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Jožef Stefan Institute TRIGA Research Reactor Activities in the Period from September 2020 – August 2021

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ABSTRACT

After the calendar year, operating performance indicators for Jožef Stefan Institute TRIGA Mark II research reactor are analysed. After several years of increasing yearly operating hours, a significant decrease is observable last year due to the pandemic of the SARS-CoV-2 virus. However, the number of irradiated samples was larger than the year 2019, indicating that the reactor was operated more efficiently. Furthermore, reactor personnel tried hard to adjust the situation. Since September 2020 we can offer all exercises designed for education and training purposes in remote option. In that way, our reactor became much more accessible, especially for students who cannot afford to travel to Slovenia.

1 INTRODUCTION

Firstly, operating performance indicators are analysed for the year 2020. Indicators are important for safe future operation since they allow to quickly see which fields need improvements from the analysis. Operating performance indicators can also be compared to other research reactors, not just in the region but worldwide. In this paper besides performance indicators, some highlights from the last year of operation are presented, like engaging research campaigns or significant upgrades and modifications of the JSI TRIGA research reactor.

2 OPERATING PERFORMANCE INDICATORS

In 2020, the reactor was in operation for 464 hours which corresponds to about 64 % of operation time in the year 2019 (723 h). Produced energy decreased from 112.6 MWh to 78.8 MWh. The main reason for the decreased operation lies in the SARS-CoV-2 virus and the measures taken to control the spread. JSI personnel were advised to work from home. Operators were present at the reactor only when necessary. Most of the reactor's domestic users organised their work to not use the reactor itself. The decrease in demand was also observed among international users. In Figure 1, one can see how last year produced heat differed from the 2010 – 2019 average. January was above the average. In February, a decrease is observed since the reactor was out of operation for two weeks due to maintenance work. From March until May, there was a “lockdown” due to the epidemic. In the second half of March and in April, the reactor was available only for the most urgent irradiations. During the summer, the reactor was once again back to regular operation. Towards the end of the year, another decrease can be observed due to the second wave of the virus.

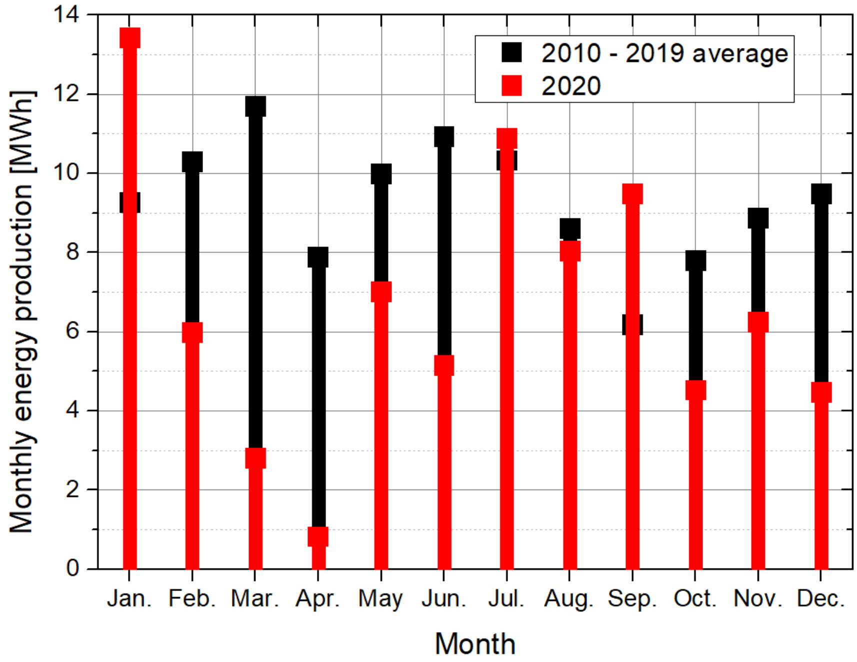

Figure 1: Produced energy per month in 2020 compared to the average of the previous 10 years.

Although the reactor operation was limited in 2020, we have not rejected any users. The fact can support this, that a higher number of samples was irradiated than in 2019 and the yearly received doses by the operating personnel are comparable to the year 2019. The received doses are presented in the table below.

Table 1: Annual received doses by the personnel in the period 2016 to 2020.

Safety Performance Indicator	**2016**	**2017**	**2018**	**2019**	**2020**
Operating staff: collective radiation dose [mSv]	0.678	0.53	1.08	1.31	1.29
Average dose [mSv]	0.170	0.133	0.270	0.328	0.323
Maximum individual dose [mSv]	0.208	0.16	0.41	0.36	0.56
Reactor-related staff: Collective radiation dose [mSv]	1.053	1.15	2.31	2.87	2.23
Average dose [mSv]	0.035	0.044	0.072	0.093	0.077
Maximum individual dose [mSv]	0.208	0.20	0.41	0.36	0.56
Over-exposures	No	No	No	No	No

From Table 1, one can see that operators received basically the same dose as in the year 2019. The dose received by the researchers is lower, and also the number of reactor related staff was lower in 2020. The reason may lie in the measures taken to limit the spread of the virus. There was more remote work – usually, the samples were only delivered to the operating staff who then took the samples for irradiation. It can be concluded that the received doses are low. For example, the yearly individual dose constraint for the TRIGA operator is set to 2 mSv per year, 10 % of the limit set by national legislation [1]. In Table 1. Received doses can be compared to the ones from the last five years.

In the year 2020, the reactor also operated in pulse mode and produced 37 pulses. The purpose was to observe the response of the micro fission chamber, to test the newly designed

Cherenkov detector and to perform a Pulse mode operation exercise for the students from the University of Ljubljana.

In the year 2020, there were seven unplanned shutdowns which is more than in the previous years. There were three unplanned shutdowns due to the testing of automatic change in a power range of the Linear nuclear channel. The function was enabled in 2019 but finally realized in 2020 which required some fine-tuning during reactor operation at low power. Although most of the year 2020 students and trainees were not allowed at the reactor, we have hosted some groups in January and during the summer window. Students and trainees caused three unplanned shutdowns. One unplanned shutdown was caused by an operator's mistake. Such errors are expected during the start-up period when operators have to be careful not to exceed a reactor period of 7 seconds or 91 % of power range if a manual range selection is enabled. Such SCRAMs usually occur at power levels below 100 W which does not stress the fuel.

In the year 2020, gaseous effluents released to the environment decreased due to lower reactor operation. The total activity of aerosols released through the ventilation system was less than 2 kBq. Detected elements were ^{24}Na and ^{82}Br. Instead of limits for the effluents, there is a limit for the annual dose received by the reference person that should not exceed 1 μSv. As presented in Table 2, the yearly limit was not exceeded. Furthermore, effluents for the year 2020 can be compared to the effluents from the last five years. Besides the significant decrease in the ^{41}Ar release, no other changes are observed.

Table 2: Radioactive releases for years 2016 – 2020.

Safety Performance Indicator	**2016**	**2017**	**2018**	**2019**	**2020**
Activity of noble gases released to the atmosphere	1000 GBq	1200 GBq	1260 GBq	1300 GBq	700 GBq
Activity of iodine released to the atmosphere	0 Bq	0 Bq	0 Bq	0 Bq	0 Bq
Activity of aerosols and particulates	0 Bq	0 Bq	< 5 kBq 24Na	< 1 kBq 24Na < 1 kBq 82Br	< 1 kBq 24Na < 1 kBq 82Br
Low-level liquid radioactive waste released	20.5 m^3	15 m^3	20 m^3	18 m^3	12.3 m^3
Concentration	14.3 kBq (24Na, 60Co)	< MDA	< MDA	< MDA	< MDA
Intermediate-level liquid radioactive waste released	0 m^3	0 m^3	0 m^3	0 m^3	0 m^3
High-level liquid radioactive waste released	0 m^3	0 m^3	0 m^3	0 m^3	0 m^3
Public dose	< 0.55 μSv	< 0.63 μSv	< 0.65 μSv	< 0.65 μSv	<0.38 μSv

3 RESEARCH WORK

In the year 2021, a 2-year contract with Rolls Royce Nuclear SAS was concluded. The company was using our services to develop a reactor power acquisition system reading the signal from a fission chamber. Both sites are active in extending the contract for another three years.

In the framework of the NATO SPS-funded project E-SiCure2 ([2] and [3]), silicon carbide (SiC) detectors of different active areas and neutron-to-charge-particle converters consisting of different thicknesses of $^{10}B_4C$ and ^{6}LiF deposited onto substrate were tested in the Dry Chamber of the JSI TRIGA reactor. The results show that the neutron response of the detectors is linear with the active detector area (varying from 1 mm^2 to 9 mm^2). The recorded charged particle spectra show that with increasing converter layer thickness (from approximately 1 μm to approximately 27 μm) the overall neutron count rate increases; however, there is an observable loss in the detector energy resolution.

Figure 2: SiC neutron detector, that was tested inside the dry chamber facility at JSI TRIGA research reactor.

During the lockdown period in spring 2021, a collaboration with the National Institute of Chemistry was initiated. The idea is to study the utilization of the waste radiation for the splitting of relevant hydrogen carriers, which are arising as the conversion of choice for long term storage. Correspondingly, ammonia, methanol and hydrocarbons still seem to be preferred over compressed hydrogen storage due to economics. Radiation could thus be prudently used to split methanol in the hydrogen production cycle of the integrated carbon capture and utilization, considering CO_2 reduction. Nonetheless, this has not seemed to be investigated or assessed to date. Therefore, the first batch of samples containing various catalysts was already irradiated by neutrons and analysed. So far, the intermediate results are promising and the whole project is worth continuing.

In July 2021 an experimental campaign was carried out by a team of researchers from JSI and the French Atomic and Alternative Energy Commission (CEA), in which gamma heating measurements in different fission and fusion relevant materials were made in the Central Channel of the JSI TRIGA reactor [4]. The campaign was carried out in the framework of a bilateral project, funded by ARRS and CEA, the materials were graphite, aluminium 6063, Eurofer 95 and tungsten. The results of the experimental campaign will serve as a basis for the characterization of the gamma heating rates in the JSI TRIGA reactor, and the validation of computational methods and associated nuclear data. The results will also facilitate the possibility of new measurements of gamma and neutron heating rates in other fusion relevant materials, e.g. Nb_3Sn superconducting material, copper, ceramic materials and beryllium.

Articles on testing autonomous vehicle capable of dose rate mapping were published ([5] and [6]). An article on testing the sterilization of protective face masks using gamma radiation was published [7]. The MCNP (Monte Carlo N-Particle transport code) model describing complete reactor building and control room was successfully validated ([8] and [9]). The code RAPID was validated using dosimetry measurements at JSI TRIGA [10]. The first calculations on the new water activation loop were done, which could be used for gamma irradiations with accurately known dose rates [11]. A code GRUPINT was used to characterize neutron spectra in TRIGA irradiation channels [12]. PC based research reactor simulator was updated [13]. The simulator can be downloaded free of charge at https://reactorsimulator.ijs.si/.

4 OPERATIONAL HIGHLIGHTS

Education and training activities are important when operating a small research reactor like TRIGA. Sharing of nuclear knowledge is our mission and a complete lockdown in spring 2020 stopped all activities in the field. Travel restrictions remained and that meant we were unable to host foreign students. During summer 2020, we have tested various options for remote training and education. When the second wave of SARS-CoV-2 virus started we were prepared to offer remote education services worldwide. At the end of September, we "hosted" virtually a group of students from Uppsala University (Sweden). The whole winter semester students from the University of Ljubljana were attending practical exercises in remote versions. Recently, in July 2021, a group of students from Aix-Marseilles University took a short practical course on reactor physics (Figure 3).

By introducing remote reactor exercises, our reactor became even more accessible for students all over the world. It is agreed that remote exercises cannot replace hands-on experiments, but it could be a great compromise when students are not allowed to travel.

Figure 3: Demonstrators during Flux mapping exercise for French students who participated in the remote course on reactor physics.

Due to the pandemic, all public events like Open day for the public are cancelled. At the end of November 2020, a virtual event "Noč raziskovalcev" (Researchers Night) was organized and reactor personnel participated. A virtual tour through the reactor was broadcasted live. There were over 130 clients following our presentation, and they could visit our control room and reactor platform. The reactor was shown during full-power operation. Visitors were able to ask questions which were answered during or after the presentation. Due to the excellent feedback from the broadcast, it was decided to record a similar video and publish it on our YouTube channel [14]. The video was also presented to scholars who were visiting remote sessions at Nuclear Training Centre.

5 MODIFICATIONS DONE AT THE REACTOR IN LAST YEAR

The old triangular irradiation channel was replaced by a new one which has a larger volume. The cross-section is presented in Figure 4 – left. Since the old triangular channel was fully utilized, a decision was made to insert another identical channel to the new one symmetrically over the core (Figure 4 – right). In June 2021, a new configuration number 244 was established (Figure 5). The idea is to keep the configuration stable as long as excess reactivity will be high enough. This is useful for researchers who need stable parameters for consecutive irradiation over a more extended period. The parameters of the new triangular channels were also measured and calculated. The results are presented in Table 3. Neutron spectra are presented in Figure 6.

Table 3: Calculated and measured properties for new triangular channels.

Neutron flux [$cm^{-2}s^{-1}$]	**Channel 1**		**Channel 2**	
	calculated	**measured**	**calculated**	**measured**
Thermal (< 0.625 eV)	3.29×10^{12}		3.21×10^{12}	
Epithermal (0.625 – 10^5 eV)	3.36×10^{12}		3.29×10^{12}	
Fast (> 10^5 eV)	3.80×10^{12}		3.71×10^{12}	
1 MeV equivalent	3.58×10^{12}	3.81×10^{12}	3.50×10^{12}	3.5×10^{12}
Total	1.04×10^{13}		1.02×10^{13}	

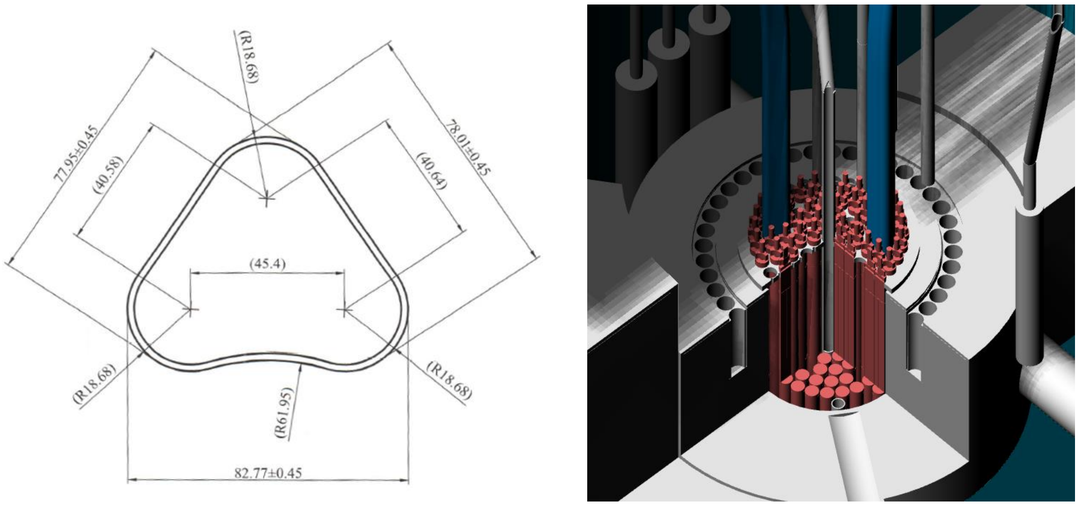

Figure 4: Left: cross-section of the new triangular channels. Right: location of the two triangular channels in-core.

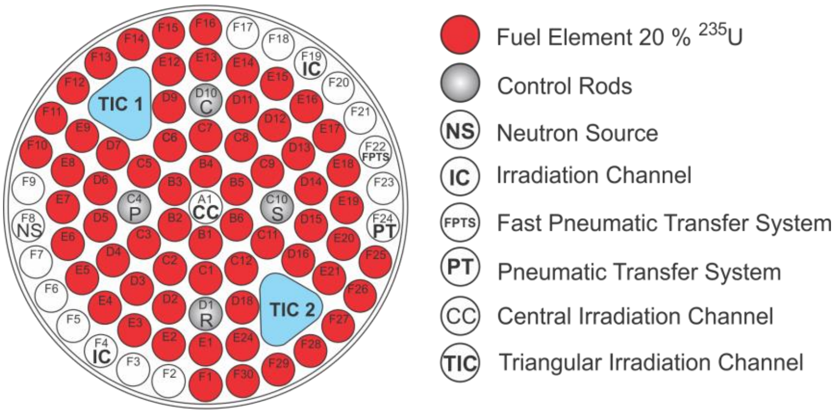

Figure 5: Core 244 configuration

6 FUTURE PLANS

In the following months, there is a plan to construct a device for spent fuel gamma spectrometry. The device will be installed inside the spent fuel pool. The idea is to determine a burnup for single fuel elements. In future, it could also be used to characterize spent fuel. These days, we have no spent fuel elements on site. The detector, HPGe (High Purity Germanium) was already acquired this spring and will be fully characterized by the autumn.

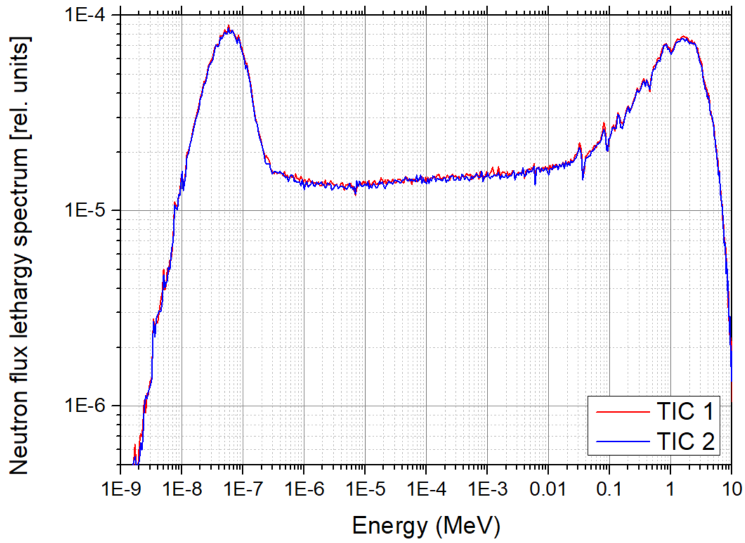

Figure 6: Neutron spectra for both triangular irradiation channels.

JSI TRIGA is taking part in the European Nuclear Experimental Educational Platform (ENEEP) together with partners STU Bratislava, CTU Prague, TU Wien and BME Budapest [15]. The project will be concluded next year and the outcome will be a platform that will fulfil the needs of European users to significantly enhance their experimental education and hands-on activities in nuclear curricula, particularly in the field of nuclear safety and radiation protection. More information can be acquired from the ENEEP web page [16]. DEMO courses will take place in February 2022 where one of them will also be hosted by our reactor facility.

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