

MCNP Calculations Supporting The Start-up Of The New Core At The TRIGA VIENNA

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ABSTRACT

During 2012 the TRIGA Mk II reactor in Vienna was converted from a highly heterogeneous core which included HEU fuel elements to an all LEU core. Because after 45 years of operation a simple exchange of the HEU with new LEU elements would have been insufficient to reach the necessary excess reactivity, most old pins were sent back to the US. As replacement 77 slightly used (burn up < 1.3%) 20% enriched stainless steel fuel pins were leased from the US Department of Energy (DOE), which together with the 13 retained elements should ensure another 20 years of operation. The previously developed MCNP model was adapted for the new core and used to calculate the basic core load. As it turned out the reactivity was considerably overestimated. This paper presents a discussion of these results together with the measured values and changes in the neutron flux at several experimental positions compared to the 2011 values.

1 INTRODUCTION

During 2012 the TRIGA Mk II reactor in Vienna was converted from a highly heterogeneous core which included HEU fuel elements to an all LEU core. At the time new fuel elements weren't available commercially due the shut down of the fuel fabrication line. To insure further operations low burn up TRIGA fuel elements from the storage site at Idaho National Labs (INL) were leased from the US DOE. In order to generate more reliable expectation values for reactivity and control rod worth before the restart, MCNP [1] calculations with individual fuel element modelling were done and are presented in the following. They are based on a detailed reactor model by R. Khan [2] and previous calculations with homogeneously burned fuel elements used as basis to estimate the amount of new elements needed early 2012.

2 GEOMETRY AND MATERIAL COMPOSITION

Generally the standard MCNP model for the reactor at the Atominstitut includes the major features in the reactor pool up to the pool wall radially and to the upper/lower limit of the thermal column vertically. Figure 1 gives a horizontal cross section of the model with the reactor configuration of late 2007/early 2008 as illustration. For more details please see the thesis of R. Khan [2] in the following only the changes in the fuel elements and the core configuration are discussed further.

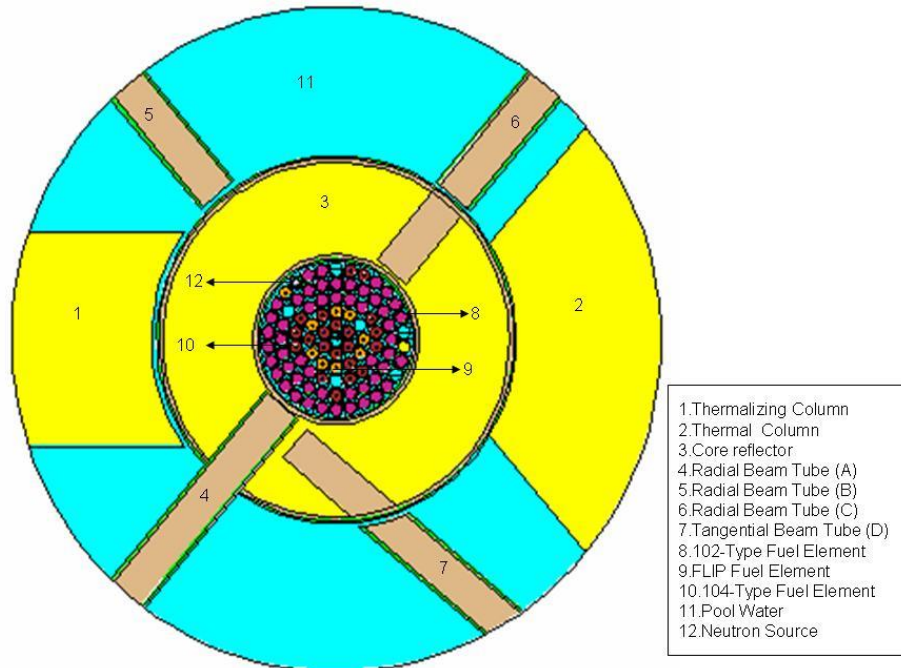


Fig 1: Horizontal cross section of the TRIGA Mark II core in Vienna 2008

2.1 Fuel Elements

As of middle of November 2012 the fuel inventory in Vienna consists solely out of stainless steel clad elements with 20% enrichment and 8.5% uranium content albeit at different levels of burn up. The 77 freshly delivered fuel elements have a burn up ranging from 0.5 to 1.3 % of initial ^{235}U content with most of them having around 0.7% according to the shipping papers provided by INL. This means the reduction of ^{235}U due to burn up of about 0.4g maximum should be lower than the manufacturing tolerances for new elements, which is about $\pm 1\text{g}$ with an average $38\text{g } ^{235}\text{U}$. The 13 retained ones range from completely fresh to 11.5% burn up for one instrumented element, for which the burn up was calculated locally according to the model introduced by R. Khan [2]. Additionally General Atomics (GA) provided a more detailed initial mass inventory [3] including hydrogen weight for the newly shipped elements, which is unfortunately currently not available for the 13 retained elements.

For modelling purposes the average hydrogen weight (35.5 g with a maximum deviation of 1g according to the GA provided data) of the new FE was assumed for the others. The impact of the assumption should be very small and local because only 2 retained elements are planned for in the start up core configuration. In the MCNP model the burn up is restricted to the reduced uranium content and only includes produced plutonium isotopes but no fission

products. The main reason for this is the avoidance of detailed burn up calculations for the new elements as there is currently no detailed burn up history available anyway. Due to the generally low burn up, the effect was expected to be small and generate an overestimation of the reactivity because of the reduced neutron capture keeping the calculations conservative for regulatory purposes.

Additionally for trouble shooting the model a hypothetical average fresh fuel element was generated from the GA data set [3] with a reduction of ^{235}U in steps from 0% to 7% to simulate burn up.

2.2 Core Configuration

For easy book keeping the base line start up core is constructed by starting with new fuel element with the lowest serial number in core position B1 and then filling the rest of the 65 needed positions clock wise with the next highest serial number. The only exceptions are the instrumented elements at positions C6 and E13 (serials 8730 and 8257) and the F-ring, where placement starts from F30 going counter clock wise. The primary reasons for the placement in the F-ring are ease of handling, keeping the neutron source at F28 and increasing the reactivity worth of the regulating rod. The other core positions beside central experimental position and the three absorber rods are filled with graphite elements. Because the burn up of the fuel elements besides the fixed instrumented ones is only in the 0.5 to 1% range, any shuffling between them should have only very minor consequences. Based on this configuration core loadings ranging from 60 to 67 FE have been simulated by either adding at the positions F1 and F2 or replacing F22 and up with graphite elements.

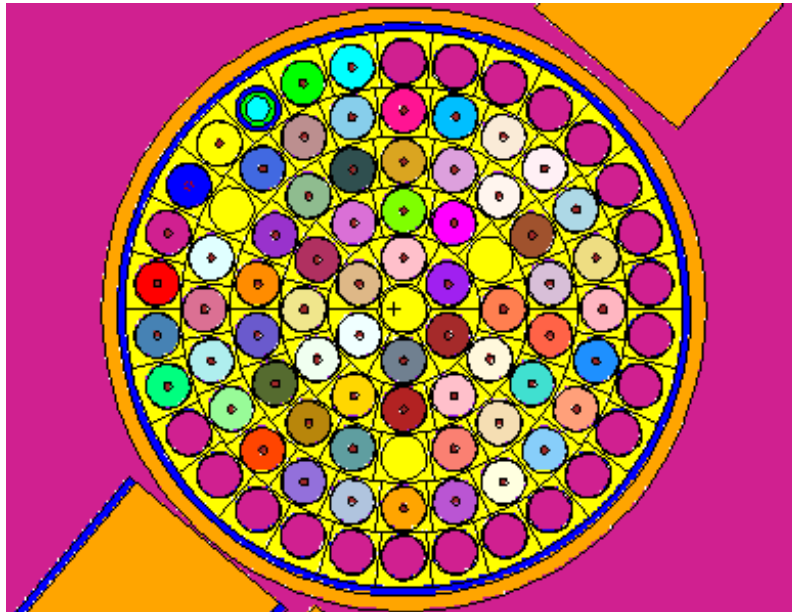


Fig 2: Horizontal cross section of the 65 fuel element base line case

For estimating the average burn up of the core several configurations were also calculated for which the newly delivered elements (all besides 8730 and 8257) were replaced with homogeneously depleted elements with a given ^{235}U reduction.

3 METHODOLOGY AND RESULTS

Unless otherwise noted all calculations were done with MCNP5 1.40 coupled with the JEFF3.1 cross section library on a normal office computer, which limits the accuracy especially for the flux calculations on the outskirts (beam lines) of the model isn't much of a problem for reactivity determination. It was naturally run in the criticality mode with flux calculation based on power normalization via fission energy deposition in the fuel meat for a cold core. Beta effective was assumed as 700 pcm based on GA recommendations [3] for TRIGA cores with stainless steel clad fuel.

3.1 Reactivity and Integral Control Rod Worth

The core configurations given in table 1 below are all constructed according to the method stated previously (F30 counting down) till 65 FE, for 67 FE two elements are added at F1 and F2. Criticality is expected at 60 FE and operational excess reactivity at 65 FE with the change of reactivity per fuel element at that point of about 35 cent. As discussed in the section about material composition of the fuel this estimate is conservative meaning 66 FE should be needed to reach 2\$ excess reactivity. The last two cases in the table are remnants of calculations performed to estimate the FE needs during the negotiations with DOE given for comparison only. The case 67 FE with fresh elements in the B-ring would be practically possible but neither the reactivity gain nor the flux gain in the central experimental position would warrant it.

Tab 1: k_{eff} and reactivity for various core configurations

core	k_{eff}	sigma	reactivity [pcm]	reactivity [\$]
60 FE	1.00086	0.0001	86	0.12
64 FE	1.01141	0.0001	1128	1.61
65 FE, base line	1.01402	0.00011	1383	1.98
67 FE	1.01853	0.00007	1819	2.60
67 FE, fresh B-ring	1.0193	0.00008	1893	2.70
67 FE, all fresh	1.02317	0.00068	2265	3.24
67 FE, hom. -1g U235	1.01709	0.00005	1680	2.40

The integral control rod worth calculations were based on the 65 FE base line scenario and are given in table 2 below. As in the previous core configurations the regulating rod alone is insufficient to shut down the reactor.

Tab 2: Integral control rod worth for the 65 FE base line core configuration with 1.98 \$ excess reactivity

control rod	shut down margin [\$]	Integral rod worth [\$]
Shim	2.61	4.58
Transient	0.32	2.29
Regulating	-0.13	1.84

3.2 Burn Up Estimation in Reaction to reduced Reactivity at Start Up

As it turned out the original start up calculation presented above were far too optimistic. Criticality was reached 65 FE showing a reactivity shortfall of nearly 2\$ compared to the reference model and full power, although barely, was reached with 71 elements. As the model is well tested with the previous core configurations estimating the critical configuration within +- 1 FE, this came as surprise and will make reaching another 20 years of operations very difficult in any case. To get a first idea how far the fuel data would have to be off in order to reconcile the simulation and the actual reactivity measurements, simulations were run with reduced ^{235}U content. This resulted in a match with 5% depletion, which is far higher than the 0.68% average burn up given in the shipping documents.

3.3 Effects of different Cross Section Libraries

As explained above the standard model was done with MCNP5 1.40 and JEFF3.1 cross section data. Originally JEFF3.1 was chosen over the standard library for MCNP because erbium cross sections were needed to model the FLIP elements in the old core. To check for possible cross section dependency several simulations were done with ENDF6.6 data for parts or the entire problem using the 65 FE core with homogenized FE as a baseline. It turns out that switching only the UZrH fuel meat to ENDF6 gives an additional 1\$ reactivity increase compared to the 2\$ offset with JEFF3.1 for a total of a 3\$ difference to the experimental result. Successively increasing the endf6.1 modelled part (steel clad, water and complete model) further raises reactivity by about 10 cent in total, which is barely statistically significant. Using MCNP5 1.60 with ENDF7.0 gives 80 cent additional reactivity compared to the baseline, which is a still a worse fit to the experiment than the original model although somewhat better than ENDF6.6.

3.4 Flux Changes in the Central Irradiation Tube

Most of the irradiation positions utilized by users at the TRIGA Vienna are either located at the outer edge of the core in the F-ring or outside the core altogether like in several positions in the reflector groove. These as well as the beam lines and thermal column are not expected to be affected by the core renewal outside minor flux changes due to the replacement of several FE in the F-ring by graphite dummy elements. The softened neutron spectrum is usually perceived as positive by users because they are only interested in the thermal part anyway. Positions further to the centre of the core are normally only used for reactor characterization experiments usually during reactor physics courses. So there are no specific requirements for neutron flux level or shape of the spectrum.

The sole exception to this happy state of affairs is the central irradiation position. Besides being utilized for student experiments and basic reactor physic training, a group at the institute uses it to irradiate super conductor samples for the ITER project. Here high fast flux is of interest and while the change to a uniform core makes the reactor calculations somewhat easier, it also removes the option of utilising the power peak introduced by the highly enriched FLIP fuel elements. The calculated peak power per FE element was 9 kW for a FLIP element at 250 kW power operation with an all FLIP B-ring, which stands in stark contrast to 4.5 kW maximum for the LEU core. Not only did this reduce the flux in the central position by a factor of 2.5, it also reduced fast neutron flux fraction from 25% over 0.3 MeV to 20%.

4 SUMMARY AND CONCLUSIONS

As it stands the discrepancies in reactivity between the MCNP model and the experimental values are not satisfactorily explained. So far everything points to problems in the modelling of the SS clad fuel elements themselves. The Musashi TRIGA reactor, the only other reactor which used a core purely fuelled by SS clad 8.5% 20% enriched fuel elements, reported [4] a critical configuration of 66 FE for the SS clad elements compared to 58 for the original Al clad core. This matches well with the experimental results (65 and 57 FE due slightly different core configuration) for the Viennese reactor and gives a upper limit on the effect of omitting the build up fission products, which is lower than the reactivity value of a single FE in the F-ring (~30 cent). Although the current model is just a replacement of the material composition in the old model, which gave good results for criticality [5], the model for the old core might have been right for the wrong reasons. Because the old core was a mix between 3 fuel element types with long operational history any effects of the SS clad 8.5 wgt% fuel elements might have been hidden by the majority Al clad ones or the highly enriched FLIP elements.

Regardless exact cause for the problem, it resulted in an underestimation of the fuel needs for the planned 20 years of operation time. So a review of the operating pattern to conserve fuel and/or additional fresh fuel with higher uranium content will be necessary.

REFERENCES

- [1] J. F. Briesmeister, Ed, MCNP – A General Monte Carlo N-Particle Transport Code, Version 5, Manual, April 2003
- [2] R. Khan, Neutronics Analysis of the TRIGA Mark II Reactor Core and its Experimental Facilities, Thesis TU Wien, Vienna March 2010
- [3] General Atomic, TRIGA Mark II Reactor General Specification and Description, Reverence, GA-2627, March 1964
- [4] N. Horiuchi, T. Matsumoto, T. Nozaki, O. Aizawa, T. Sato, “Measurement of new core characteristics at the Musashi reactor”, Proc. 10. European TRIGA users conference, 1988, p. 570.
- [5] R. Khan, S. Karimzadeh, H. Böck, “Neutronics Analysis of CURRENT CORE OF THE TRIGA MARK II REACTOR VIENNA”, Proc. RRFM 2010, Marrakech, Morocco 23-25 March 2010, p 218.