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Jožef Stefan Institute TRIGA Research Reactor Activities in the Period from September 2021 – August 2022

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ABSTRACT

The paper focuses on the operational highlights of the Jožef Stefan Institute (JSI) TRIGA Mark II research reactor from the previous year. Firstly, some of the important operating performance indicators are presented and compared to the ones from the previous years. In 2021, we operated the reactor for over 700 hours and broke the ten-year record. Important research work performed in the last year is presented. These are research campaigns carried out in collaboration with CEA and others. In the field of education, the first demonstrational ENEEP (Europen nuclear experimental educational platform) course was carried out. For the first time, SARENA students were attending practical exercises on our TRIGA. During the summer months, a detailed inspection of our pool tank was performed.

1 INTRODUCTION

Operating performance indicators are analysed for the year 2021 and compared to the ones from the previous years. Indicators are important for safe future operation since they allow us to quickly see which fields need improvements from the analysis. In this paper besides performance indicators, some highlights from last year operation are presented, like engaging research campaigns or significant upgrades and modifications of the JSI TRIGA research reactor.

2 2021 OPERATING PERFORMANCE INDICATORS

In 2021, the JSI TRIGA reactor operated for 739 hours which is a record for the last ten-year period (2nd best; year 2019, 723 hours) and is a continuation of the trend set in the years before the CoVid pandemic. Furthermore, produced energy in 2021 was 128.2 MWh which is also the highest in the last ten-year period (2nd best; year 2012: 124,6 MWh). The detailed history of produced power is presented in Figure 1. In the year 2021, 70 reactor pulses were produced which is a comparable number to the previous years.

An important performance indicator is also the received dose from the operating personnel and all staff related to the reactor operation. They are presented in Table 1. After a slight decrease in received doses by operating personnel in 2020, we can once again see an observable increase compared to the years 2019 and 2020. Although the collective dose is higher than ever, it was evenly spread among all four operators. The maximum received dose by a single operator is lower than in the year 2020. Since the internal constraint (2 mSv/year per person) was not violated, no corrective actions were taken.

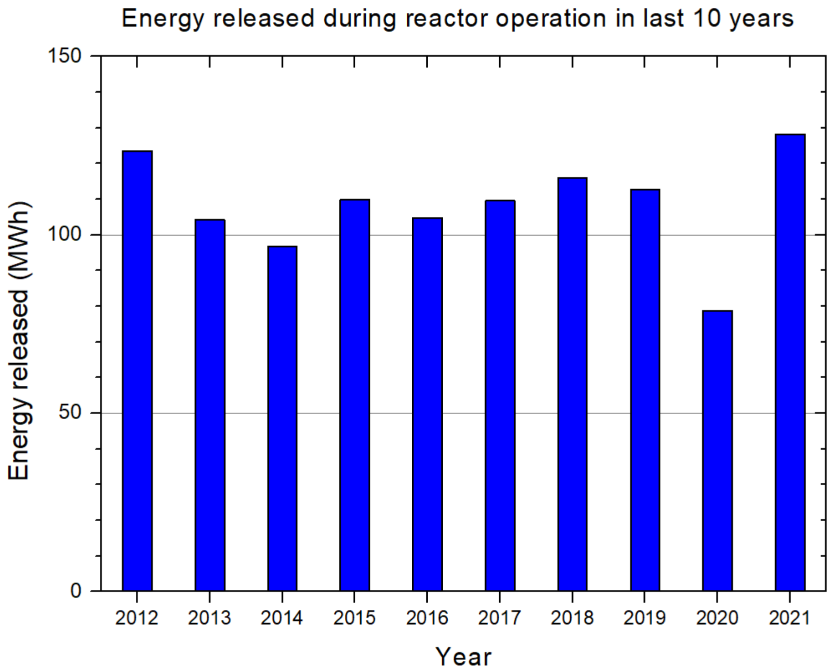

Figure 1: Energy produced by the JSI TRIGA reactor in the last ten years.

Table 1: Annual received doses by the personnel in the period 2017 to 2021

Safety Performance Indicator	**2017**	**2018**	**2019**	**2020**	**2021**
Operating staff: collective radiation dose [mSv]	0.53	1.08	1.31	1.29	1.82
The average dose for operating staff [mSv]	0.133	0.270	0.328	0.323	0.455
Maximum individual dose [mSv]	0.16	0.41	0.36	0.56	0.52
Reactor-related staff: Collective dose [mSv]	1.15	2.31	2.87	2.23	3.34
The average dose for reactor-related staff [mSv]	0.044	0.072	0.093	0.077	0.107
Maximum individual dose [mSv]	0.20	0.41	0.36	0.56	0.52
Over-exposures	No	No	No	No	No

Received radiation dose to the reactor-related staff has also an observable increase compared to the previous five years. We believe that the main reason for the increase in received doses are the extensive research campaigns carried out in the year 2021. Current research work requires a lot of handling of activated equipment after each experiment. The operating schedule of the reactor is sometimes tight and there is no time to wait for components to decay completely. This requires shifting activated material from the reactor pool to other shielded locations inside the reactor building.

Although the received doses are the highest in the last ten-year period, no overexposures were recorded and the internal weekly dose constraints (0.1 mSv) was never violated.

In the year 2021, there were 3 unplanned reactor shutdowns which are less than in the year 2020 (seven unplanned shutdowns), but comparable to the number of unplanned shutdowns in the previous years. The first one occurred on the 1st of October due to a large flux tilt at full power. The Linear channel was still showing a power of 250 kW, but the power on the safety nuclear channel exceeded the 120 % range. The issue was solved by a more accurate calibration of the safety channel. The next two shutdowns took place at the end of December. The second one occurred due to a too short reactor period, a mistake done by an operator. The last unplanned shutdown in the year 2021 occurred due to interference inside the linear nuclear channel. It was not the channel which generated a SCRAM signal, but it was a local controller which is an independent unit monitoring reactor safety-relevant parameters. No further corrective actions were taken.

Except for the first SCRAM, both of them occurred at low power and therefore represented no stress to the fuel and relevant components. The first SCRAM occurred at full power. Since TRIGA reactors are designed to be operated in pulse mode, we believe that such an event represents smaller stress to the components than a single pulse where power increases up to several MW and decreases back to a few kW in less than one second. Part of each pulse is a generation of a SCRAM signal a few seconds after its initiation.

Gaseous effluents released to the environment in the year 2021 were higher than in the year 2020 but lower than in the year 2019. The reason for this is a different configuration of experiments inside tangential beam tubes, consequently, a different volume of air is exposed to neutrons. ^{41}Ar production does not depend only on reactor operation but also on the vacancies exposed to neutrons. Besides ^{41}Ar, we have measured small quantities of ^{24}Na and ^{82}Br lower than 1 kBq. The Sodium originates from primary water as one of the impurities. Bromine originates from our Lazy Susan facility. A few years ago we faced an incident where a sample containing bromine was damaged inside the facility. The major part of the sample was extracted. However, some trace quantities of bromine remained inside the Lazy Susan. Total activities of gaseous effluents are so low that they do not represent any danger to the operating personnel, JSI staff or people in surrounding villages. In the year 2021, no liquid radioactive waste was produced. We collected 9.3 m^3 of wastewater inside the radiological controller area. Its activity was below the clearance level [1] and was released into the environment as non-radioactive effluent.

3 RESEARCH

In the last 12 months, we continued most of the projects that started in the previous years. JSI TRIGA is still recognised as a reference centre for irradiating detectors for accelerators all over the world. It has been 10 years since the discovery of the Higgs boson, but the demand for new detectors is still growing. The reactor was also used for the neutron activation analysis and testing of various detectors. A RAPID code is being used to model dynamic changes in neutron flux for our TRIGA [2]. In collaboration with the Ceramics department at JSI, we studied the radiation hardness of certain ceramics [3]. E-SiCure project under NATO support is still active – in June, additional testing of the SiC detector was performed ([4] and [5]). The collaboration between Lancaster University and JSI is still active – recently, we published an article about the possibility of converting waste like glycol to something useful using radiation [6]. More interesting research campaigns are mentioned below.

3.1 Catalytic methanol-reforming to hydrogen by radiolysis

Recently, we have started research in collaboration with the National Institute of Chemistry. The lack of energy sources is a hot topic these days. Hydrogen is becoming a relevant component in energy conversion applications. Its main disadvantage is the difficulty of storage. Methanol is one of the possibilities since it is storable and can be produced from CO_2. On the other hand, nuclear power plants and their spent fuel pits are a great source of radiation which is not utilised at all. It was predicted that radiation could be used to split methanol in the hydrogen production cycle. The objective of this research work is to assess the feasibility of the γ-ray and neutron radiolysis-initiated catalytic methanol reforming reactions over known thermal and photocatalysts for methanol steam reforming.

3.2 CEA research campaigns

In the last 12 months, the reactor was being operated for CEA-related research for over 2 months. There were several campaigns measuring reactor parameters using various detectors like micro fission chambers, self-powered detectors and thermoluminescent dosimeters. The purpose of such measurements is to calibrate the detectors and improve computer models of the JSI TRIGA reactor. The most interesting campaign was carried out in January. In just two weeks, almost 150 pulses were created and plenty of data was collected. This was later used to develop an accurate computer model that describes reactor pulse mode operation.

Another extensive campaign was carried out in March this year. Specially designed probes were inserted into measuring positions which are located between the fuel elements. Each probe contained about 40 gold detectors which were later measured for activation using a gamma spectrometer. In that way, we were able to measure the vertical reaction rate distribution on gold. Such data can be once again used to improve the performance of the computer model of the reactor. In the same week, Instrumentation Technologies representatives joined the campaign (Figure 2). They are developing the MONACO system together with the CEA. The system will be able to measure the power of a nuclear facility using several detectors simultaneously.

Figure 2: CEA and Instrumentation Technologies representatives at the JSI TRIGA reactor platform.

3.3 Fuel burnup measurements through their effect on reactivity

In April, we had an extensive fuel handling plan with over 100 manipulations. The purpose of that was to measure the effect of several fuel elements on reactivity. By measuring this, we were able to determine the single fuel burnup. The measurements were done using two different methods; the fuel swap method and the Ravnik method. The results will be published in one of the future PhD thesis. The operators took the opportunity and visually checked all 16 fuel elements that have been shifted during the experiment by using an underwater camera. No unusual observations were discovered.

4 EDUCATION AND TRAINING

In the field of education and training, there were some important steps taken for future activities. Only highlights are presented in this paper. In autumn, we carried out a standard practical experimental course for the students of the Faculty of Mathematics and Physics University of Ljubljana for the first time joined by the participants of the SARENA project – Europen joint masters and reliable nuclear applications. The entire project lasts 24 months as a regular master's study program. The lectures are shared among four countries (France, Spain, Finland and Slovenia) and participants also spent six months studying in Ljubljana. Since the SARENA participants were from different countries, also outside Europe, the lectures were held in English. This was a useful upgrade for Slovenian students as well since they got familiar with “Nuclear English” (Figure 3).

Figure 3: SARENA participants and Slovenian students performing an exercise called Pulse mode operation at the JSI TRIGA research reactor.

In February, we hosted a demonstration course organized within the Europen Nuclear Experimental Educational Platform (ENEEP). Currently, the platform consists of five partners; BME Budapest, CTU Prague, STU Bratislava, TU Wien and JSI Ljubljana. The mission of the ENEEP (www.eneep.org) is to 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.

ENEEP will provide access to nuclear facilities for students and young professionals. Either they will take one of the available courses, or a group of students can arrange for a dedicated course; also individual activities can be offered. Some capabilities of the platform were demonstrated in spring and others will be demonstrated this autumn when additional demonstration courses will take place. In future, we hope other partners join the platform and make it even more versatile.

The course held in Ljubljana hosted 11 students from different European countries (Figure 4). Altogether, seven exercises were performed including pulse mode operation and research reactor operation – participants were allowed to start up the reactor, change its power and shut it down.

Figure 4: ENEEP demonstration course. Participants are performing fuel temperature coefficient measurements inside the control room.

For the second year in a row, an experimental course for Aix Marseille University students was organized. This time, students were allowed to visit our facility and perform hands-on experiments (Figure 5). In the year 2021, the course was carried out in a remote way. The course lasted for two weeks. During this time, students performed nine exercises. Two of them were performed for the first time; SiC neutron detector response and measurements of gamma heating using various calorimeters. Calorimeters have been used for the first time during one of the CEA research campaigns [7]. During the course, two technical tours were organized for the students, of the Pipistrel and Akrapovič factories.

Figure 5: Two-week course focusing on radiation detection organized for Aix Marseille University students.

In the last year, we were not focusing only on training others, but we also organized a technical tour for our operators in December. We visited the shutdown reactor Orphee in Saclay, France. In the second part of the tour, they attended World Nuclear Expo (WNE) which was held in Paris. This was a perfect opportunity to see the latest trends in nuclear technology (Figure 6) and get some useful ideas and contacts for future maintenance, modifications and upgrades of our TRIGA reactor.

Figure 6: Autonomous robot carrying contamination probe presented at WNE 2021.

After three years, we were able to host visitors during the open public day. The number of visitors was comparable to the years before the pandemic. They were able to visit our control room, reactor platform and hot cell facility. At the end of September 2021, we were participating in the Researchers Night project. The event was organized late Friday afternoon. The visitors were able to visit our reactor platform during reactor operation at 30 kW. It was a unique opportunity to visit operating nuclear reactor and also a good opportunity to improve public opinion on nuclear energy. Due to the good feedback, we plan to repeat the whole event this year.

5 MAINTENANCE

In July 2022, the external company Q Techna performed a detailed inspection of the reactor tank, beam tubes and both spent fuel pools as a part of the periodic safety review. A similar inspection was already performed in 2011. They used a visual camera to observe the inner surface of the pool liner. In addition, an ultrasound probe was used to measure the thickness of the liner (Figure 7). The condition of the reactor pool, beam tubes and bigger spent fuel pool is almost as good as during the construction. There is no observable decrease in aluminium thickness. The original spent fuel pool had a micro leakage and was therefore put out of service. The company managed to find a small pinhole at one of the welds. The weld was repaired and currently, we are performing a leakage test. The pool can be used in future to store larger activated experimental equipment like the various detectors we use to characterize our core or perform some of the training exercises.

6 FUTURE PLAN

In January 2023, we plan to replace the secondary cooling loop components that are installed inside the reactor hall. The existing heat exchanger was installed in 1966 and the installed valves are almost 20 years old. We faced a small leakage on one of the valves in the past, therefore we decided to replace the whole system. New valves will be made out of stainless steel and should therefore be more durable. The new heat exchanger will have the same capacity but will be plate-type. The current one has U-shaped tubes inside and takes a lot of space. An important part of the refurbishment is the installation of the motorized valve outside the reactor building. The valve will allow operators to remotely close the flow in the secondary loop. This can be useful in case of leakage inside the reactor building to prevent water from flooding the critical structures.

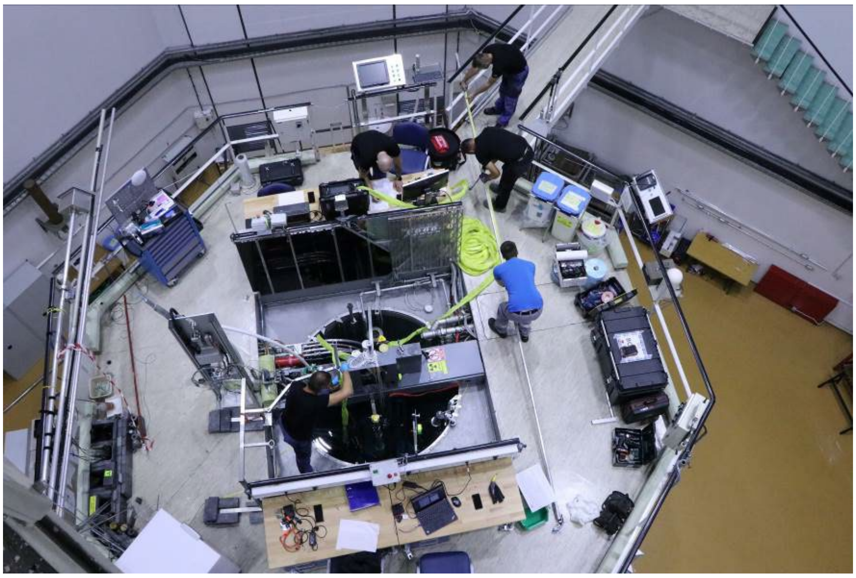

Figure 7: Q Techna team during reactor tank inspection.

The major modification we plan for next year is to replace the radiation monitoring system inside the reactor hall and hot cell facilities. Some of the detectors we use today are difficult to calibrate. In addition, the hot cell facility has a radiation monitoring system which is independent and not connected to our control room. The new system will consist of brand new detectors where all of them would be connected into a single system. It would allow the operator to have a complete overview of the dose rate levels from the control room. This could be crucial in case of abnormal events and emergencies.

In near future, we plan to set up a new experimental facility called a water activation loop. The facility will be used to investigate water activation for education purposes and as a radiation source of 6 MeV and 7 MeV gamma rays. The facility will be located at beam port no. 1.

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