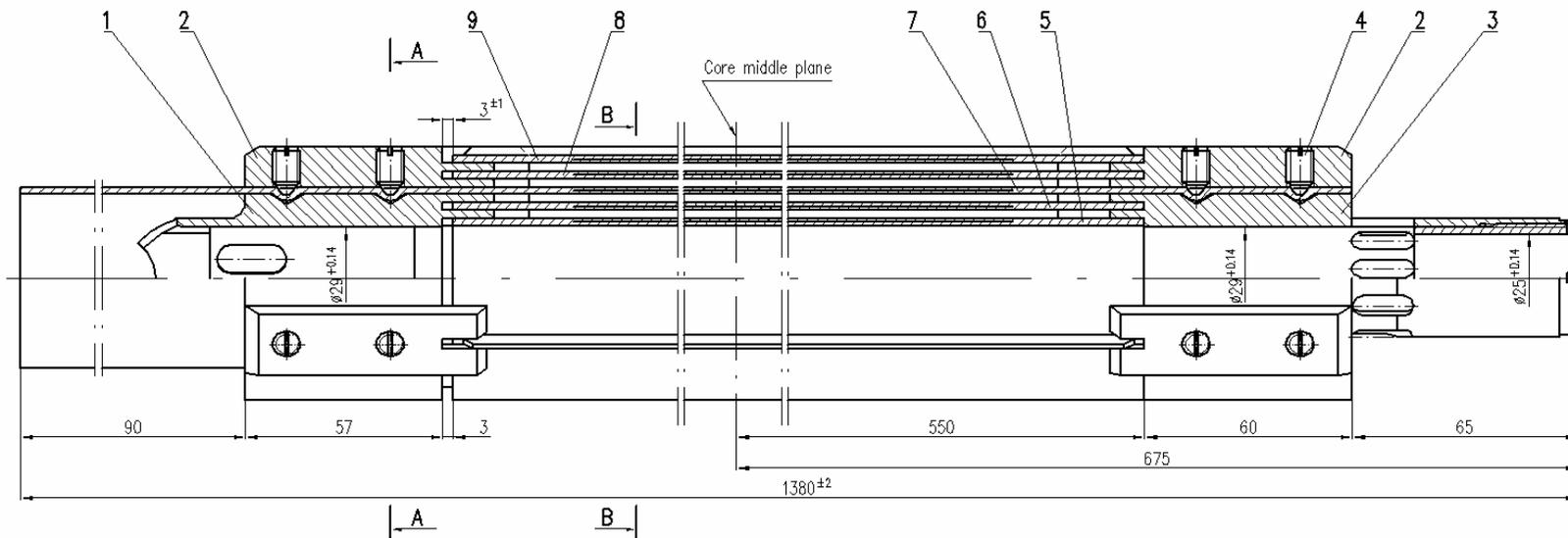
- The Regional Laboratory of Neutronography provides experimental facilities and research experience,
- The Laboratory operates six horizontal channels of the MARIA reactor and six instruments designed for elastic and inelastic neutron scattering,
- Available instruments at horizontal channels (H 3÷7) are computer controlled using the unified code,
- The neutron and gamma radiography (NGR) station is situated at the horizontal channel H8.

Neutron physics and thermo-hydraulic analysis

- The neutron physics parameters were calculated for MARIA reactor lattice containing low enriched uranium silicide fuel elements,
- Each fuel element tube was assumed to be formed of three bent plates connected by welds,
- Calculations were carried out with 19,75% enrichment and 485g U-235 per element,
- Thermal-hydraulic calculation will be performed at the steady states for the uncertainly factors and for the transients.

Final fuel specification for fuel procurement contract

- the fuel element shall meet as close as possible the design of the actual used MR-5 fuel element,
- there are five concentric tubes made from curved fuel plates with inner diameters,
- one fuel element shall contain 485 ± 5 gram uranium,
- it is noted that the degree of difficulty in manufacturing high curvature fuel plates increases significantly as fuel volume loading increases,
- the central fuel partitions the coolant flow, which enters the fuel assembly in a downward direction for three outer coolant channels, reverses at the lower end of the assembly, and proceed, upwards for the three inner coolant channels.



The attached construction of the MR Fuel Element details was developed by IAE Reactor Materials' Department based on the drawing-up inventory, originally produced by Novosibirsk Factory of the Chemical Concentrates (Russian Federation).

9	1	Fuel tube 6 ($\phi 70 \times 2$)	n/a
8	1	Fuel tube 5 ($\phi 61 \times 2$)	n/a
7	1	Fuel tube 4 ($\phi 52 \times 2$)	n/a
6	1	Fuel tube 3 ($\phi 43 \times 2$)	n/a
5	1	Fuel tube 2 ($\phi 34 \times 2$)	n/a
4	12	Screw	n/a
3	1	Spacer III	M390-3
2	2	Spacer II	M390-2
1	1	Spacer I	M390-1
Item No	Quantity	Item name	Drawing No
Drawing name			Drawing No
FUEL ELEMENT MR-5			M390-0

Operational limits of fuel element

- Coolant – demineralised water PH 5.5÷6.5
- Allowable coolant velocity in the slots between the fuel element tubes, less than 9 m/sec
- Coolant temperature at the inlet within the range (30÷50) °C
- Maximum temperature of the fuel element wall with accounting for the uncertainly coefficients resulting from inaccuracy of dimensions and the material composition 180°C
- Maximum heat flux 2.6 MW/m²
- Maximum pressure of coolant in the header:
 - delivery branch 1.7 MPa
 - off take branch 1.1 Mpa

Preparation for testing

- The first type of test involves measuring the pressure drop across the FA versus coolant flow rate through the new MR-5 LEU FA,
- The second type of test is measurement of coolant leakage across the fuel element tube which separates the down flowing (inlet) coolant from the up flowing (outlet) coolant,
- IAE will need to build an out-of-reactor test stand with data acquisition system in order to perform the tests.

Insertion procedure of two LTA's into the reactor

- A reference measurement of core excess reactivity with the fresh MR-430 fuel element along with measurement of absorbing rods' weight will be performed,
- The basic reactivity measurements and LTA's integrity measurements will be performed,
- Thermal loads of the LTAs being inserted into the core will gradually be changed through the spotting the LTA at the peripheral part of the core in the first irradiation cycle (the thermal power 0.5-0.8 MW),
- In the second operation cycle the examined LTA will be shifted into the central part of the core where its thermal power will be within the range of 1.0-1.6 MW,
- Similar procedure will be repeated with the second LTA in the course of two successive cycles of reactor operation.

Testing irradiation of LTA's

- The testing of the LTA's in MARIA reactor is aimed to proving the behaviour of the new fuel located in the vicinity of the Russian fabricated fuel with 36% U-235 enrichment,
- Successive insertion of the two LTA's into the reactor (four weeks operating cycle),
- Continuous operation of the two LTAs in the central zone of the core,
- Maximum thermal loads until the preset burnup of both fuel elements achieved,
- The measurement indication of the FEIMS system for individual fuel channel determines the rate of fission product releases and fuel activation to be transferred to the cooling circuit,
- In the second stage a systematic surveillance over the LTA's status will be conducted by means of FEIMS,
- Testing irradiation of the LTA's to the burn-up for qualification (40÷60%) is expected.

Correlations of the FEIMS indications, contamination of the circuit and fission product releases

Parameter	2003	2005	2006	2007
FEIMS [cpm]	$5.2 \cdot 10^5$	$2.8 \cdot 10^5$	$9.3 \cdot 10^4$	$2.4 \cdot 10^4$
Water Np-239 [Bq/l]	$7.5 \cdot 10^6$	$5.2 \cdot 10^6$	$8.1 \cdot 10^5$	$7.7 \cdot 10^4$
Water I-131 [Bq/l]	$2.4 \cdot 10^6$	$8.2 \cdot 10^5$ *	$1.5 \cdot 10^5$	$3.6 \cdot 10^4$
Releases of I-131 [% of limit]	38	21	10	3*

* an extrapolation to the end of 2007

Post irradiation examination

- After achieving the required burn-up the LTA's will be discharged from the reactor core into the storage pool in accordance with established procedure,
- The fuel element will be dismantled from the channel,
- The examinations will be performed under water layer and be put on:
 - visual control by means of underwater TV camera,
 - measurements of gaps between fuel tubes,
- Any surface blisters or deformation are not allowable.

Agreement with the Regulatory Body associated with reactor core conversion

- The scope of safety analyses pertaining to conducting the LTA's examination in the MARIA reactor was agreed,
- Demanded safety analyses comprise the neutron and thermal-hydraulic calculations, limit, protection threshold etc.,
- Acceptance of the LTA design project by the Regulatory Body to be developed by fuel manufacturer,
- Adjusting conditions for the LTA's irradiation in the reactor core relevant to safety analyses,
- The positive irradiation results and the data from measurements to be performed after the LTA's discharging from the reactor,
- The applied procedure of consecutive discharging of fuel elements.

Conclusions

- Institute of Atomic Energy and the Government of Poland presented in September of 2004 the readiness for MARIA reactor conversion from HEU to LEU,
- Due to the unique type of the fuel (tube type) and the demanded density (larger than 4,5 g/cm³) for the time being it is possible to apply fuel elements based on U₃Si₂,
- Because of prototype nature of the new fuel it is necessary to irradiate LTA's in MARIA reactor and achieve the fuel burn-up within the range of 40-60%,
- According to the actual status of preparatory works one can anticipate that the irradiation process of the LTA's in MARIA reactor will start in the IV Q 2008.