Maria research reactor conversion to LEU fuel

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Abstract.
The multipurpose high flux research reactor MARIA is a water and beryllium moderated reactor of a pool type with graphite reflector and pressurised fuel channels. The main areas of reactor application is production of radioisotopes and physics research with usage of a neutron beam from horizontal channels.

Conversion programme of MARIA research reactor is closely associated with the "Global Threat Reduction Initiative" (GTRI). The MARIA reactor is a Russian-designed research reactor that operates with Russian highly enriched uranium (HEU) fuel. The reactor initially was operated with 80% enriched HEU and converted to 36% HEU in 1999. The programme objective is to convert the current core to LEU fuel. The proposed silicide fuel (U3Si2) with a density of 4,8 g/cm3 has been qualified to achieving very high burnups. The assembly design proposed for use in the MARIA reactor will be unique, however, it needs to be qualified for the MARIA operating conditions by irradiating two lead test assemblies in the MARIA reactor.

The main stage for LEU fuel qualification will be irradiation of the LTA's in the MARIA core to the burn-up for qualification (~ 60%) is expected.

The affirmative results of the post irradiation examination will allow for accomplishing the core conversion of the MARIA reactor by successive replacement of the fuel channels with high enrichment by the fuel channels with low enrichment.

1. Introduction

Conversion program of MARIA research reactor is closely associated with the „Global Threat Reduction Initiative" (GTRI). 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 high density has been qualified to achieving very high burn ups.

The assembly design proposed for use in the MARIA reactor will be unique, however, it needs to be qualified for the MARIA operating conditions by irradiating two lead test assemblies (LTA's) in the MARIA reactor.

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 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

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

- nominal power 30 MW(th),

- thermal neutron flux density 4×10^{14} n/cm^2·s,
- moderator H_2O, beryllium,
- cooling system   channels type,
- fuel assemblies:
  - material: UO_2-Al alloy
  - enrichment: 36%
  - cladding: aluminium
  - shape: concentric tubes
  - active length: 1000 mm
- output thermal neutron flux density at horizontal channels $3\div5\times10^9$ n/cm^2·s.

2. Reactor MARIA utilization for radoisotope production and research and development program.

The main areas of reactor application are as follows:

- 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.

Neutron irradiation services utilizing MARIA research reactor include as the main subjects radioisotope production, neutron activation analyses and biomedical technology. The vertical in-core isotope channels were considered as design requirements for high activity radioisotope production as well as the modernized hydraulic transfer system. For the domestic customer the following major target materials were irradiated: S, TeO_2, Lu_2O_3, Yb_2O_3, Cu, Se, $SmCl_3$, KCl etc. Most of them were produced for the Isotope Research and Development Center. Among the new approches being developed for processing of a variety of radioisotopes of a current interest in nuclear medicine and industry are iridium seed-targets.

The Regional Laboratory of Neutronography provides experimental facilities and research experience in the field of thermal neutron scattering studies of condensed matter and material engineering.

The Laboratory operates six horizontal channels of the MARIA reactor and six instruments designed for elastic and inelastic neutron scattering. A beam time allocation at our facility can be applied for by submitting proposals directly to the responsible researchers. Available instruments at horizontal channels (H 3÷7) are computer controlled using the unified computer code.

The neutron and gamma radiography (NGR) station is situated at the horizontal channel H8. Due to ample space by the channel H8 and its relatively large neutron flux, this NGR facility has many advantages, especially for diagnostics of industrial objects.

3. Neutron physics, thermo-hydraulic analysis and technical specification of prototype LEU fuel.

The neutron physics parameters were calculated for MARIA reactor lattice containing low enriched uranium silicide fuel elements [1], [2]. 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. The basic neutron physics parameters have been determined and compared with the parameters for the first MARIA fuel with 80% enrichment and 350g of U-235 per element and the presently used fuel with 36% 430g U-235.

Thermal-hydraulic calculation will be performed at the steady states for the uncertainly factors and for the transients by means of the un-steady states and by RELAP code when a model of MARIA reactor and its preliminary validation be developed.

The IAE have elaborated also the final fuel specification for fuel procurement contract [3].

Main assumption of this document was that the fuel is LEU (19,75% U-235) and chemical composition of the fuel is U_3Si_2 with a uranium density of 4.8 g/cm^3. The following characteristics of the MARIA research reactor LEU fuel are as follows:

- 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 curred 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.

A prototype dummy fuel element shall be fabricated for hydraulic testing and check of dimension and coupling with the existing fuel extensions tubes.

The fuel elements shall resist the mechanical solicitation during the irradiation, summarized in the Table 1.

Also in the technical specification there are deisgn of the laminated fuel (fuelled zones, fuel density distribution, bounding between fuel meat and cladding, fuel and cladding thickness, surface contamination).

Under the IAEA bidding process the technical evaluation team's conclussion was that the CERCA and INVAP are qualified to manufacture U_3Si_2 fuel elements with flat or lightly curved plats at densities of 4.8 g/cm^3.

Table 1. Operational limits of fuel element

Parameter	Value
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) ^{0}C
Maximum temperature of the fuel element wall with accounting for the unceratainly coefficients resulting from inaccuracy of dimensions and the material composition	180^{0}C
Maximum heat flux	2.6 MW/m^2
Maximum pressure of coolant in the header: - delivery branch - off take branch	 1.7 MPa 1.1 MPa

4. Qualification of LEU.

There are three steps in this work: preparation for testing, testing of existing fuel assembly (FA) and new dummy fuel assembly (DFA), and testing of LTA.

4.1. Preparation for testing

Two types of FA testing are expected. The first type of test involves measuring the pressure drop across the FA versus coolant flow rate through the new MR-5 LEU FA at various coolant temperatures. These data are to be compared with data for the existing 36% enriched FA, denoted MR-6-430.

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. This test is necessary due to the change in design of the tubes from a single piece to three 120-degree arc segments swaged into spacers. Significant leakage could provide a path for coolant to bypass a substantial portion of the heat generating fuel elements. These test are expected to subject the FA to numerous cycles of temperature and pressure changes.

IAE will need to build an out-of-reactor test stand with data acquisition system in order to perform the tests. Different test stands may be required for the two types of tests. Tests are to be performed on an existing MR-6-430 FA, the MR-5 DFAs, and the MR-5 LTAs. The tests on an existing MR-6-430 FA are to be compared with existing results as a part of test stand checkout. There are to be two (2) DFAs and two (2) LTA's; all four (4) of these are to be tested. With regard to the LTA's, the tests in this work order are the ones to be performed prior to irradiation of the LTA's in MARIA.

4.2. Testing of MR-6-430 FA and MR-5 DFAs

An MR-6-430 FA and the two (2) MR-5 DFAs are to be tested for the task described in Section 4.1. The post-test report will be containing all relevant data from the testing of the DFAs. For the MR-6-430 FA a comparison shall be provided between the data obtained under this task and previously existing data.

4.3. Testing 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 elements with 36% U-235 enrichment. In particular, the impact of the LTA's on core reactivity characteristics as well as the loss of the tightness in the fuel will be checked in relation to the thermal loading and burnup of the fuel. The LTA's examination in MARIA reactor will be performed in two stages: successive insertion of the two LTA's into the reactor (four weaks operating cycles) and continuos operation of the two LTAs in the central zone of the core, i.e. with maximum thermal loads until the preset burnup of both fuel elements will be achieved.

In the first stage the basic reactivity measurements and LTA's integrity measurements will be performed by means of the Fuel Elements Integrity System (FEIMS). 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 surveilance 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.

Insertion procedure of two LTAs into the reactor will be performed under the following assumptions:

- Before succesive LTA will be inserted into the core a reference measurement of core excess reactivity with the fresh MR-430 fuel element along with measurement of absorbing rods' weight 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 then by gradual power variation during each start up and appropriate positioning of the shim rods. The thermal power to be generated in the LTA should be within the range of 0.5-0.8 MW. Each of the newly inserted LTA will be subjected to continuous leakage monitoring by means of the FEIMS,
- 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.

As a parameter characterizing the quantities of releases into environment one can assume a weekly amount of emission of iodine isotopes, in that mainly I-131.

Preliminary analysis of the operational parameters such as the FEIMS indications, contamination levels of the fuel channel cooling circuit and iodine isotopes releases into environment performed for the period 2003-2007 allows for an estimation of the correlation for these parameters, (Table 2).

Table 2. 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

4.4. 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. Then the fuel element will be dismantled from the channel and be examined. The examinations will be performed under water layer and be put on visual control by means of underwater TV camera and on measurements of gaps between fuel tubes. Any surface blisters or deformation are not allowable.

5. Cooperation with the Regulatory Body associated with reactor core conversion.

On the onset stage the scope of safety analyses pertaining to conducting the LTA's examination in the MARIA reactor was agreed upon. The demanded Safety analyses comprise the neutron and thermal-hydraulic calculations, limit, protection threshold etc.

The next step is to accept the LTA design project by the Regulatory Body to be developed by fuel manufactured.

The major stage will be to adjusting conditions for the LTA's irradiation in the reactor core relevant to safety analyses, results of hydraulic examination and the irradiation procedure.

On achieving the positive irradiation results and the data from measurements to be performed after the LTA's discharging from the reactor as well as by means of the applied procedure of consecutive discharging of fuel elements there will be agreed conversion of MARIA reactor core with the Regulatory Body.

6. 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/cm^3) for the time being it is possible to apply fuel elements based on U_3Si_2. 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%. This quantity will confirm the possibility of reactor core conversion.

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.

REFERENCES

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[3] MIELESZCZENKO W., et al., „Project of prototype fuel element with low enrichment for MARIA research reactor, March 2006