

OPERATION OF THE MARIA RESEARCH REACTOR

G. Krzysztozek, A. Gołąb, J. Jaroszewicz

Institute of Atomic Energy

The multipurpose high flux research reactor MARIA is a water and beryllium moderated reactor of a pool type with graphite reflector and pressurized channels containing concentric six-tube assemblies of fuel elements. It has been designed to provide high degree of flexibility. The fuel channels are situated in a matrix containing beryllium blocks and enclosed by lateral

reflector made of graphite blocks in aluminum cans. The MARIA reactor is equipped with vertical channels for irradiation of target materials, a rabbit system for short irradiations and six horizontal neutron beam channels. The main elements of the reactor pool are presented in Fig. 1.

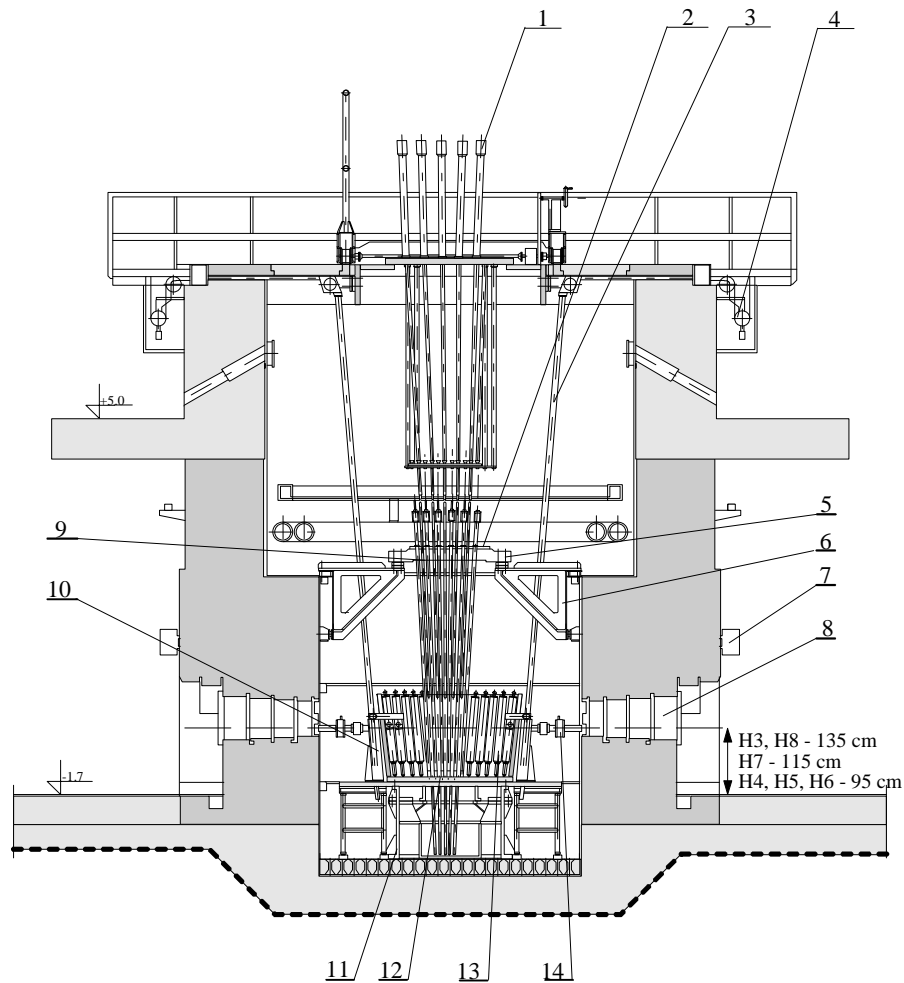


Fig. 1. Vertical section of MARIA reactor. 1. control rod drive mechanism, 2. mounting plate, 3. ionisation chamber channel, 4. ionization chamber drive mechanism, 5. fuel and loop channels support plate, 6. plate support console, 7. horizontal beam tube shutter drive mechanism, 8. beam tube shutter, 9. fuel channel, 10. ionization chamber shield, 11. core support structure, 12. core and reflector support plate, 13. reflector blocks, 14. beam tube compensation joint.

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

- nominal power 30 MW(th),
- thermal neutron flux density $4.0 \cdot 10^{14}$ n/cm²s,
- moderator H₂O, beryllium,
- cooling system channel type,
- fuel assemblies:
 - material UO₂-Al alloy

- enrichment 36%
- cladding aluminium
- shape six concentric tubes
- active length 1000 mm.
- output thermal neutron flux at horizontal channels $3 \div 5 \cdot 10^9$ n/cm²s

The MARIA reactor reached its first criticality in December 1974. The reactor was in operation until 1985

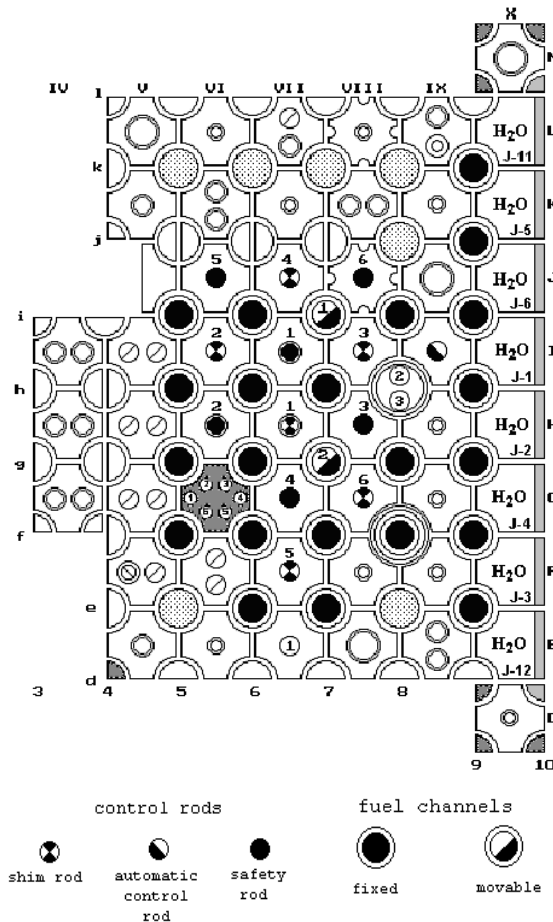


Fig. 3. Core configuration of December 2007.

364 spent fuel assemblies have been collected during many years of reactor operation. The assemblies have been stored under water in the special pool adjacent to the reactor pool. To prevent possible damage of fuel cladding due to the corrosion processes the assemblies are encapsulated in special tight cans filled with inert gas. The encapsulation technology was developed and implemented in 2002. Until the end of 2007 157 fuel assemblies were closed successfully in cans made of stainless steel.

The removal of the encapsulated fuel assemblies from the reactor fuel storage has been initiated on December 2005. Until the end of 2007 96 encapsulated fuel assemblies were removed from the reactor storage pool to the temporary wet spent fuel storage.

In 2007 the MARIA reactor was operated successfully. Nevertheless the reactor scram was activated 11 times. Nine times the reactor was shut down only for a very short time, mainly for the reason of drops in electrical power supply system and malfunction of the reactor instrumentation system. Two reactor scrams caused shortening of the operation cycles:

- first due to a leakage in the primary cooling system,
- second due to malfunction of transducer in the main pump supplying system.

Operational availability factors were:

$$A1 = \frac{OT}{NH} \cdot 100\% = 98.7\%$$

$$A2 = \frac{OT}{8760} \cdot 100\% = 45.7\%$$

where OT (operational time) denotes the number of hours on power and NH is the sum of number of hours on power and on unscheduled shutdown.

In 2007 the total emissions of radioactive materials to the environment were as follows:

- inert gases (mainly ^{41}Ar): $1.19 \cdot 10^{13}$ Bq, i.e. 1.2% of the limit determined by the NAEA,
- iodine: $1.37 \cdot 10^8$ Bq, i.e. 2.7% of the limit determined by the NAEA,
- ^{88}Rb and ^{138}Cs : $1.87 \cdot 10^9$ Bq.

In 2007 99 workers received measurable whole body doses from 0.1 to 3.82 mSv and 8 workers received skin doses from 0.65 to 5.34 mSv.

The electrical conductivity and pH value of water in the main reactor systems were controlled permanently (Fig. 4, 5).

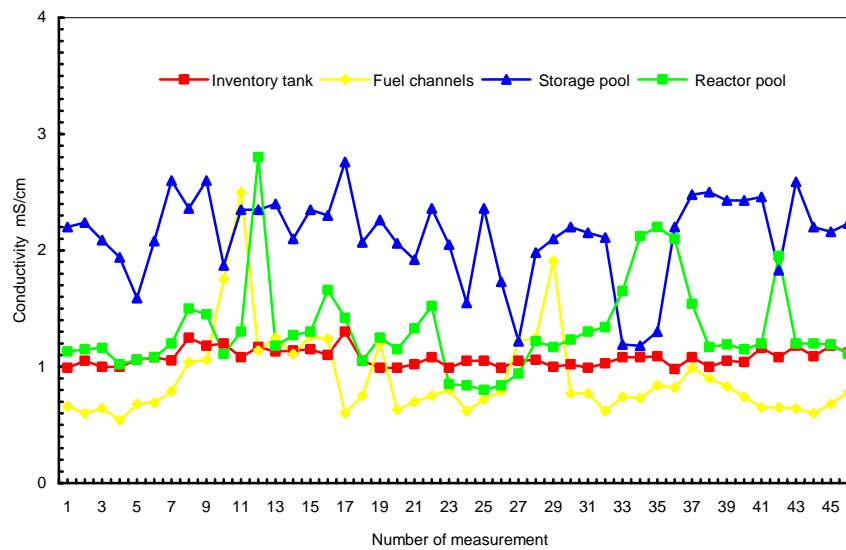


Fig. 4. Conductivity of water in the primary circuits of the reactor Maria in 2007.

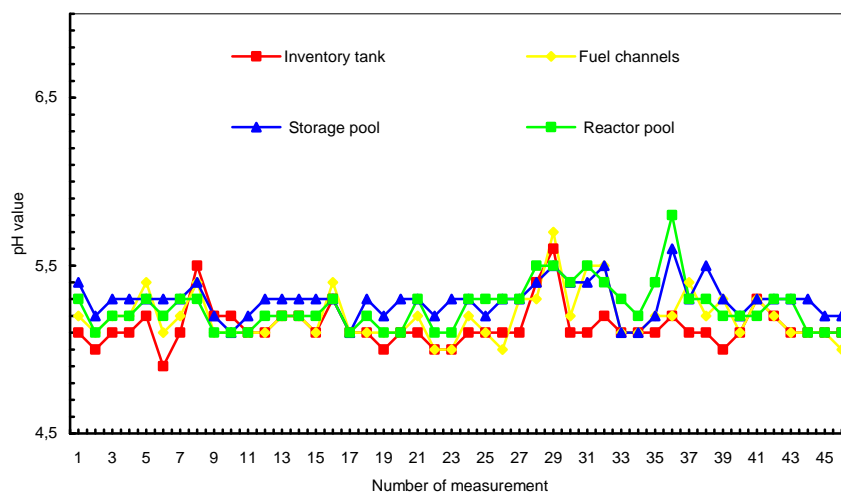


Fig. 5. pH value of water in the primary circuits of the reactor Maria in 2007.

New technology - neutron irradiation services

Neutron irradiation services utilizing MARIA research reactor include radioisotope production, neutron transmutation doping of silicon, neutron activation analyses and biomedical technology.

Available services cover the activation of a large variety of target materials for the production of isotopes which would subsequently be processed at the discretion of the customer. For irradiation services various systems are available in the MARIA reactor, providing necessary irradiation conditions according to the re-

quired neutron flux levels, irradiation times, target mass and size.

The vertical in-core isotope channels were considered as a design requirements for high activity radioisotopes production as well as the modernized hydraulic transfer system. For the domestic customers the targets of S, TeO₂, Lu₂O₃, Yb₂O₃, Cu, Se, SmC₁₃ and KCl were irradiated (Fig. 6).

Most of the radioisotopes were produced for the Isotope Research and Development Center POLATOM. Among the new approaches developed for radioisotopes of current interest in nuclear medicine and industry were

iridium seed-targets. The source wire in each seed was made of platinum - iridium alloy. The Ir-192 seeds used in Intravascular Radiation Therapy (IRT) and low activity Ir-192 ribbon for oncology applications were produced.

The irradiation services offered at MARIA research reactor include the Neutron Transmutation Doping (NTD) of silicon crystals. High purity silicon single crystals are doped to produce n-type semiconductor material. The NTD is based on the transmutation of ³⁰Si atoms into ³¹Si by the capture of thermal neutrons. The ³¹Si decays by the emission of beta particles to ³¹P. The results of experimental irradiation of silicon ingots of 5" and 6" diameter confirmed good quality of neutron doped silicon crystals. The uniform neutron dose distribution over the ingot ensures the homogeneous distribution of phosphorous atoms throughout the silicon crystal, resulting in uniformly doped n-type silicon matching the electrical resistivity needed. The axial and radial resistivity variation of the sample is controlled to satisfy the customer needs. At present the facility installed in the poolside region of the reactor is ready for commercial neutron transmutation doping of silicon ingots for Toshiba Ceramics. The range of irradiation services offered using the test facility was extended by transmutation doping of multicrystalline silicon wafers for photovoltaic cells.

Neutron irradiation service utilizing reactor MARIA includes the coloring of topaz minerals. The irradiation of minerals in special channels located outside reactor core change its colorless transparent natural state to shades of blue, thereby increasing the commercial value of the product. After appropriate cooling time the blue minerals are released to the market as the non-radioactive material.

Feasibility study on irradiation of ²³⁵U targets in the MARIA reactor for ⁹⁹Mo production has been started in 2007. The main objective is to obtain the ^{99m}Tc isotope, which is widely used in the medical diagnostics. The decisive factor determining its availability, despite its short life time, is the radioactive decay of ⁹⁹Mo into ^{99m}Tc. One of the possible sources of molybdenum can be achieved within the ²³⁵U fission reaction. Currently ⁹⁹Mo is produced by most producers by irradiation of HEU targets. The new idea that conforms to the Reduced Enrichment for Research on Test Reactors (RERTR) program is to use LEU-foil targets. Technology for production of ⁹⁹Mo is based on the core loop which consists of standard fuel channel supplemented with necessary control units.

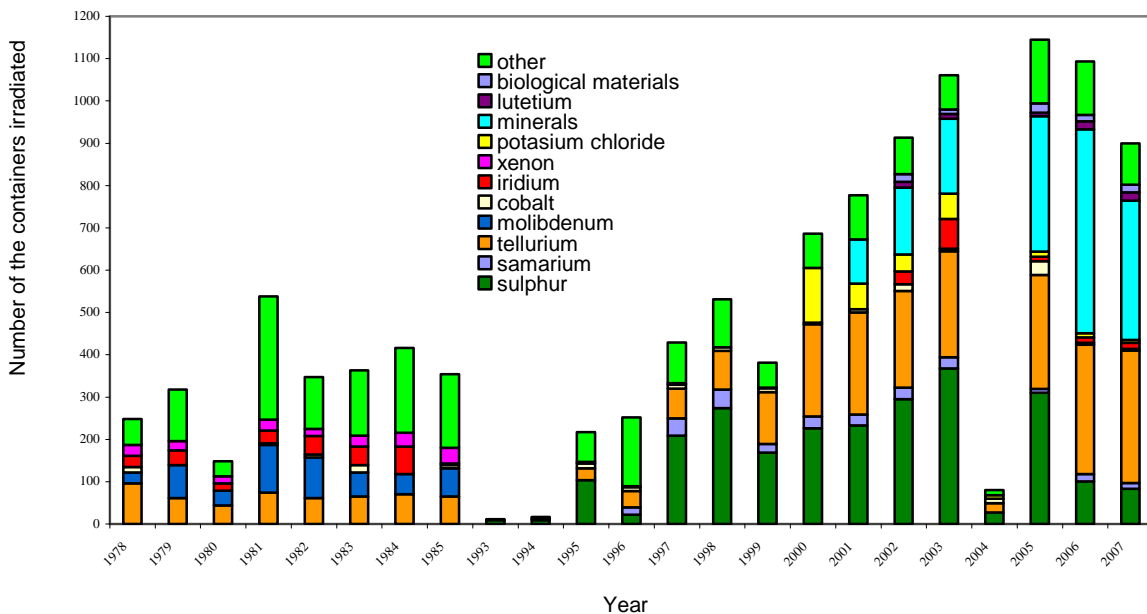


Fig. 6. Distribution of target materials irradiated.

UPGRADE OF MARIA REACTOR MODEL FOR OPERATIONAL PREDICTIONS IN 2007

K. Andrzejewski, T. Kulikowska, Z. Marcinkowska

Institute of Atomic Energy

The development of computational capabilities and permanent need for predicting the reactor MARIA operating conditions lead to the upgrading of the existing methods for MARIA core neutron-physics analysis.

In 2007 a full description of the MARIA reactor core has been completed [1], including the special purpose channels and blocks. On the basis of this description the models developed in the REBUS code have been extended.

The present model accounts for:

- initial fuel element material composition given in fuel certificates,
- individual fuel element burnup history,
- 15 types of geometry of beryllium blocks,
- individual beryllium block transmutation history,
- special purpose channels and blocks including irradiation channel,
- control and safety rods with their operational positions in 3D calculations,
- core reflectors.

The computations are performed using current data on the core configuration, reactor power, control rods position and materials temperatures.

Computational results are routinely compared to the measured data on reactivity change with fuel burnup and transmutations in beryllium (weekly and annually), control rod worth, temperature reactivity coefficients.

The analysis of the burnup level of particular fuel elements [2] resulted in the corrections of geometrical representation of irradiation channels and absorbing filters. Without corrections marked differences between the calculated and measured burnup level are observed (Fig. 1). The corrections improved the compatibility of the calculation results of the new model with the measured fuel burnup of fuel elements (Fig. 2).

Further analysis carried out together with Argonne National Laboratory [3] under the RERTR cooperation, has shown the effects of:

- application of burnup dependent library of REBUS for MARIA fuel elements gives improvement of about 2% in k_{eff} ,
- introduction of axially dependent burnup gives up to 1% improvement in k_{eff} .

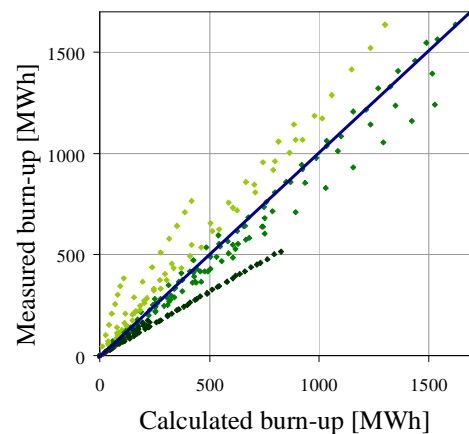


Fig. 1. Calculated vs. measured burn-up level of fuel elements, old model. Light green points correspond to fuel channels neighboring to isotope channels, dark green – close to absorbing filters, green – the others.

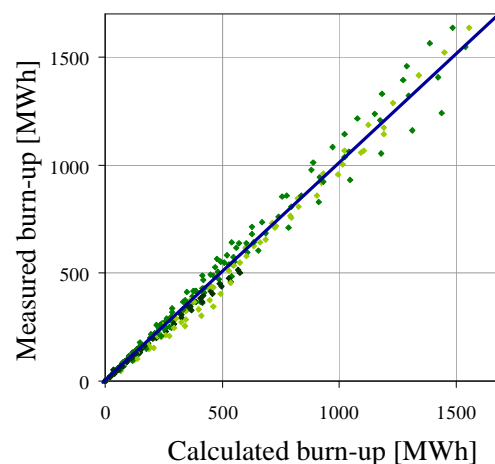


Fig. 2. Calculated vs. measured burn-up level of fuel elements, new model. The description of points is the same as in Fig. 1.

Three new auxiliary programs [4] have been developed to facilitate REBUS input preparation.

The computational model has been used in prediction of the reactivity change of planned beryllium blocks reloading. Block from position I-VII is going to be exchanged with that at K-IX, and H-VII with that at K-V.

References

- [1] K. Andrzejewski, T. Kulikowska, Z. Marcinkowska, Raport IAE-129/A (2007)
- [2] K. Andrzejewski, T. Kulikowska, Z. Marcinkowska, (in Polish), IAE Report B-5 (2007)
- [3] N. Hannan, Private communication, (2007)
- [4] K. Andrzejewski, T. Kulikowska, Z. Marcinkowska, IAE Report B-7 (2007)