FEASIBILITY STUDY TO RESTART THE RESEARCH REACTOR RA WITH A CONVERTED CORE

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ABSTRACT

Main options are specified for the future status of the 6.5 MW heavy water research reactor RA. Arguments *pro* and *contra* restarting the reactor are presented. When considering the option to restart the RA reactor, possibilities to improve its neutronic parameters, such as neutron flux values and irradiation capabilities, are discussed, as well as the compliance with the worldwide activities of Reduced Enrichment for Research and Test Reactors (RERTR) program. Possibility of core conversion is examined. Detailed reactor physics design calculations are performed for different fuel types and uranium loading. For different fuel management schemes results are presented for the effective multiplication factor, power distribution, fuel burnup and consumption. It is shown that, as far as reactor core parameters are considered, conversion to lower enrichment fuel could be easily accomplished. However, conversion to the lower enrichment could only be justified if combined with improvement of some other reactor attributes.

1. Introduction

Basic facts about operation, ageing, reconstruction and spent fuel storage of the research reactor RA, at the VINČA Institute of Nuclear Sciences near Belgrade, have been presented and discussed in detail in some earlier papers [1-3]. This 6.5 MW thermal heavy water moderated and cooled research reactor of USSR origin was shut down for renewal and reconstruction in 1984, after 25 years of operation. Since for a number of reasons this refurbishment has not yet been completed, and having in mind the long shut-down period, the future status of the RA reactor is presently being seriously reconsidered.

Three main options for the future status of the reactor are identified: (1) restarting the reactor, (2) conservation of reactor systems and components and (3) reactor decommissioning. In view of natural degradation and ageing, conservation of the reactor systems and components, in fact, is just a postponed decommissioning. Among arguments against restarting the reactor, one should mention the difficult economic situation and limited investment funds in the country, lower requirements for experimental research and irradiation services and decreased domestic market for radioisotopes and radiopharmaceuticals. On the other hand, there are arguments in favor of restarting the reactor: reserves of fresh fuel are sufficient for years of reactor operation; fresh heavy water is available at the site; most of the new electronic equipment for safety, control and radiation systems has already been obtained through the IAEA technical assistance program; the reactor vessel was in good condition at the time of inspection and reasonably good condition of other major reactor components can be assumed. Restarting of the reactor would help to preserve domestic knowledge and manpower in nuclear fission energy production and application. Arguments *pro* and *contra* restarting the reactor are summarized in Table 1

Table 1. Facts important for deciding the future status of the RA research reactor

Reactor status	**Arguments *pro***	**Arguments *contra***
Restarting the reactor	• In a relatively short time it would be possible to activate a research facility which could be used for different purposes: radioisotope production, research in physics and biology, different applications in industry and medicine. • Considerable reserves of fresh fuel and heavy water are available at the site, most of the new electronic equipment for safety, control and radiation systems has already been obtained through the IAEA technical assistance program; the reactor vessel was in good condition at the time of inspection and reasonably good condition of other major reactor components can be assumed. • Technical assistance and support could probably be obtained either from Russia or from China. Contacts have been established with both countries, which operate similar reactors. • With relatively small investments, the residual value of the facility, estimated to about 30 million US$ in 1995, would be preserved. • By restarting the RA research reactor possibilities would be established for international cooperation, particularly with the neighboring countries, the existing knowledge and manpower in nuclear fission energy production and application would be preserved and new manpower would be prepared for the implementation of nuclear power program when it becomes necessary.	• Because of the difficult economic situation and limited investment funds in the country, in the immediate future a lack of qualified personnel and very limited possibilities for research and development can be expected, what means lower requirements for experimental research and irradiation services and decreased domestic market for radioisotopes and radiopharmaceuticals. • Covering the maintenance and operation costs of the research reactor could be a serious problem for the country in the immediate future, if additional financial resources are not provided through profitable programs and international cooperation. • Before the reactor is restarted, a new dry spent fuel storage facility has to be built and the existing spent fuel has to be removed from the reactor building, in order to prepare the temporary spent fuel storage pool to accept the new irradiated fuel.
Final shut down and decommis sioning	• Difficult economic situation and limited investment funds in the country will result in lower requirements for experimental research and irradiation services and decreased domestic market for radioisotopes. • If it is decided to finally shut down the reactor, the maintaining costs would be lower than the operating costs. However, the decommissioning activities would require larger investments, than restarting the reactor. • The problem of long term storage of the existing spent fuel could be solved in the course of a longer time period and in a way which would require lower investments.	• If it is decided to shut down the reactor, the considerable residual value of the facility would be finally lost in the situation when it can not be expected that another new facility of similar characteristics and possibilities will be built in the foreseeable future. • The available fresh 80% enriched uranium fuel has no market value if not used in the reactor. • Decommissioning of the reactor is a complex and expensive project, which could only be performed by engaging foreign expertise and equipment, which could be a serious problem in the forthcoming period. • By closing finally the RA reactor, work in the field of using the energy of nuclear fission would be stopped for a longer period.

The first step towards restarting, or eventual decommissioning, of the RA research reactor must be safe and reliable disposal of spent fuel. Adequate storage of fuel irradiated so far is to be provided, as well as disposal of new irradiated fuel if or when the reactor is restarted. Current activities are related to identification and minimization of corrosion processes and further degradation of spent fuel in the existing storage pool [4-6]. In the second phase, dry storage of spent fuel should be provided.

When considering the option to restart the RA reactor, possibilities to improve its neutronic parameters, as neutron flux values and irradiation capabilities, should be studied, as well as the compliance with the worldwide activities of the Reduced Enrichment for Research and Test Reactors (RERTR) program [7]. In the following paragraphs, possibility of core conversion is examined. Detailed reactor physics design calculations are presented for different fuel types and uranium loading. The results obtained for the effective multiplication factor, reactivity and power distribution, fuel management schemes, fuel burnup and consumption, are presented and discussed.

2. Reactor Core Configurations

The RA reactor fuel element is an 11.3 cm long cylinder, with 3.72 cm of outer diameter, consisting of an outer tube with 2 mm thick fissionable material, having 1 mm thick inner and outer Al cladding, and 1 mm thick inner Al tube which serves as the cooling intensifier. Fuel elements are inserted into a 2 mm thick Al tube (10 or 11 slugs/tube), thus forming a fuel channel. The reactor RA core, Fig. 1, consists of up to 84 channels in a square lattice with 13 cm pitch. Originally, the fissionable material was 2% enriched uranium metal. After 1976, new fuel, of the same geometry and the same content of ^{235}U, but in the form of 80% enriched uranium-oxide dispersed in aluminum, was purchased from the USSR supplier.

If the RA reactor is to be reconstructed and restarted, possible core conversion and power upgrade should be examined. The following main options can be anticipated:

(1) The existing 80% enriched fuel in the form of tubular slugs can be used in the standard RA reactor core arrangement, with the 13 cm lattice pitch. If reactor power is kept at or below the nominal level of 6.5 MW, the reactor cooling system would probably require no special reconstruction. If an in-core fuel management scheme is applied in which fresh fuel is inserted in the central core region and burned out fuel is removed from the outer region of the core, radiation damage of the rather old reactor vessel would be kept at the lowest possible level, while maximum value of neutron flux would be attained in the central irradiation channel. The main advantages of this option are relatively low investments and short reconstruction period. The main disadvantages are low neutron flux and limited irradiation space in the core.

(2) In order to comply with the worldwide activities of the Reduced Enrichment for Research and Test Reactors (RERTR) program [7], the existing fuel could be refabricated into 20% enriched fuel with the same geometry of tubular slugs and the same content of ^{235}U per slug. Supposing that the price of 20% enriched uranium per unit of mass of ^{235}U is about half the price of that for the 80% enriched uranium, the difference in price of uranium could only cover the cost of fuel refabrication. If this new fuel would be used in the same regime as in the previous option, which is technically feasible, all main advantages and disadvantages would be about the same.

(3) The fuel refabrication process could be used to produce advanced fuel in the form of a solid tube or a cluster of rods. In this way the amount of fissionable material per fuel channel could be increased, as well as neutron flux and the total power level. If the same lattice pitch was preserved, not too large reconstruction of the cooling system would be required, e. g. one additional pump. At the same time, a more compact reactor core would leave more free space for irradiation purposes

inside the reactor vessel, while the thus formed additional radial reflector would prevent radiation damage of the vessel. Generally, the reconstructed reactor would be a much more powerful and versatile facility for research and isotope production than the original one.

(4) The most serious reconstruction of the reactor would require change of the reactor vessel. This would enable a decrease of the lattice pitch and formation of a compact reactor core with a much higher neutron flux. At the same time additional irradiation space could be provided, for instance horizontal experimental channels through the reactor core could be introduced. Of course, this option would also require a serious reconstruction of the cooling system. The whole operation would be very expensive and could only be justified if decision to restart the reactor was made even if it implies exchange of the reactor vessel for technical reasons.

Main features of the above explained options are summarized in Table 2. In the present economic situation of the country, and also having in mind the general negative attitude of the society towards the use of nuclear energy, the last two options seem to be very unlikely. Thus, in the present paper only the first two options are studied in more detail, while extrapolation to the third option is rather straightforward. Detailed reactor physics design calculations are performed for the first few cycles with the existing 80% enriched fuel and with the possibly refabricated 20% enriched fuel with the same geometry and the same content of ^{235}U per a fuel element. Consumption of ^{235}U per day of reactor operation at the same nominal power was taken as a representative quantity for intercomparison of the two options.

Table 2. Main options for the eventual core conversion and power upgrade of the RA research reactor

	Fuel type	Lattice pitch	Power	Special requirements	Advantages	Disadvantages
1	80% ^{235}U tubular slugs	13 cm	6.5 MW	-	low cost, short reconstruction period	no improvement of irradiation possibilities
2	< 20% ^{235}U tubular slugs	13 cm	6.5 MW	new fuel	moderate cost, compliance with RERTR	no improvement of irradiation possibilities
3	< 20% ^{235}U tube or cluster of rods	13 cm	> 6.5 MW	new fuel, additional cooling	compliance with RERTR, increased irradiation possibilities	considerable investment
4	< 20% ^{235}U tube or cluster of rods	< 13 cm	> 6.5 MW	new fuel, additional cooling, new vessel	compliance with RERTR, considerably increased irradiation possibilities	very high cost, long reconstruction period

3. In-Core Fuel Management Studies

When original 2% enriched uranium metal fuel was used, the RA reactor in-core fuel management scheme was based on a three step cycle, each lasting 15-20 days, with both radial and axial fuel shuffling. The average fuel consumption was 1.5 fuel elements per operating day at nominal power. For the purpose of the analyses performed here, a two-step fuel management scheme with radial fuel shuffling is assumed. At the end of each cycle about half of the fuel channels is removed from the outer region of the core. To begin a new cycle, the fuel from the central core region is moved into the outer region, while fresh fuel is inserted into the central region.

Schematic representation of ¼ of the reactor core horizontal cross section, as used in the 3D fewgroup diffusion theory calculations, is presented in Fig. 1.

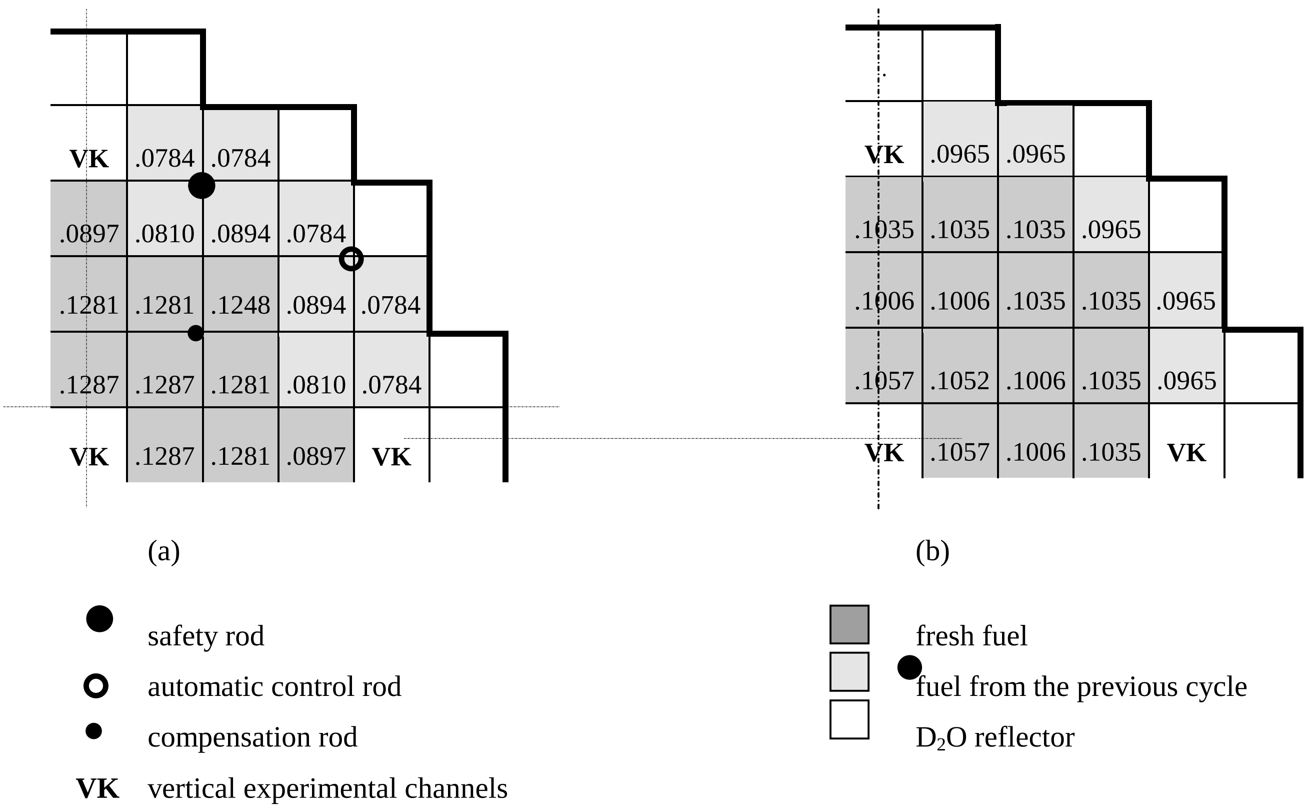

Fig. 1. Schematic representation of 1/4 of the equilibrium RA reactor core with (a) fuel having initial enrichment 80% ^{235}U, (b) fuel having initial enrichment 20% ^{235}U.

4. Results

The standard reactor computation scheme WIMS-TRITON was applied to perform detailed neutronic calculations for different fuel types and uranium loading. Experimental verification of the WIMS-TRITON scheme was performed previously by studying different configurations of the critical facility, i.e. the zero power research reactor RB at the VINČA Institute [8]. The complex modular code WIMS is used to calculate the space-energy dependence of neutron flux and reaction rates and to produce few group burnup dependent data needed in diffusion theory calculations. Its main advantages are a very elaborate nuclear data library, several transport theory procedures and geometry options, and the fact that, being generally available, it was thoroughly tested by a large number of users. The 3-D few group diffusion theory code TRITON is used for calculating overall reactor core parameters like effective multiplication factor, neutron flux and power distribution, fuel burnup and consumption.

For both 80% enriched and 20% enriched fuel, two different configurations of the first core were studied, the number of fuel channels being 64 or 44, and 64 or 76, respectively. In all the cases studied, it was supposed that there are 11 fuel elements per a fuel channel, each fresh fuel element containing 7.5g of ^{235}U. It was assumed that a cycle is completed when k_{eff} becomes less than 1.02. For the core with fuel having initial enrichment 80% ^{235}U, the third cycle was considered to be an equilibrium one. For the core with fuel having initial enrichment 20% ^{235}U, it was considered that equilibrium is established after four cycles.

Power peaking factors (channel power/average power) are presented for each channel in Fig. 1. Variation of effective multiplication factor k_{eff} as a function of time of the reactor operation at the full power is presented in Figs. 2 and 3.

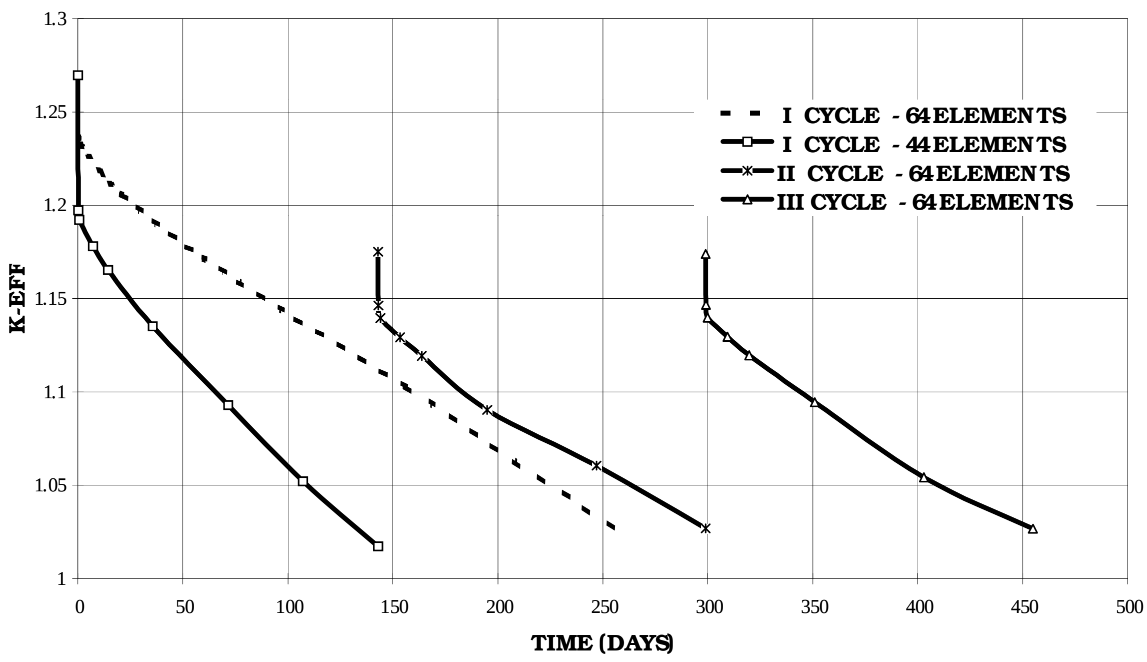

Fig. 2. Variation of the k_{eff} as a function of time of the reactor operation at the full power for the first few cycles with fuel having initial enrichment 80% ^{235}U

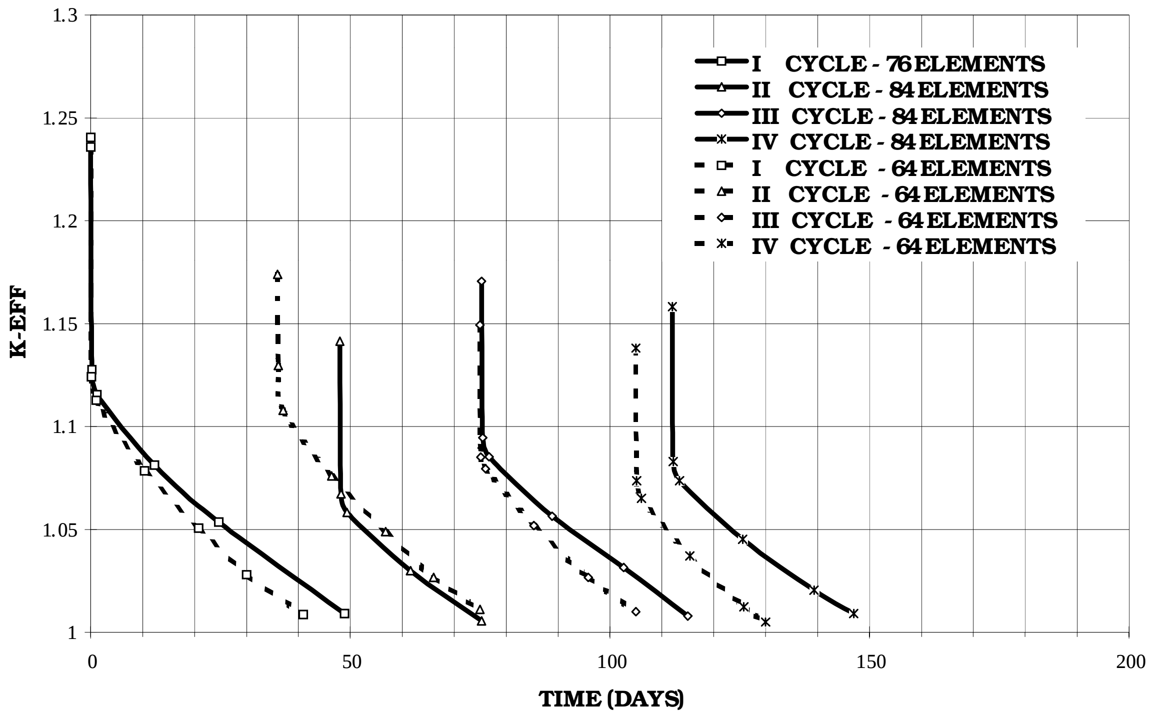

Fig. 3. Variation of the k_{eff} as a function of time of the reactor operation at the full power for the first few cycles with fuel having initial enrichment 20% ^{235}U

Basic data about fuel inventory and consumption in the considered cycles are summarised in Table 3. Amount of ^{235}U at the beginning of a cycle (BOC) is the sum of the ^{235}U content in the fresh fuel and the ^{235}U content in the fuel left in the core from the previous cycle. Consumption of ^{235}U in a cycle is a sum of the ^{235}U amount burned during the cycle and the content of ^{235}U in the fuel to be removed from the core at the end of the cycle (EOC). Taking into account the length of the equilibrium cycle, the average ^{235}U consumption per operating day at the full reactor power was calculated for both initial fuel enrichments.

Table 3. Equilibrium cycle parameters for different initial fuel enrichment

Initial fuel enrich-ment	Number of fuel channels left from previous cycle	Number of channels with fresh fuel	Cycle length (days)	^{235}U consumption (g)	^{235}U consumption per an operating day (g/day)
80%	36	28	150	2360	15.1
20%	40	44	60	3620	60.1

The results presented here should be considered as qualitative ones. They indicate that, as far as reactor core parameters are considered, conversion to lower enrichment fuel could be easily accomplished. By optimizing the in-core fuel management schemes, fuel consumption could certainly be decreased for both initial fuel enrichments. Still, most efficient use of the available fissionable material can be achieved if the existing fuel is burned in its present form.

5. Conclusions

If the general belief prevails that the RA reactor could still represent a valuable facility for research and isotope production, and if it is decided that the RA reactor is to be reconstructed and restarted, options for eventual core conversion and power upgrade should be examined.

Reactor physics calculations presented in this paper indicate that, as far as reactor core parameters are considered, conversion to lower enrichment fuel could be easily accomplished. However, from the point of view of the efficient use of the available fissionable material, conversion to the lower enrichment could only be justified if combined with other major reconstruction of the reactor.

6. References

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