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Jožef Stefan Institute TRIGA Research Reactor Activities in the Period from September 2022 – August 2023

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ABSTRACT

The paper focuses on the Jožef Stefan Institute (JSI) TRIGA Mark II research reactor's operational highlights from 2022. Firstly, some essential operating performance indicators are presented and compared to the ones from the previous years. In 2022, we operated less than in years 2019 and 2021. However, more than 660 hours of operation presents more than the average from 2013 to 2018. Research work performed in the last year is described. The research campaign involving CEA has continued from the previous years. Installation of a new irradiation facility called a water activation loop is in progress. In education, we continued all standard activities. For the first time, we hosted an experimental course for King Fahd University from Saudi Arabia. A major renovation of our secondary cooling loop was carried out in winter.

1 INTRODUCTION

Operating performance indicators are analysed for the year 2022 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. Besides performance indicators, this paper presents some highlights from last year's operation, like engaging research campaigns or significant upgrades and modifications of the JSI TRIGA research reactor.

2 2022 OPERATING PERFORMANCE INDICATORS

In 2022, the JSI TRIGA reactor operated for 661 hours (Figure 1), lower than expected but higher than in 2012 – 2017. Produced energy in the year 2022 equals 89.7 MWh (Figure 1), the lowest number in the last 10 years, except in 2020 when Covid restrictions obstructed the reactor operation. On the other hand, in the year 2022, 188 reactor pulses were performed, which is the ultimate record in our operational history. They represent over 25 % of all pulses produced at our reactor.

The main reason for lower production and only average time in operation is the lack of long, 250 kW operation for neutron activation analysis (NAA). In 2022, the laboratory for NAA was renovated. Therefore, only a few samples were irradiated and analysed. On the other hand, last year, more weeks were booked for training and education activities not performed at high reactor power.

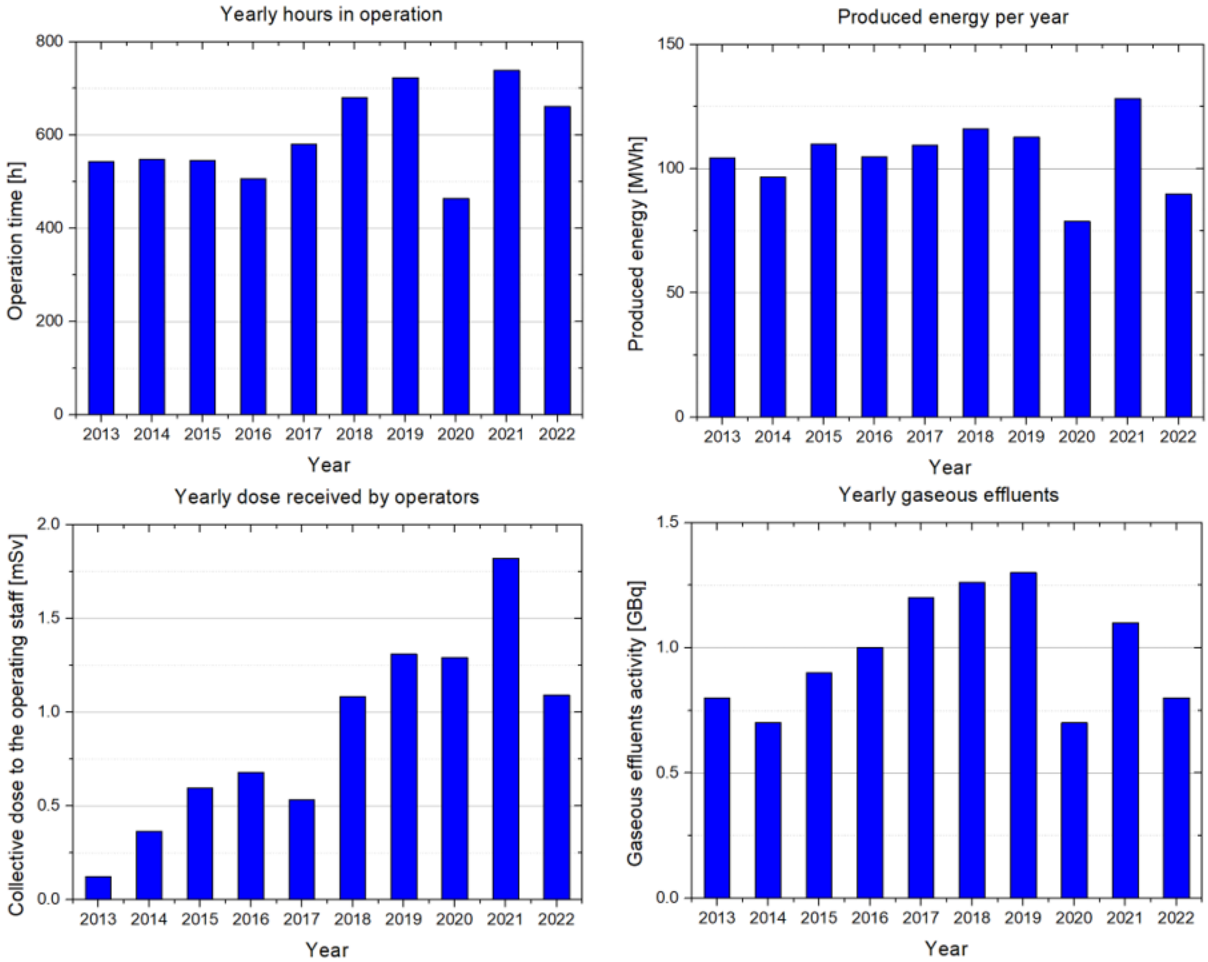

Figure 1: Operating hours (left, top), yearly production of energy (right, top), collective operators dose (left, bottom) and gaseous effluents (right, bottom) for the last ten years.

An important performance indicator is the received dose from the operating personnel and all staff related to the reactor operation. They are presented in Figure 1 and Table 1. In 2022, the received doses were lower than the year before but remained at a comparable level to 2018 – 2020. The main reason for higher doses in 2021 is an increase in removing unused experimental equipment from the site. Some of the equipment was still active and had to be cut into smaller pieces to fit the radioactive waste drum.

Table 1: Performance indicators related to radiation production for the last ten years.

	2013	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
D1a	0.123	0.363	0.594	0.678	0.53	1.08	1.31	1.29	1.82	1.09
D1b	5	4	4	4	4	4	4	4	4	4
D2a	0.521	0.567	0.876	1.053	1.15	2.31	2.87	2.23	3.34	1.65
D2b	27	24	23	30	26	32	31	29	31	35
D3a	0.085	0.136	0.242	0.208	0.16	0.41	0.36	0.56	0.52	0.32
D3b	0.118	0.136	0.242	0.208	0.20	0.41	0.36	0.56	0.52	0.32

- D1a - Collective radiation dose to the reactor operating staff (man mSv)
- D1b - Number of the operating team
- D2a - Collective radiation dose to all persons in reactor-related work (man mSv)

- D2b - Number of exposed staff at the reactor
- D3a - Maximum individual dose to an operating staff member (mSv)
- D3b - Maximum individual dose to any person at the reactor (mSv)

Important parameters we strictly measure are liquid and gaseous effluents in the environment. The TRIGA reactor produces ^{41}Ar during operation since some voids are near the core. In 2022, the total amount of gaseous release was 0.8 GBq of ^{41}Ar (Figure 1). We also detected Na-24 and its activity was estimated to be less than 1 kBq. It originates from primary water as one of the impurities.

All liquid releases are stored in specialised water tanks. Before emptying the tanks, a water sample is taken and measured for the activity. In 2022, the activity in all samples was below the detection level, which is lower than the clearance level. The total amount of released liquids into the environment is 15.5 m^3. The liquid effluents in the previous 10 years are between 10 m^3 and 20 m^3.

Last year, we faced five automatic shutdowns of the reactor. Three times, it was on the 10th of February due to the failure of one of the thermocouples inside the fuel element. The failure was not instant; after every SCRAM, it seemed like the thermocouple performed normally. Just six days later, we hosted visitors in the control room. One of them accidentally pressed the calibration button on the safety channel, which caused an automatic shutdown due to the exceeded power reading – the button simulates 120 % of full power and consequently triggers the SCRAM signal. On the 24th of October, the reactor was operating with a high flux tilt, which caused a high power reading on the safety nuclear channel. When the power reading exceeded 120 %, a SCRAM signal was generated.

3 RESEARCH

Research campaigns with CEA and Instrumentation technologies continued from the previous years. The product Monaco

A new European project called EURO-LABS (EUROpean Laboratories for Accelerator-Based Science) was launched in September 2022. The project marks a collaboration that unites three research realms: nuclear physics, accelerator technology, and high-energy physics detectors. This convergence creates an innovative super-community comprising experts in sub-atomic sciences, a first of its kind. This initiative facilitates seamless entry into a network of 47 Research Infrastructures. The project propels scientific advancement and endeavours with widespread societal significance by delving into fundamental inquiries and tackling technological frontiers. Moreover, it cultivates the exchange of knowledge across diverse scientific domains, amplifying Europe's capacity to confront forthcoming challenges effectively [1].

In the last year, several articles related to the JSI TRIGA reactor were published. Burnup of TRIGA fuel was calculated using the RAPID code [2]. The design of our future experimental device – water activation loop was provided [3]. Nuclear heating was characterised by aluminium, graphite and Eurofer steel [4]. Several ATLAS detectors, including radiation resistance [5 - 7], were characterised.

Much effort in the last year was focused on installing a new experimental device. A water activation loop will be installed on beam tube no. 1. The idea is to activate demineralised water near the core and quickly take it to the reactor hall, where it can be used as a high-energy gamma source – activated water emits 6.1 MeV and 7.1 MeV gamma rays. The device will be used to study water activation, perform educational exercises for students, study shielding and perform shielding experiments. Once the field is accurately characterised, it could be used to calibrate gamma detectors.

Firstly, the interior of the beam tube was inspected and cleaned. An additional concrete shield was constructed outside the reactor body to ensure a safe working environment during device operation. After the design phase, the inner activation part, pipes, valves, pumps, outer observation part and other components where water will flow are under construction. There will be an option to use longer or shorter circuits or a combination of both. Two HPGe spectrometers and one ^{3}He counter were acquired to characterise the radiation field. Besides gamma rays emitted from ^{16}O(n,p)^{16}N reaction, we expect also to produce some neutrons from ^{17}N decay. The current plan is to install all components by the end of this year.

4 EDUCATION AND TRAINING

In education and training, we continued all activities that started in the previous years. These are regular exercises for the students from the University of Ljubljana, Faculty of Mathematics and Physics. This year, the course was again organised together with the SARENA project. The number of participants was twice as usual. Therefore, the students were split into two groups, and all exercises were repeated twice. In September, we hosted students from Uppsala University (Figure 2). ENEEP (European Nuclear Experimental Educational Platform) organised a Train the Trainers course at our reactor in September. The audience was professors performing practical laboratory exercises for their students at European universities. The next course, Train the Students, organised by ENEEP, followed in October (Figure 2). Both courses served as demonstrational to promote future ENEEP activities. In October, we hosted participants from the EERRI (East European Research Reactor Initiative) course (Figure 3). The course lasts six weeks, and trainees travel across three countries. Usually, they spend two weeks in Slovenia. In November, we hosted about 50 students from Politecnico di Milano (Figure 3). Students performed a practical exercise called Pulse mode operation. In addition, they visited our reactor and accelerator. In January, a remote course was organised for the students from Aix Marseille University (Figure 4). In June, we hosted students from the same University for two weeks. We hosted King Fahd University of Petroleum and Minerals students in the same period (Figure 4). They were taking a course at our reactor for the first time.

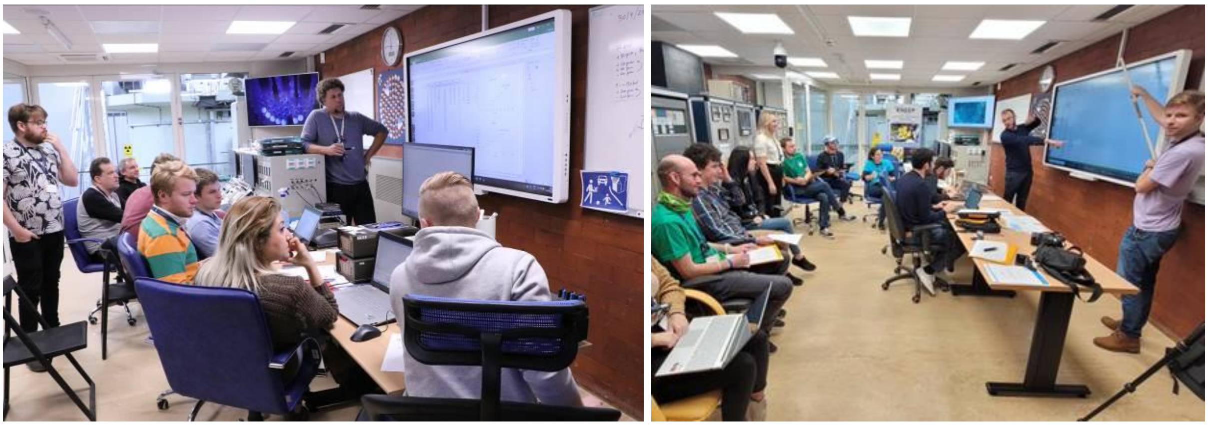

Figure 2: Left: Practical exercise for the students from Uppsala University. Right: ENEEP Train the Students course.

Often, our operating personnel is involved in educational and training activities. On the other hand, we should not forget about their training. Therefore, every two years, we organise a technical tour. This year, our operators went to Romania and Serbia. They visited the most powerful TRIGA research reactor, which is located in Pitesti, Romania. The reactor is specific since it has two TRIGA cores inside the single reactor pool. The large core is operated in steady-state mode, achieving power levels up to 14 MW. The smaller core is similar to ours but is operated mostly in pulse mode, achieving peak power of up to 20 GW. In Serbia, they visited the Vinča Nuclear Institute (Figure 5). There are still two reactors to be seen. Critical configuration and 6.5 MW material testing reactor. Both are shut down and waiting to be decommissioned. On the same site, there is also a national radioactive waste storage.

Figure 3: Left: Group photo of EERRI participants. Right: Students form Politecnico di Milano at the reactor platform.

Figure 4: Left: Group photo of students from Aix Marseille University. Right: King Fahd University students receive certificates on completed practical course.

Figure 5: Left: critical assembly. Right: JSI TRIGA operators admiring the view.

At the JSI the TRIGA reactor, we emphasise preparedness for emergency events. Last year, an exercise was organised. We simulated an explosion inside the Hot cell laboratory during radioactive waste management (Figure 6). Several workers were trapped inside, and a fire broke out. Besides JSI staff, the participants were from the professional Ljubljana Fire Brigade, two local volunteer fire brigades and the Ecological laboratory with the mobile unit.

Several observers from the Slovenian Nuclear Safety Administration and Administration for Civil Protection and Disaster Relief were there.

Our approach to the exercise was as realistic as possible. The idea was to identify any gaps in our emergency preparedness. A detailed analysis followed the exercise where we identified about ten minor gaps, most of which were already implemented. The others will be during an emergency procedure revision.

Figure 6: Two photos taken during an emergency exercise in December 2022.

5 REACTOR UPGRADES AND MAINTENANCE

In February 2023, our secondary cooling loop was under a major renovation. The main upgrade was replacing the old pipe-type heat exchanger from 1966 with a new plate type (Figure 7). The performance of both are the same with the difference in size – the new one is about four times smaller. We replaced all the pipes and valves inside the reactor basement with new ones, including the original temperature and pressure sensors. The ones installed in 2016 and connected to our SCADA system remained.

The reason for the renovation was a small leakage in one of the valves a few years ago. To prevent such events in the future, all the new valves are made out of stainless steel, which is a more durable material than regular iron. Another difference is that we made a sampling station more accessible. This eased the regular secondary water sampling performed by our radiation protection unit.

Another improvement is installing a motorised valve on the secondary cooling loop outside the reactor hall. In case of an internal flood, the valve will be automatically closed, preventing further consequences on the reactor hall interiors.

6 OTHER ACTIVITIES

In October 2022, our reactor hall was converted into a movie set. A team led by producer Dragan Bjelogrlić was shooting a scene for a movie called Čuvari formule (Guardians of the Formula). The movie is about the nuclear accident at the Vinča critical assembly in 1958. Six students were performing an experiment during which the reactor became supercritical. All of them were overexposed and taken to France for state-of-the-art treatment.

Most of the interiors in the reactor hall were removed, including all radiation sources, experimental equipment and other accessories. The film crew brought props, including a control board, heavy water containers, an additional platform constructed underneath the original one, measuring devices, etc. In one day, the reactor TRIGA was converted into a nuclear facility in the 1950's. The crew consisted of about 100 people working mostly at night time. The major challenge for our team was to take care of all procedures that apply to the radiological controlled area for every crew member and to ensure a qualitative environment for the shooting. The shooting itself took three days. The shots were taken at the reactor platform, reactor hall, reactor basement, and the parking lot between the chemistry and physics building. The movie was already presented at the Locarno Film Festival. This autumn, everyone could see the movie in the cinemas.

Figure 7: Brand new secondary cooling loop including new plate-type heat exchanger.

Figure 8: Some photos taken during the shooting of the movie Čuvari formule (Guardians of the Formula) at Jožef Stefan Institute Reactor Centre.

7 FUTURE PLAN

In autumn 2023, we plan to replace the existing radiation protection system. The plan is to replace all radiation monitors, including stack and wastewater monitors.

Currently, we are in the process of refurbishing the purification loop for the spent fuel pool. We plan to finish the project by the end of the year. The tank containing the ion exchange resin will be replaced by a new one – identical we already use in a primary reactor loop. A new pump and new pipes will be added to the system.

We are about to finish our secondary periodic safety review in one year. It is a systematic review of 15 so-called safety factors like design basis, the actual condition of systems, structures and components, ageing, radiation protection, operating procedures, emergency preparedness, etc. With the review, we will prove that the reactor is as safe as it was after the construction phase and complies with current legislation and standards. It is a basis for extending our operating license for another ten years.

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