

OPERATION AND SAFETY OF MARIA REACTOR

OPERATION OF THE MARIA RESEARCH REACTOR

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The multipurpose high flux research reactor MARIA is a water and beryllium moderated reactor of a pool type with graphite reflector and pressurised channels containing concentric six-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 fuel channels are situated in a matrix containing beryllium blocks and enclosed by lateral reflector made of graphite blocks in aluminium cans. The MARIA reactor is equipped with vertical channels for irradiation of target materials, a rabbit system and six horizontal neutron beam channels.

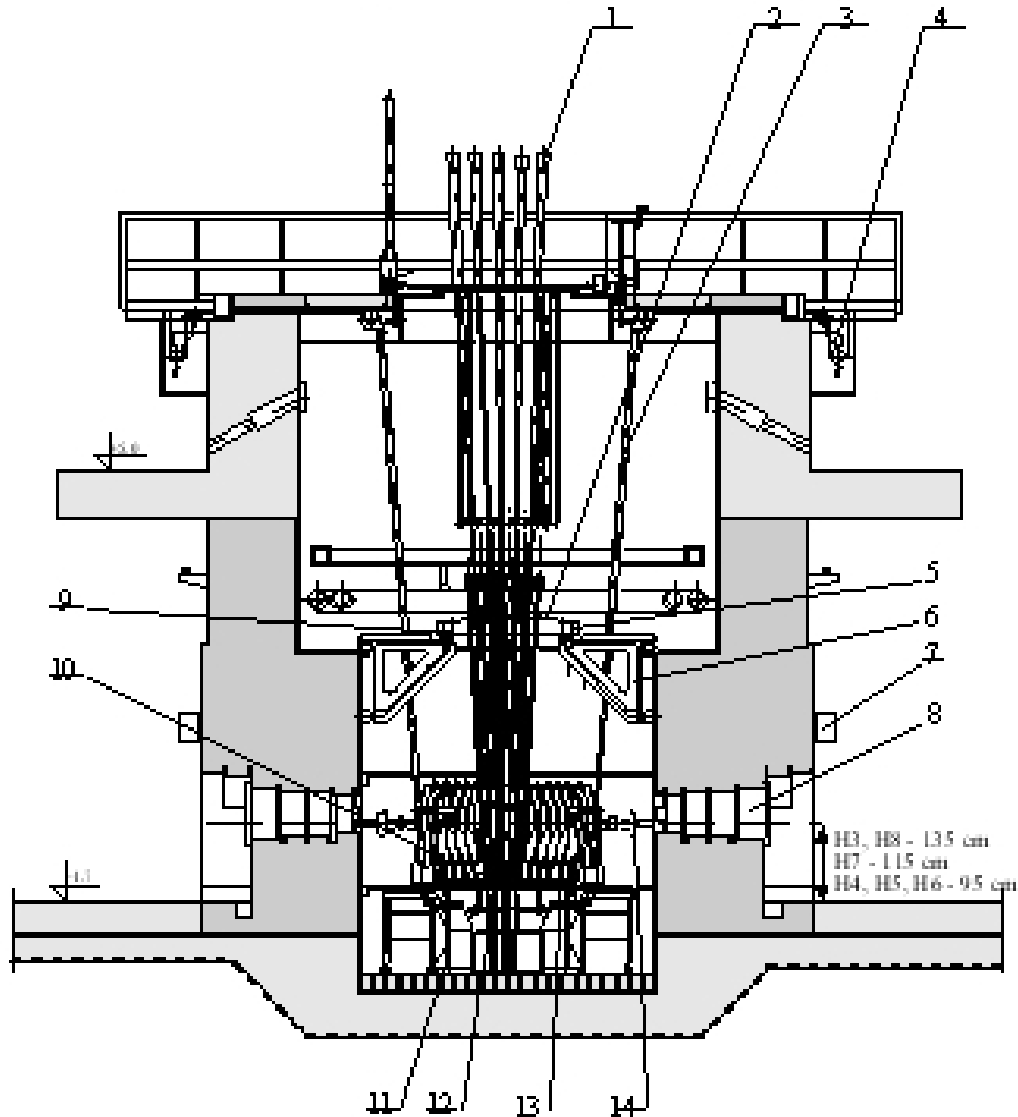


Fig. 1. Vertical section of MARIA reactor. 1. control rod drive mechanism, 2. mounting plate, 3. ionisation chamber channel, 4. ionization chamber drive mechanism, 5. fuel and loop channels support plate, 6. plate support console, 7. horizontal beam tube shutter drive mechanism, 8. beam tube shutter, 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 element:
 - material UO₂-Al alloy

- enrichment 36%
- cladding aluminium
- shape six concentric tubes
- active length 1000 mm
- output thermal neutron flux density 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 when it was shut down for modernisation. The modernisation encompassed refurbishment and upgrading of technological systems. In particular, the efficiency of ventilation and cooling systems was improved. In 1993 the MARIA reactor was put into operation again.

The main areas of reactor application are as follows:

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

In 2005 the reactor completed 35 operation cycles at power from 30 kW to 20 MW. The overall operation time was 3830 h. The reactor operational chart is shown in Fig. 2.

The main activities carried out in MARIA reactor were focused on:

- irradiation of target materials in vertical channels and in rabbit system;
- experiments with utilization of neutron beams from reactor horizontal channels;

- neutron radiography based on neutron beam from horizontal channel N^o 8;
- neutron modification of crystals and minerals.

In February a lot of 84 MR-6 type fuel assemblies with 36% enrichment in U-235 was supplied and regular reactor operation has been restarted.

At present only MR-6 type fuel assemblies with 36% enrichment in U-235 are loaded into the reactor core. The fuel assemblies of two kinds are used the old with 540 g contents of U-235 and the new ones with 430 g contents of U-235.

The new fuel with 430 g contents of U-235 is better quality than the old. The release of fission products is very low and achievable burn-up is higher than for old fuel with contents of U-235 540 g. Actually it is possible to achieve burn-up above 50%.

The configuration has been changed several times because of fuel and irradiation requirements. Fig. 3 shows the core configuration of December 2005.

Untypical core configuration (16 fuel elements-main core and 6 fuel elements near) is matched by the needs of irradiation of minerals under special neutron flux conditions.

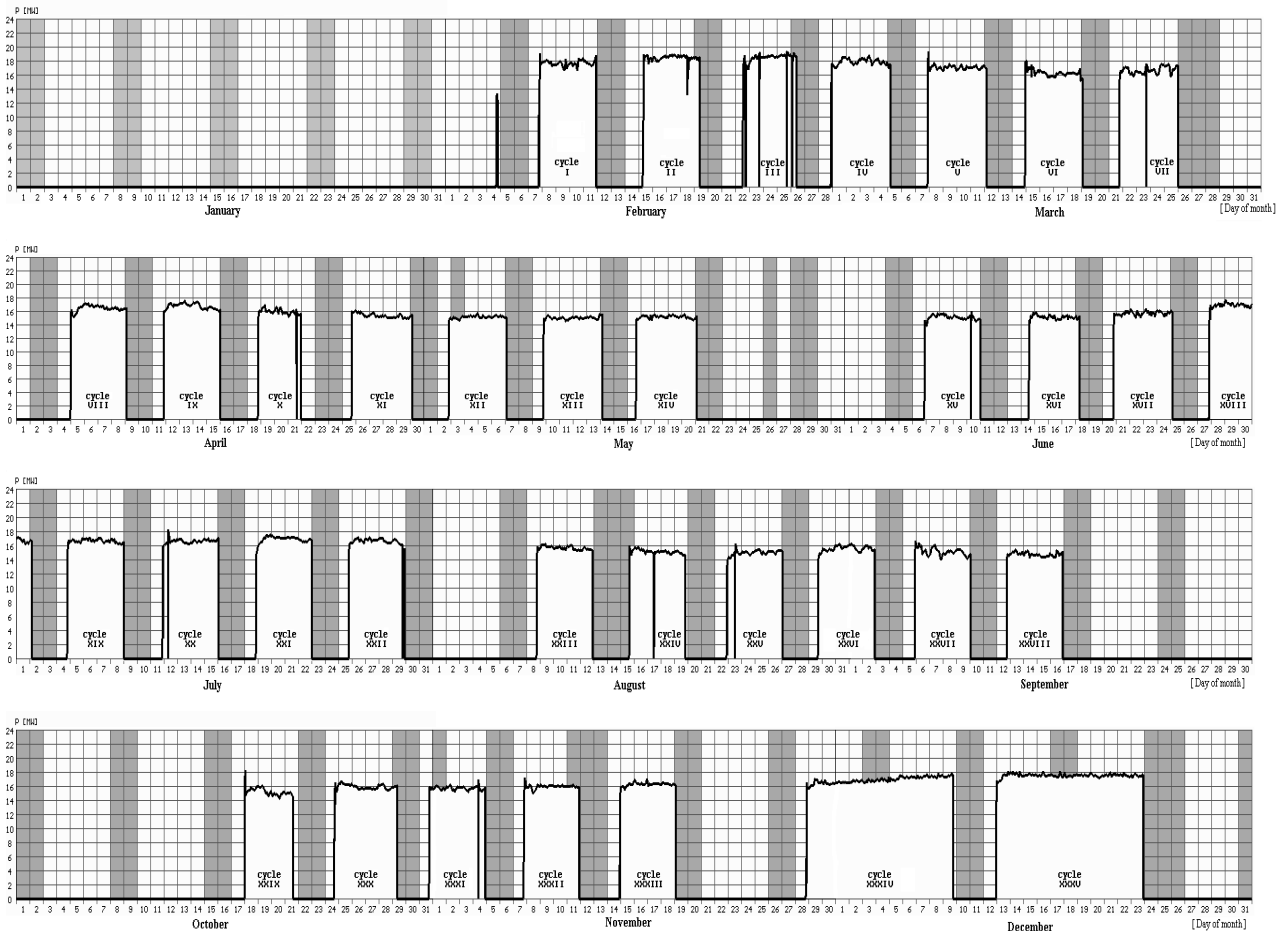


Fig. 2. Schedule of the reactor MARIA operation in 2005.

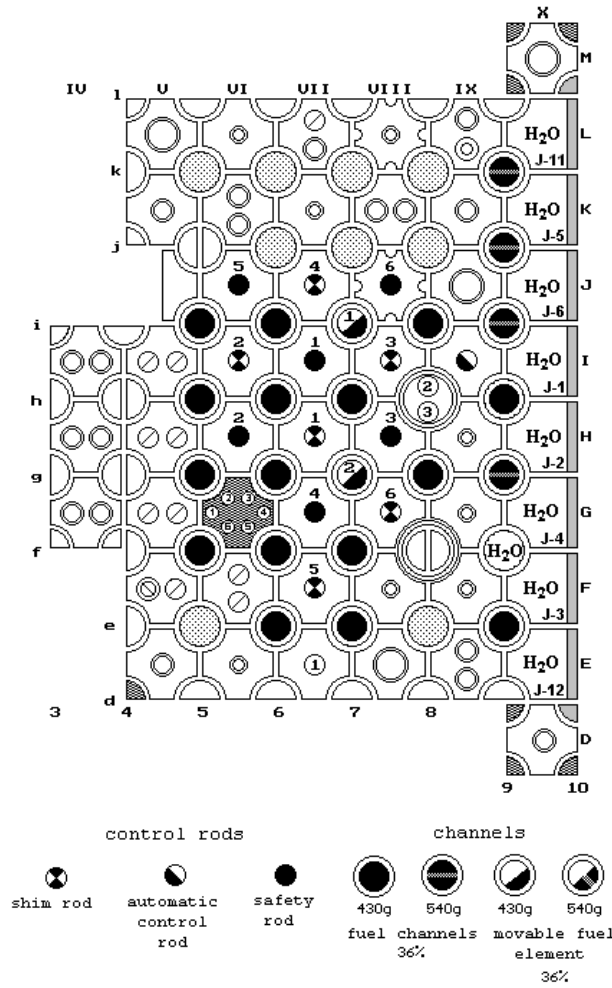


Fig. 3. Core configuration of December 2005.

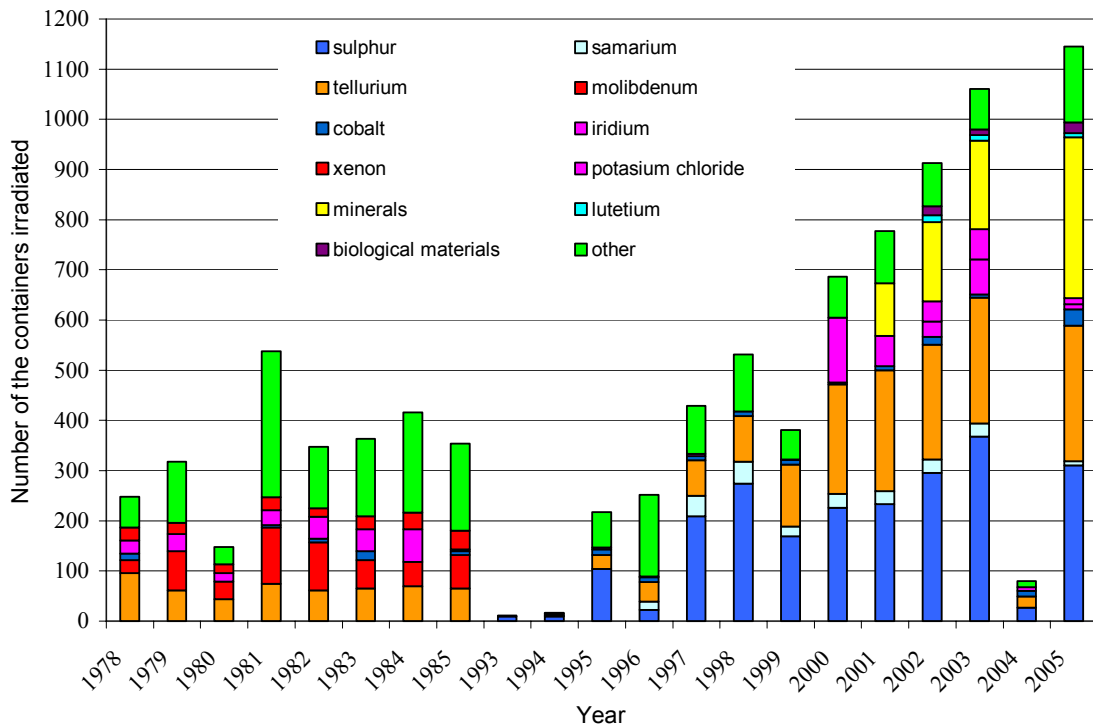


Fig. 4. Distribution of target materials irradiated.

More than 330 spent fuel assemblies were collected during many years of reactor operation. So far these elements have been stored under water in the special pool adjacent to the reactor pool. To prevent possible damage of fuel cladding due to corrosion process the decision has been made to encapsulate the elements in special tight cans filled with inert gas. In 2002 the encapsulation technology was developed and implemented. Until the end of 2005 134 fuel assemblies were closed successfully in cans made of stainless steel.

In December the process of removal at these encapsulated fuel assemblies from the reactor fuel storage was initiated. A lot of 24 encapsulated fuel assemblies was removed to the wet spent fuel storage in building 19a located 300 m from the reactor MARIA.

In 2005 the MARIA reactor was operated successfully. Nevertheless, the reactor scram was activated 15 times. 13 times the reactor was shut down only for a very short time, mainly for the reason of breaks in electrical power supply system. Two reactor scrams were due to a leakage in the heat exchangers and caused shortening of the operation cycle.

Operational availability factors were following:

$$A1 = \frac{OT}{NH} \cdot 100\% = 99\%$$

$$A2 = \frac{OT}{8760} \cdot 100\% = 43.7\%$$

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

In 2005 the following total emissions of radioactive materials to the environment were recorded:

- inert gases (mainly ⁴¹Ar): 2.7·10¹³ Bq, i.e. 2.7% of the limit determined by the NAEA,
- iodine: 1.68·10⁹ Bq, i.e. 33.6% of the limit determined by the NAEA,
- ⁸⁸Rb and ¹³⁸Cs: 5.95·10⁹ Bq.

In 2005 the 94 workers received measurable whole body doses from 0.1 to 13.9 mSv and 10 workers received skin doses from 1.6 to 21.8 mSv.

Continuous control of water quality in the main reactor systems was carried out. In Fig. 5, 6 and 7 the results of these measurements are presented.

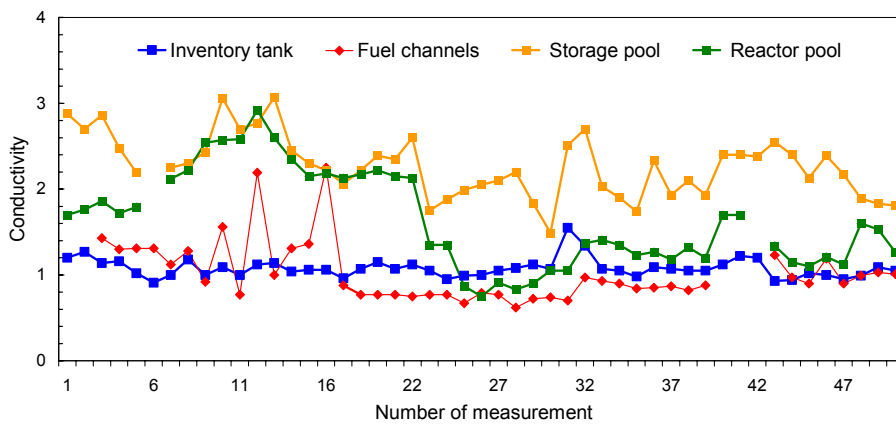


Fig. 5. Conductivity of water in the primary circuits of the reactor Maria in 2005.

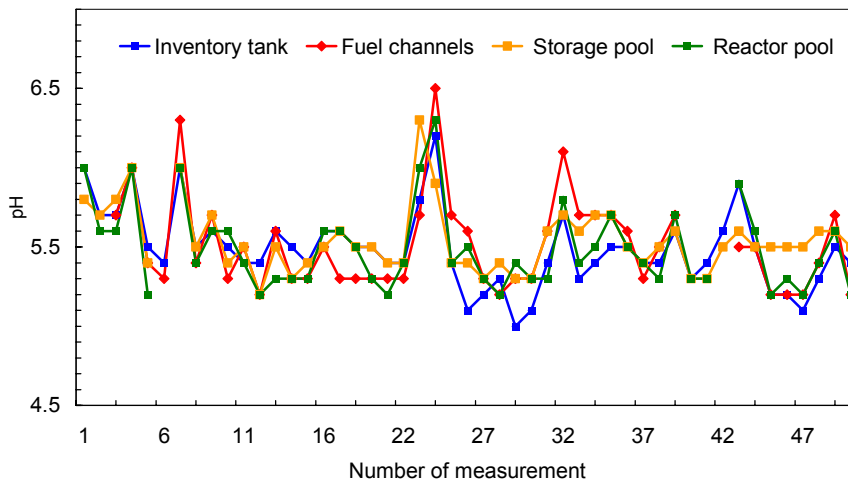


Fig. 6. pH value of water in the primary circuits of the reactor Maria in 2005.

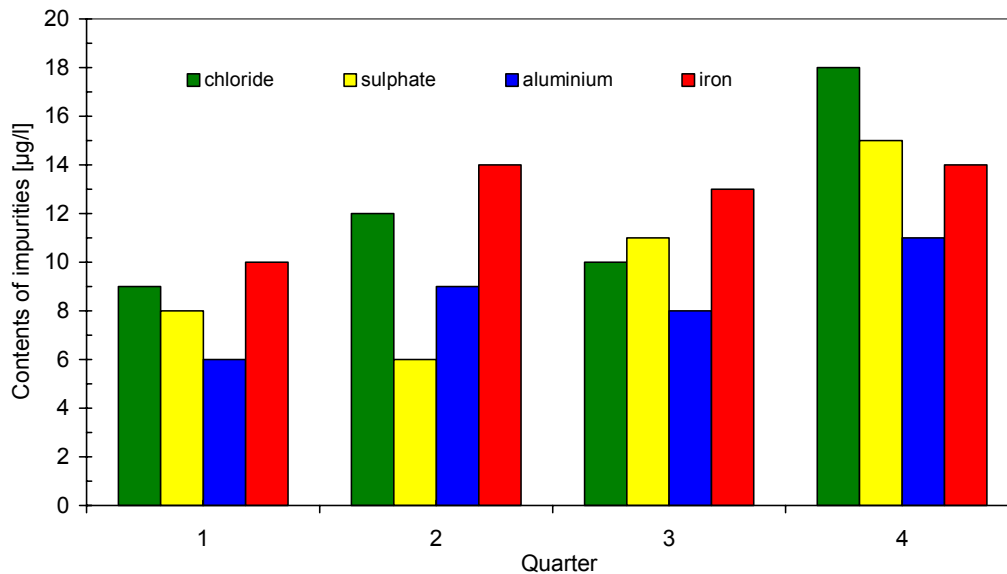


Fig. 7. Contents of impurities in the water of the fuel channels in the primary circuit of the reactor MARIA in 2005.

New technology - neutron irradiation services

Neutron irradiation services utilizing MARIA research reactor include as the main subjects 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. Irradiation services can be performed in a number of the available facilities in the MARIA reactor, depending on the required neutron flux levels, irradiation times, target mass and geometry.

The vertical in-core isotope channels were considered as design requirements for high activity radioisotopes production as well as the modernized hydraulic transfer system. For the domestic customers the following major target materials were irradiated: S, TeO₂, Lu₂O₃, Yb₂O₃, Cu, Se, SmCl₃, KCl. In Fig. 4 the distribution of target materials irradiated is presented. Most of them were produced for the Isotope Research and Development Center. Among the new approaches being developed for processing of a variety of radioisotopes of a current interest in nuclear medicine and industry are iridium seed-targets. The source wire in each seed is platinum iridium alloy wire doubly swaged by stainless steel. The Ir-192 seeds used for Intravascular Radiation Therapy (IRT) and low activity Ir-192 source ribbon for Oncology Applications have been irradiated in the reactor.

The irradiation service offered at MARIA research reactor includes irradiation of silicon crystals. The test facility installed in the poolside region of the reactor

after series of experimental irradiation of silicon samples is ready for commercial neutron transmutation doping of silicon ingots. The neutron characteristics of the facility have been matched by means of combination of theoretical neutron transport calculations and experimental flux and spectrum determinations. High purity silicon single crystals are doped with dopants such as phosphorous to produce n- type semi-conductors. The Neutron Transmutation Doping (NTD) process is based on the transmutation of ³⁰Si atoms by the capture of thermal neutrons into ³¹Si, which decays by the emission of beta particles to ³¹P. The results of experimental irradiation of silicon ingots 5 and 6 inches confirmed good quality of neutron transmutation silicon crystals. A uniform neutron dose distribution over the ingot will therefore ensure a homogeneous distribution of phosphorous atoms throughout the silicon crystal, resulting in uniformly doped n-type silicon with accurately predetermined resistivities. The axial and radial resistivity variation of the sample is controlled to satisfy the customer. The range of irradiation services offered using the test facility is extended by transmutation doping of silicon multicrystals for photovoltaic cells purpose.

Neutron irradiation service utilizing reactor MARIA includes the colouring of topaz minerals. The irradiations of minerals in special channels located outside reactor core change their clear natural state to shades of blue, thereby increasing the commercial value of the product. Blue topaz is released to the market as non-radioactive material, conforming to strict international criteria.

NEUTRON – PHYSICS CHARACTERISTICS FOR MARIA REACTOR WITH MR-6/80%, MR-6/36% AND U₃Si₂ 19.75% ENRICHMENT FUEL ELEMENTS

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In 2005 the analyses of various geometry variants of U₃Si₂ fuel with 19.75% enrichment for MARIA reactor have been continued [1]. The fuel manufacturer proposed fuel tubes made of 120° bent plate sectors joined together with three flat aluminium stiffeners. Initially the central fuel tube of the original MR-6 design was removed. The resulting five-tube fuel element contained 480.93g of U-235 (Fig. 1). In parallel, the fuel element was considered with similar amount of fuel and the third tube containing no fuel.

The WIMSD-5B code with its latest library [1] was applied to calculate the cell characteristics in cylindrical approximation. The suitable homogenization was necessary to preserve the amount of different materials in the fuel cell. The Monte Carlo code MCNP-4B [3] was used to estimate the error introduced by the homogenization of aluminium stiffeners with water and with fuel. The MCNP-4B calculations have shown that the WIMSD-5B gives for the fuel cell considered the multiplication factor higher by 1.3% only.

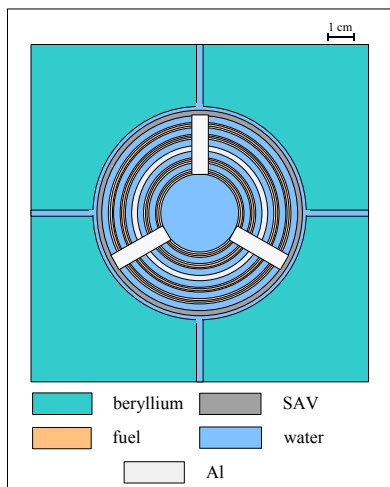


Fig. 1. Elementary fuel cell with four tube U₃Si₂ element.

The temperature of 20°C and the typical beryllium moderator poisoning was assumed. The characteristics for all elements were normalized to 1.15 MW from fuel element. The power generated in tubes (Fig. 2) is higher for 19.75% fuel than for the presently used 36% fuel. The power density in tubes (Fig. 3) is comparable for both types of fuel. Global thermal coefficient (calculated for infinite cell with using geometrical buckling) of reactivity is negative and decreases with temperature (Fig. 4).

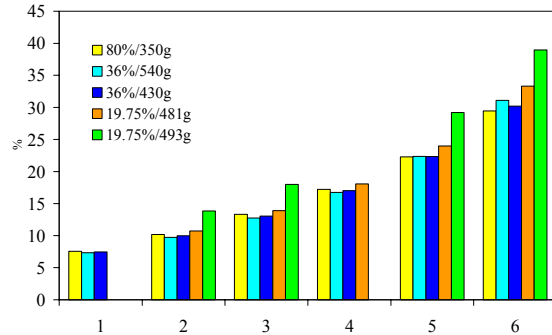


Fig. 2. Power distribution in tubes normalized to 1.15 MW in element.

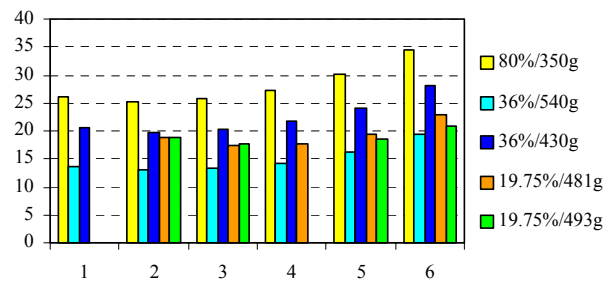


Fig. 3. Power density distribution in tubes normalized to 1.15 MW in element.

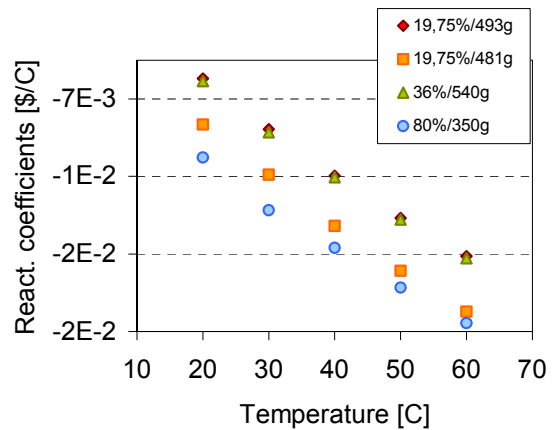


Fig. 4. Global temperature reactivity coefficients.

References

- [1] K. Andrzejewski, T. Kulikowska, Z. Marcinkowska: IAE Report B-23 (2005)
- [2] WIMSD-5B, IAEA WIMS Library Update Project, <http://www.nds.iaea.org/wimsd>
- [3] J. Briesmeister, MCNP - A General Monte Carlo N-Particle Transport Code Version 4A, LA-12625, (1993)

CRITICALITY CALCULATIONS OF A STORAGE POOL WITH ENCAPSULATED MR-6 FUEL

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The burned up MR-6 fuel elements with 36% enrichment and 540 g of U-235 per element will be moved to the storage pool. The subcriticality of the system had, therefore, to be confirmed. In the storage pool the encapsulated fuel elements will be placed in rectangular separators (Fig. 1). The separators will form a single layer in the pool.

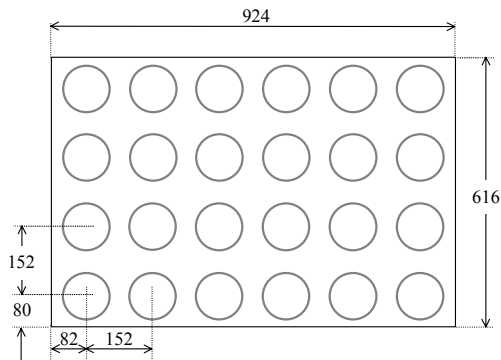


Fig. 1. Horizontal cross section of the separator.

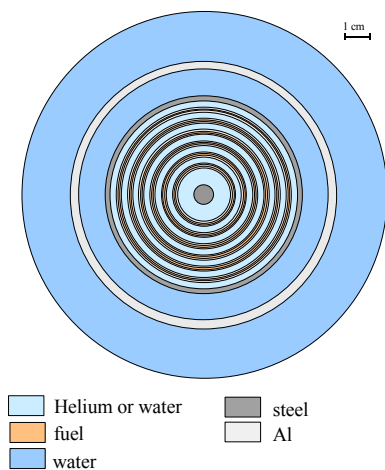


Fig. 2. Horizontal cross section of the simplest model.

The criticality calculations were performed using two codes: MCNP-4B [1] based on the Monte Carlo method and WIMSD-5 [2] – a deterministic lattice spectrum code, based on deterministic solution of the neutron transport equation. The simplest model comprised a horizontal intersection of an infinite basic fuel cell surrounded by the capsule wall and a layer of water. Its horizontal cross section (Fig. 2) forms an infinite mesh in WIMSD-5 calculations. In MCNP-4B calculations both the infinite vertical cells and the model of finite length (Fig. 3) have been treated. In case of MCNP-4B the more sophisticated horizontal models have been also taken into account including the actual configuration in the separator (Fig. 1).

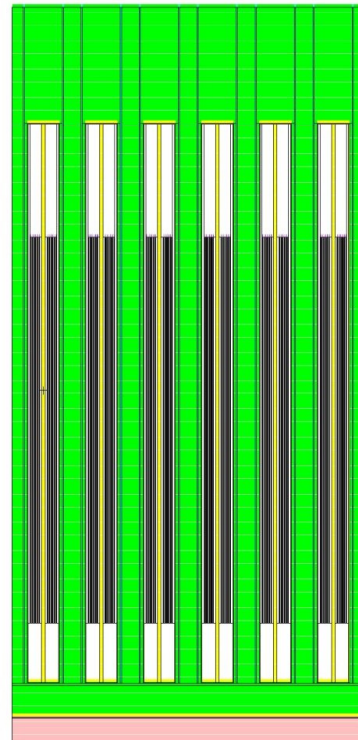


Fig. 3. Vertical cross section of the separator in MCNP-4B models.

Results of all the computations have shown a deep subcriticality of the storage pool even for the fresh fuel, independently of water temperature and taking into account the possibility of capsule flooding with water. Some representative values of multiplication factors are given in Table 1. More detailed description of the results is given in [3].

Table 1. Multiplication factors of storage pool models.

Model geometry	with helium	with vacuum	with water inside capsule
Infinite cell by WIMS-D5	0.671	0.677	0.624
Infinite cell by MCNP-4B		0.637	0.615
Finite cell by MCNP-4B		0.611	0.599
Separator		0.589	0.586

References

- [1] J. Briesmeister, MCNP - A General Monte Carlo N-Particle Transport Code Version 4A, LA-12625 (1993)
- [2] WIMSD-5, NEA Data Bank documentation, 1507/01 (1996)
- [3] K. Andrzejewski, T. Kulikowska, Z. Marcinkowska, IAE Report B-24 (2005) (in Polish)

TRANSPORTATION OF ENCAPSULATED SPENT FUEL ELEMENTS FROM MARIA REACTOR TO 19A STORAGE

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During operation of the MARIA research reactor 346 fuel subassemblies of the MR type were burned up including MR-6–80%, MR-5–80% and MR-6–36% fuel elements. 124 spent fuel elements with 80% enrichment have been encapsulated already in the stainless steel capsules (Fig. 1).



Fig. 1 Spent fuel in MARIA reactor storage pool.

However, the encapsulated spent fuel is stored in the reactor storage pool (Fig. 2) limiting the space available for new spent fuel.

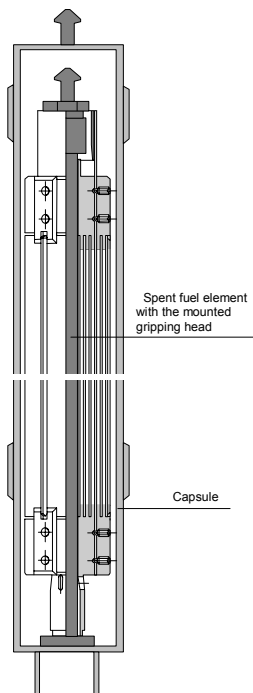


Fig. 2. MR type spent fuel in capsule.

For this reason it has been decided to begin the transportation of the spent fuel from MARIA reactor to

Radioactive Waste Management Plant 19A storage facility. For this purpose the special container for transporting encapsulated MR type spent fuel was constructed (Fig. 3). The container was designed to provide loading the capsule from above in reactor dismantling cell and unloading it from the bottom to 19A storage pool.

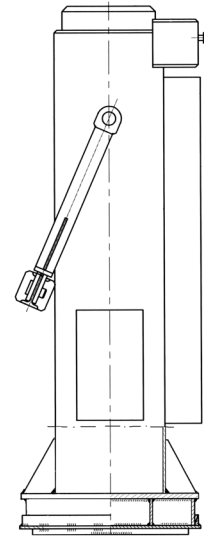


Fig. 3. Scheme of the transporting container.

The technology [1], safety analysis [2] and Quality Assurance Program [3] for transportation of encapsulated MR type spent fuel from MARIA reactor to 19A storage were accepted by Department for Radiation and Nuclear Safety of National Atomic Energy Agency.

According to the technology, the capsule, including the MR type spent fuel element, is transferred manually from the separator in the reactor pool to a trolley. The trolley is moved to a position directly below the entrance to the hot cell and the capsule enters the hot cell. The capsule is then transferred into the container placed under the hot cell chamber.

The container including the capsule is first transported inside the reactor building on a transport sleeve and then on a transport bridge to a platform trailer. With the platform it is transported to 19 A storage where it is unload to the storage pool. The transfer operation started on November 2005 and the first 24 elements have been safely positioned in the water storage.

References

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