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BENCHMARK EXPERIMENTS AT THE TRIGA MARK II REACTOR

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ABSTRACT

The benchmark experiments performed in an operating research reactor cannot achieve the same level of accuracy as benchmarks in dedicated facilities that are specifically designed for such a purpose. However research reactors offer a great opportunity for benchmark experiments when designed and performed with great caution and accuracy. The paper describes a series of experiments performed at the JSI TRIGA reactor that can serve as benchmark experiments for testing computer codes and nuclear data. The experiments described are: criticality, Au (n,g) and Al (n,a) reaction rates in irradiation channels, absolute and relative Au (n,g), ^{235}U (n,f) ^{238}U(n,f) reaction rates in the core, burnup, control rod worth, isothermal reactivity coefficient, self-shielding. Some of the experiments have already been evaluated and are available to worldwide community, while the others are yet to be evaluated.

Key Words: **TRIGA, benchmark, MCNP, reaction rate, criticality**

1. INTRODUCTION

The need for benchmark experiments has already been identified in the international community resulting in several international projects, some of them coordinated by the OECD Nuclear Energy Agency, that is the International Criticality Safety Benchmark Evaluation Project (ICSBEP) [1], International Reactor Physics Experiment Evaluation (IRPhE) Project [2], Shielding Integral Benchmark Archive and Database (SINBAD) [3]. The majority of the benchmark experiments described in the abovementioned databases were performed in special dedicated facilities and consequently feature relatively small experimental uncertainty. The number of benchmark experiments compiled in the databases grows continuously as new experiments are performed or new information about past experiments is found. In parallel the need for testing computer codes as well as nuclear data on reliable and well documented experiments is growing together with their development.

The benchmark experiments performed in an operating research reactor cannot achieve the same level of accuracy as benchmarks in dedicated facilities that are specifically designed for such a purpose [4].

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This is certainly the main reason for relatively small number of evaluated benchmarks on research reactors. However research reactors offer a great opportunity for benchmark experiments when designed and performed with great caution and accuracy.

The main purpose of this paper is to present experiments performed at the Jožef Stefan institute (JSI) TRIGA Mark II research reactor which can be used as benchmark experiments. The experiments are available to worldwide community interested in using the data for the testing of their computer codes. In the first section, we describe the experiments that have already been performed and evaluated. Section two describes experiments that have been performed and could be repeated but have not yet been evaluated, and some future experiments.

2. EXISTING BENCHMARK EXPERIMENTS

2.1. Criticality and burnup

The criticality benchmark experiment was performed in 1991, after the reconstruction of the reactor [4]. In 1999 the computational model of the reactor in MCNP [5] was developed, in order to evaluate the experimental uncertainties and to use the model to computationally support experimental campaigns at the reactor. The evaluated criticality benchmark experiment was later published in the International Handbook of Evaluated Criticality Safety Experiments (ICSBEP) [6]. Until recently, this was the only publicly available TRIGA criticality benchmark featuring homogenous mixture of fuel, moderator and Zr. Due to U–ZrH fuel, it is very sensitive to the Zr absorption and scattering cross sections [7]. In the last years criticality benchmark experiments from Idaho National Laboratory were also evaluated and published in the ICSBEP Handbook.

After some years of operation the criticality benchmark was repeated with burned fuel [8]. This benchmark provides useful information for testing of cross sections of burnup calculation codes as well as the reactivity effect of burnup. In addition the fuel burnup of individual fuel elements was measured by reactivity experiments [9][10]. Recently we initiated activities to thoroughly record the operational history of the reactor together with excess reactivity and control rod worth measurements, which could be used for testing of core management codes such as TRIGLAV [11] or Monte Carlo codes such as SERPENT [12]. It is important to note that one of the major uncertainties in fuel burnup determination is the uncertainty in the measured reactor power level [13]. The major source of uncertainty in the JSI TRIGA Mark II reactor is the neutron flux redistribution or tilt in radial direction due to asymmetric control rod insertion. As the reactor power is measured with one detector only, the change in measured power level can be as much as 20-30 %. This can be corrected by applying corresponding correction factors [14] or measuring the reactor power using multiple detectors [15]. The above approaches were verified experimentally and calculationally and are described in section 2.2.

2.2. Reaction rate

The neutron activation method was used to experimentally verify the calculated reaction rates in the irradiation channels of the reactor. In the experiment aluminium-gold (Al(99.9 wt. %) - Au(0.1 wt. %)) foils (disks of 5 mm diameter and 0.2 mm thick) were irradiated in 33 locations (irradiation channels); 6 in the core and 27 in the carousel facility in the reflector [16]. After the irradiation, the activation of individual samples was measured using a High-Purity Germanium detector (HPGe). The following two activation reactions were considered in the experiment: ^{27}Al(n,α) and ^{197}Au(n,γ). The results are presented in Figure 2.

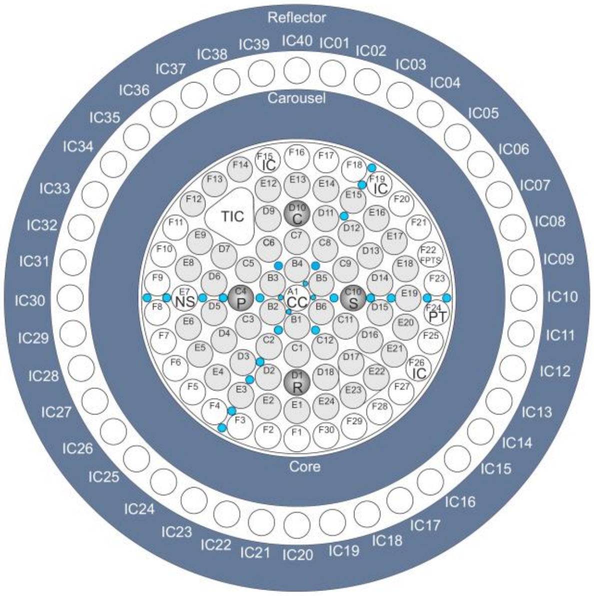

Figure 1. Schematic top view of the TRIGA reactor with marked irradiation positions. Blue circles in the core denote positions in the core, where axial reaction rate profile measurements were performed.

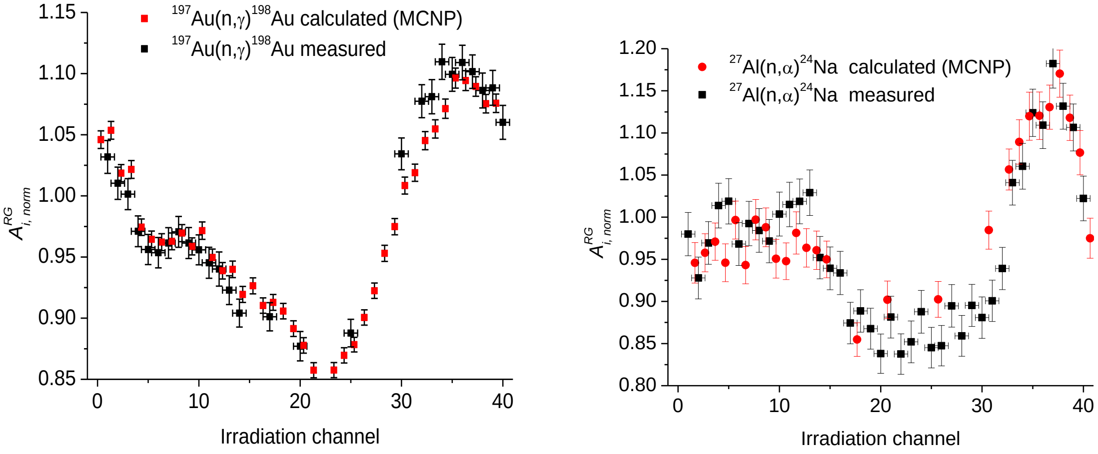

Figure 2. Calculated and measured Au (n,g) and Al (n,a) reaction rates in the carrousel facility. The Y error bars represent 1σ uncertainty in measured or calculated results. The X error bars represent the uncertainty in the irradiation channel position during the experiment.

In addition axial ^{197}Au(n,γ)^{198}Au reaction rates measurements performed in four core positions at full power. This was accomplished by irradiating aluminium probes, which contained 5 mm lengths of Al–0.1% Au wire, 1.0 mm in diameter [17].

Fission rate measurements were performed using a fission chamber containing approximately 10 μg of 98.49 % enriched ^{235}U.Axial measurements (23 axial positions) of the fission rate along the complete core height at 9 radial measurement positions are shown in Figure 1 [18].

These measurements are used for verification and validation of our computational model as well. An interesting feature of the above experiments is that they provide absolute values of the reaction rates, which are normalized to the total reactor power, hence they can be used for validation of normalization as well [19]. Some results are presented in Figure 2.

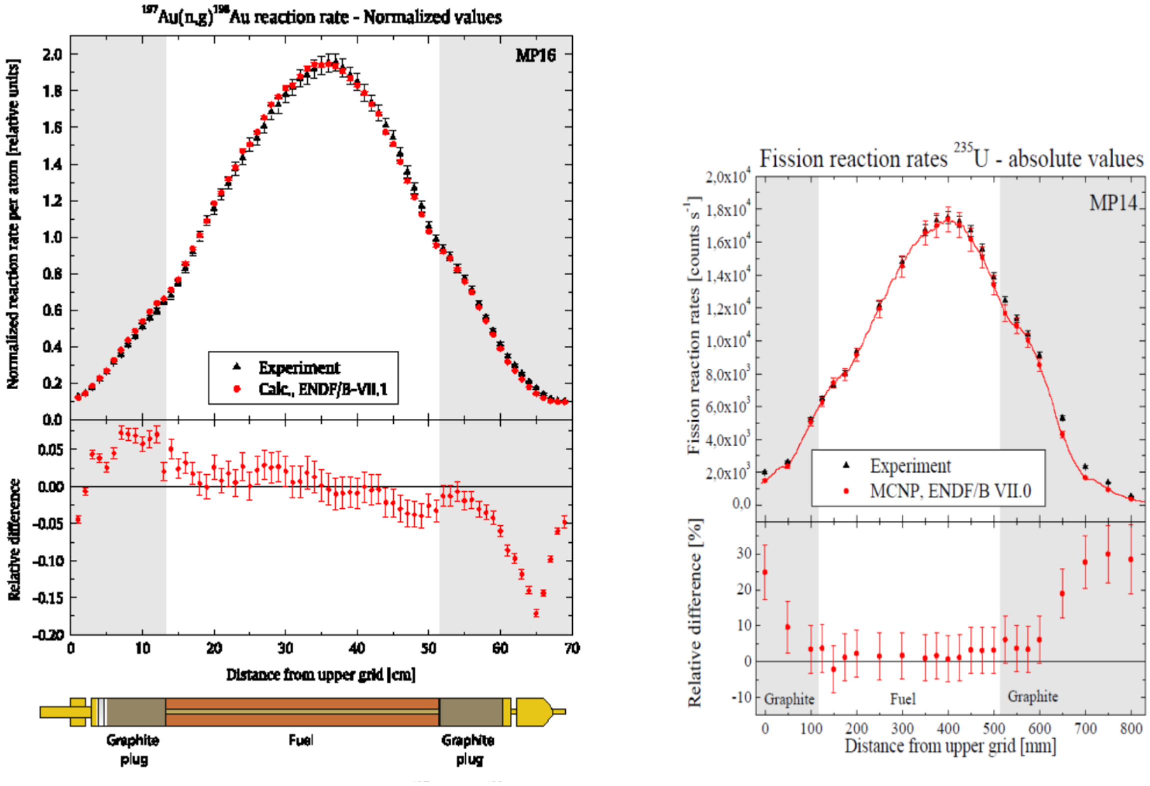

Figure 3. Calculated and measured ^{197}Au(n,g) and ^{235}U(n,f) axial profiles normalized to the reactor power.

2.3. Reactor kinetics

In 1991 the reactor was equipped for pulse mode operation. In total more than 150 pulses were performed. All of them were later analyzed for validation of the so called Fuch-Hansen model and its improvement [20]. The pulse experiments also provided valuable information on reactor kinetic parameters such as prompt neutron lifetime and effective delayed neutron fraction. These parameters were later used for validation and verification of calculations [21]. In addition both kinetic parameters were later measured by noise measurements with an Agilent spectrometer [22].

3. PLANNED BENCHMARK EXPERIMENTS

In addition to the above measurements, we regularly measure isothermal temperature reactivity coefficient as part of the exercises for students of nuclear engineering. It is interesting to note that the temperature reactivity coefficient is positive at room temperature, i.e. up to approx.. 27 °C [23].
Control rod worth measurements are also performed on a regular basis. Recently a project was initiated to evaluate the uncertainty in control rod worth by using different methods, i.e. rod swap and rod-insertion method [24].
Due to the use of the reactor for radiation hardness studies, several measurements of photon fields in the irradiation channels were made by using ionization chamber [18] as well as radFETs in operating and shutdown reactor. Such measurements are very valuable for validation of photon production methods (during operation) as well as for validation of gamma flux and shutdown dose calculations and development of the so called R2S methods. In addition, long-lived neutron activation products in reactor biological shield were measured as well [25], which is of high importance for safe decommissioning and for validation of activation codes.

4. CONCLUSIONS

Recent and current experimental programs performed with various nuclear instrumentation in the JSI TRIGA reactor have improved its measurements capacity and its intrinsic physical parameters and uncertainties (kinetic parameters, spatial flux and reaction rate distributions, power level...). Completed with a fully validated calculation scheme, these experimental data set allows considering this small and relatively old research reactor, having rather low neutron flux ($\sim 10^{12}$ n/cm^{2}s), as, even nowadays, able to efficiently support both fundamental and applied research an. The JSI TRIGA reactor can significantly contribute to the development of new methods and knowledge in reactor physics.

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